A Web of Things Approach for Indoor Position Monitoring of Elderly and Impaired People

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***Abstract*—Helping, assisting and taking care of the elderly and of impaired people is one of the greatest challenges in our society. Within this paper, we propose a new approach for indoor position monitoring of people, aiming to identify in real time dangerous situations. In order to boost interoperability and continuous adaptation of the devices used, a Web Of Things based solution will be proposed and evaluated. Our contribution, in particular, consists of a portable and user friendly Radio Frequency IDentification (RFID) reader exploiting monopulse radar and beam-steering capabilities. Such hardware, exploiting a set of software modules, will be located in an environment easily accessible and extensible to a growing number of devices. The application will be the result of the cooperation between software and hardware, eventually outlining a real and completely flexible Web Of Things environment.**

I. Introduction

In the last decades the average age of the population has been rising and, as a consequence, also the number of retired people has been significantly increasing. This paper investigates on how ICT technologies could help assisting the elderly both in their own homes or in retirement houses. In particular, the focus is on detecting the position of a person affected by whatever kind of disease that can produce for instance unawareness of danger, like the Alzheimer's disease [1]. As it is commonly known, unfortunately, this condition presents as first symptoms disorientation and short-term memory difficulties. In its early stages, however, it does not compromise deambulation capabilities, which is the reason why the task of taking care of patients with Alzheimer's disease may widely benefit of indoor position monitoring [2]. Still it is important for the patient not to feel imprisoned in his own house, and to continue the daily routine autonomously as long as possible for a better quality of life.

A scalable and dynamic provisioning of services, including the location based service here discussed, can be implemented through the Internet of Things (IoT) paradigm. IoT has become an extremely prolific field during the last years. Both the research approach and the so called *maker* approach have been constantly fed by new techniques and ideas. Moreover, it is possible to reach exceptional results with cheap and easy-to-find hardware on which we run very simple software. A sort of stream of consciousness started in all the community, as everybody knows that we don't lack in technologies, but what really is missing is the creativity and the methodology to turn ideas and challenges into new applications. Some time after the concept of IoT was first introduced [3], it became clear that to achieve real innovation the new direction to be followed was the one of interoperability between the huge number of different devices. In fact, the real difficulties during design come when we need to move the information from a device to another, as every device usually implements different ways to interact with the external world. In this paper, similarly, we will have to locate users and bring the coordinates information from the sensing hardware to the control entities.

However, interoperability is still not sufficient when the environment is not a priori defined: devices can (dis)connect at runtime unexpectedly, while various independent applications can run in parallel. In a world in which devices connected to the Internet are increasing at an extremely high rate, we expect applications to adapt to the currently reachable devices: that is not mere interoperation, this is full adaptation of software to the context and interoperation of devices.

Recently, a working group was created by the W3C with the aim of defining what is called nowadays the Web Of Things (WoT), which is an extension of the IoT standardizing the description of devices and their communication by the means of the technologies of Semantic Web [4]. This additional layer on the IoT would enable discovery of accessible devices, and clearly enhance their use and interaction.

In this paper, we present a typical application of the IoT expanded to the WoT: the indoor localization of people. More precisely, the context of our work will be the real time detection-notification of risky situations (e.g. falling, presence in unsafe zones) to assist the elderly in their everyday life. The user location is provided by a custom designed RFID reader named RID that has been interfaced to a semantic event processing architecture named SEPA, taking inspiration from the ongoing work of the WoT W3C task-force.

The paper is built up in the following way: in Section II we analyze some related works regarding the software architectures for the IoT and regarding indoor positioning systems. In Section III we describe the exact environment of our work, and the hardware we used. Then, in Section III-C, the software architecture is described. Finally, in Section IV, conclusions are drawn.

II. Related works

In this Section we are going to explore the state of the art in our research. To do so, the two following sections discuss the realization of the project by making a division into the hardware solution we decided to implement (Section II-A), and our software implementation of the WoT (Section II-B).

A. Indoor positioning

Many researches focused on RFID technologies enabling indoor localization [5], [6], movement detection of human body segments [7] and smart health care systems realization [8], [9], also exploiting pan-tilt zoom cameras [10] or accelerometers [11] for an accurate tracking, in addition to the microwave outline. Some studies, for instance [12], also explored the possibility of using Bluetooth and Wi-Fi technologies in order to achieve this same goal.

In recent years, however, many systems have been developed to locate patients affected by some kind of dementia; yet the majority of them are based on GPS localization systems [13]: these papers are about lifesaving location devices detecting the position of the tagged person for a certain period at any given time (e.g. every ten minutes), to monitor the location of the elderly in case of leaving from their own houses or from the retirement homes where they are hospitalized. One of these GPS systems includes the localization device in the sole of the shoes [14] and allows the tracking of the loved ones every 10 or 30 minutes; the shoes need to be charged every 48 hours and can be fully operational within two hours.

All these appliances can be certainly useful for noticing if a person under surveillance with space confusion troubles has left the building where he lives and is wandering, but they do not give a real answer to the problems that could occur in everyday life. Indeed a non-invasive continuous system (also known as IPS: Indoor Positioning System) to locate patients at hospitals or rest homes is certainly essential to assist them in real-time. That way we could prevent their entrance in a zone deemed unsafe, control if they fall on the floor or if they lie in bed for a long time and they should go for a walk.

In this paper, we describe how these operations can be achieved by this technology at microwave frequencies, exploiting the remote identification capabilities of a radar based on a two-element antenna array.

B. IoT - WoT Architecture

In [15], but also in general when reading a survey about the IoT, it is very likely to find out that authors agree it presents great challenges in terms of interoperability and smartification.

Concerning interoperability, different methodologies have been proposed. Among them, the so called Message Oriented Middleware (MOM) [16], that leaving unchanged the low-level protocol variety and using some application-level protocols like MQTT [17] and AMQP [18] instantiates a broker centered communication. Their use enables, through a publish-subscribe architecture, the creation of real time applications. Following the description made in [19], they offer a topic-based approach. Connected things cooperating with those protocols must agree at development time on topics and message format. Other well known protocols like CoAP [20], on the other hand, are made for REST compliance and do not present a central broker. Such approaches show an interesting difference when applied to the IoT, as the topic-based gains in effectiveness in descriptive flexibility, while REST enhances uniformity in overall device access. Some studies have been done to investigate how to merge the two concepts, like [21].

However, when it comes to describe the complete environment in which our application works, the full representation is only reachable through a graph representation, i.e. through semantics and ontological representation of knowledge as well expressed in [22]. Various IoT ontologies have been developed, for instance in [23], [24]: nevertheless, to the best of our knowledge, thing discovery task and operation management until now were left to the control of other protocols not involving the semantic description, which is what we aim to do in this paper.

III. Indoor position monitoring system

Our indoor position monitoring system tracks the location of a number of active tags into a specific room. An algorithm may, then, use the location information to decide in various ways whether an alarm should be activated because of an occurring risk.

To achieve this goal we defined an environment in which the patient carries within its clothes an RFID tag that is detectable by a specific reader. As a matter of fact, in order to continuously follow the user, our setup requires the presence in every room in the house of at least one reader. The readers are programmed to transmit the coordinates of the detected patient's position with a user defined rate. Such piece of information is then delivered to the software modules dedicated to processing. The hardware implementation of the reader is discussed in Section III-A, while the software part is analyzed in Section III-B.

A. RID hardware implementation

The hardware implementation adopted is the same proposed in [25] for an high-resolution detection of closely spaced tagged objects, static or with movements in a generic direction. The circuitry and the antennas used for the prototype are shown in Fig. 1. We exploited our own custom implementation, instead of buying a pre-existing one, because our previous background led us to a smaller, independent from human operator and faster prototype able to retrieve position of tags through a very simple raw data calculation a posteriori [26].

This work demonstrates, through measurements in different conditions, that the same light and cheap system reaches very high accuracy even for randomly moving tagged objects in an area as large as twenty-square meters: the only needed additional efforts are a proper starting calibration set-up and an elementary but extremely fast real-time post processing.

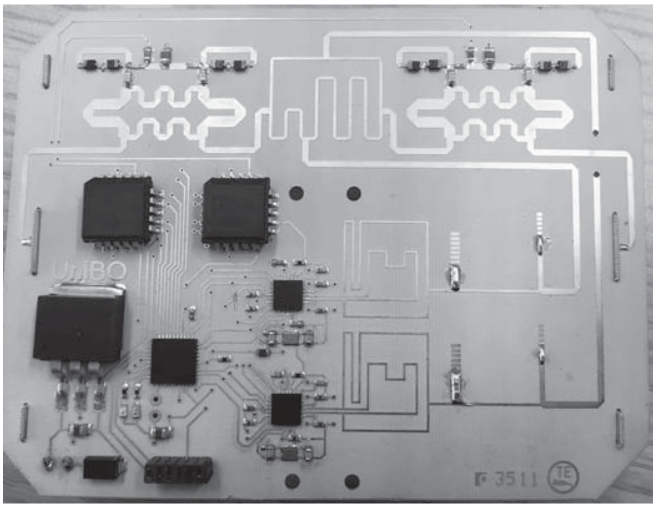

Fig. 1. Circuitry layout (back view) for the current prototype of the RFID reader [25]

The current reader has been denominated RID, that is the acronym of Remotely Identify and Detect: it makes use of the monopulse radar [27] and the array beam-steering [28] capabilities controlling the phases of signal emissions from the two flag-type dipole antennas composing the array itself: in particular, two principal radiation patterns, sum (Σ) and difference (Δ), can be obtained exploiting the complexes of two phase shifters and two varactors, electronically controlled by a microcontroller, by means of a proper in-phase and out-of-phase excitation at the port of the antennas, whose shapes and distance have been chosen aspiring to reach low directivity for the Σ radiation pattern, low side lobes levels and reduced dimensions of the overall structure at the same time.

Consequently, there are two RID-tags modalities of communication: the first phase consists in the retrieval of the tags' IDs in about 200 ms. Then, the detection mode, building up the real steering of the electromagnetic beam with a scanning resolution spanning the $\pm 45°$ interval in the azimuth plane.

Then, aboard a Raspberry Pi 3 [29], a very simple but at the same time smart data processing is computed: the values of the Received Signal Strength Indicator (RSSI) flowing from each tag, and then subsequently received at the reader Σ and Δ ports, are achieved to provide the desired figure of merit for deriving the tag position at a certain time, the so called Maximum Power Ratio (MPR), whose formulation is reported in (1):

$$MPR_i(\theta) = \Sigma^{dB}(\theta) - \Delta^{dB}(\theta); \quad i = 1, ..., N_{tag} \qquad (1)$$

where N_{tag} is the total number of detected tags, and θ is the scanning angle. The position of the maximum value of MPR provides the instantaneous angular position of each tag in the horizontal plane. In particular, this RFID reader is able to distinguish tags with horizontal reciprocal distance of few centimeters up to 3 meters far from the target.

In order to evaluate people movements in a bidimensional space and later their room occupancy by means of this technology, an opportune data processing has been developed, based on the strength of the signals received from the wearable tags, under the assumption of static channel or at least considering the possibility of human blockage. Indeed, a meticulous calibration of the room under evaluation has to be finalized: it consists in a estimation of the maximum Σ RSSI received from tags, placed in three different positions in the area in front of the reader. Thus the area under consideration is divided into three different zones (zone #1: $-45° \div -22.5°$, zone #2: $-22.5° \div 22.5°$, zone #3: $22.5° \div 45°$).

After the calibration and the real-time measurement of the received RSSI signals, the distance d of the tag from the reader is given as:

$$d = 10^{\frac{P_0 - P_R}{10n}} \qquad (2)$$

where P_0 and P_R are the maximum values of the RSSI received at the RID Σ port during calibration and in real-time, respectively, whereas n is the path-loss exponent. Depending on the location under test, it is typically located in the ranges from 2.7 to 4.3 (large areas); up to 2 for free space; from 1.6 to 1.8 for office scenarios [30].

Fig. 2 reports the testcase for $n = 2$ as first RID position, which is fully described in [31]. Table I, on the other hand, shows the results of the measures obtained for the second set-up realized in the office scenario under test schematically reported in Fig. 3, where the RID position, the actual and measured tags positions, and the calibration zones are highlighted. In detail, the data consist in: i) the real (subscript 0) and measured (subscript m) positions, reported with (x, y) coordinates; ii) the real and measured distances of the tag from the reader obtained by means of equation (2) and doing the average of ten consecutive measures; iii) the Percentage Error for the first considered setup with $n = 1.6$.

B. Software architecture

Data processing flows through the hardware-software components as shown in Fig. 4. Let us consider, for instance, location updates: they are needed by more than one software agent. The first software agent, that is a consumer of information, is an interactive map in which the user's current position is continuously updated. The second software agent, on the other hand, is a reasoning entity that can be implemented in various

TABLE I. MEASURES FROM SECOND POSITION OF RID ($n = 1.6$) [METERS]

	Real (x_0, y_0)	Measured (x_m, y_m)	Distance RID-Tag	% Error
# 1	$(5.15, 1.50)$	$(4.49, 0.88)$	3.62	16.88%
# 2	$(2.45, 1.20)$	$(2.31, 0.89)$	1.34	12.47%
# 3	$(3.35, 0.60)$	$(3.38, 0.19)$	1.62	12.08%
# 4	$(4.55, 0.90)$	$(5.01, 0.00)$	2.85	21.79%
# 5	$(5.75, 2.00)$	$(6.58, 1.35)$	4.38	17.32%

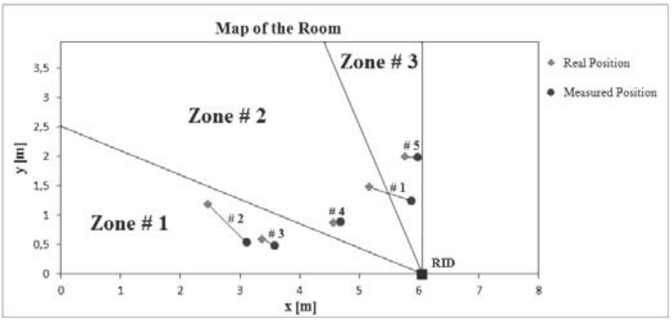

Fig. 2. Real and measured positions of the tag for the first set of measures (first position of the RID, with $n = 2$, [31]). The three calibration zones are also represented

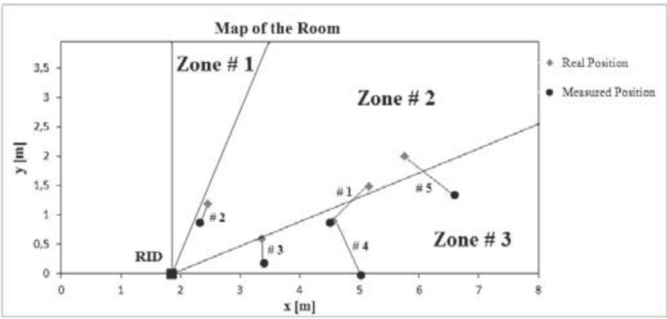

Fig. 3. Real and measured positions of the tag for the second set of measures (second position of the RID, with $n = 1.6$)

ways to obtain different results. For example, a simple *if-this-than-that* method is quite accessible and useful, if we just want to know whether a person is authorized to enter in a particular room or not. In addition to that, in general, if at setup time we identify in the map some "dangerous zones" (like the stairs, the bathroom or the kitchen), aside from detecting the presence of the patient in those areas it will be possible to obtain other kind of more effective behavior analysis. In our realization, anyway, we suggested a simple program that counts the time a user is stuck in the same place and eventually activates an alarm after 15 minutes.

What we have to notice with this reasoning module, is that it performs an *aggregation* of information, i.e. it uses data to obtain some results. Then, as an outcome, it produces new information from the results and puts it into the common storage.

Another piece of software is the information dispatcher, that is also responsible for interoperability. In our implementation interoperability is obtained by the use of standard protocols and a semantic approach: that is, we accumulate all data from the current context of the application in an RDF triple store [32], and we notify events accordingly as we will describe in Section III-C. So, the radar will elaborate the coordinates of new position, update some triples into the graph-storage that will notify observers. The usage of only standard protocols in that module, moreover, is one of the main characters that differentiate this project from the IoT towards the WoT: while the former accepts a huge variety of communication methods within every OSI level, the latter rather indicates as a solution the usage of HTTP [33] and WebSocket [34] over TCP/IP, at least for the task of device discovery. In our implementation the information dispatcher, called SEPA (derived from [35]), receives SPARQL updates on HTTP and opens a SPARQL subscription connection through WebSocket (see also [36], [37], [38]).

The remaining four software modules of the complete WoT architecture are:

1) The C firmware running in the microcontroller of the radar. It implements the communication protocol that requests scans and retrieves the results. Because of the reasons discussed in Section III-A, SPARQL updates to SEPA are demanded to another piece of hardware, namely the Raspberry PI 3.
2) The C process in the Raspberry PI 3 that takes raw scan data from the radar through USB port, calculates actual coordinates in a (x, y) form, and creates the HTTP Post to SEPA with the SPARQL update. It is a *producer*.
3) The home environment setup software. This module, that can be realized as a Python script, should create a virtual representation of the application context into the SEPA (it is a *producer* as well). In our case, it associates the RFID tag to its user (so that detecting the presence of the tag directly implies detecting the corresponding user's presence) and declares to the central storage unit the presence of every sensor and actuator. As it will be shown in the next section, the context information can also be created by the entities forming the environment themselves.
4) The alarm monitor (that is a *consumer*). This piece of software may run on a smartphone, and send notifications to the end-user, or the caregiver in our scenario. In practice, it creates a SPARQL subscription in the SEPA for the alarm triples inserted by the reasoning entity.

C. WoT application

Indeed, the architecture described above may be implemented in several ways. In this paper, the aim is to grant mainly two features.

First of all: maintaining the responsiveness in an Ambient Assisted Living (AAL) scenario: recognize a fall, disorientation or in general many non-verbal help requests is achievable by analyzing how the patient moves in his house, although it is necessary to always keep control of the overall reaction time of the system (i.e. the time elapsed from the event to notification to caregivers or to family members). This time value depends on the responsiveness of the broker and on the complexity of the reasoning software: in some easily detectable cases an almost instant call for intervention is achievable, largely satisfying the real-time constraints of the application, while in the other cases time elapsed is not expected to exceed reasonable security limits. A complete analysis of the performance of the server platform is out of the scope of the paper, while the evaluation of the proposed architecture will be carried out in a

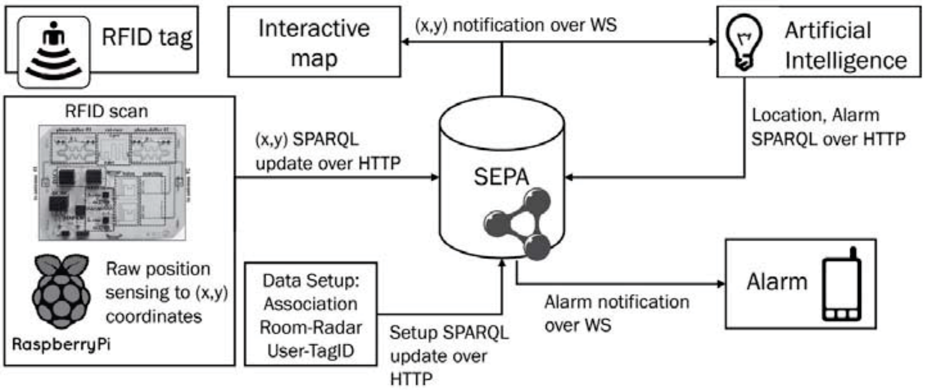

Fig. 4. The flow of information through our positioning system

second part of this research project. Given that responsiveness may be strongly affected by the flexibility requested by caring application, the Authors believe that such application would be a good test case for the initial capabilities of the WoT paradigm.

The second expected result is to create an application model that is even more than easily extensible. Semantics perfectly fits the application needs, allowing a flexible context definition together with the capabilities of every device present. In particular, the context of whatever application is semantically obtained combining together the description of devices (called *web things*) in terms of triples with any further information that may be needed about their active and passive behavior. Eventually, such description yields a complex system able to adapt to changes at runtime: a WoT system.

In Section III-B, in particular, we used the words "aggregation", "consumer", "producer", "notify", because they are the key of our Web of Things implementation. They enable WoT core functionalities: *thing discovery* and things features and data accessibility in an uniform, standard, modularized way. As already described, we obtain accessibility by performing inter-things communication through standard HTTP and WebSockets calls to the information dispatcher. Consumers do subscriptions and get notifications using WebSockets, while producers update data via HTTP. Aggregators, on their side, do both things.

The semantic mapping of the things is performed according to a proper WoT ontology. In this paper, to be more precise, we took large inspiration on the ontology suggested by the W3C drafts and introduced in [24]. In particular, for every thing participating in our environment we defined the set of Properties, Actions and Events (from now on, "PAE schema") that the thing would be able to control, execute, and generate respectively, and stored it into the SEPA in the form of a RDF graph. The overall graph is precisely what in the paper is called the application context [39]: things must be there described according to the thing ontology in their PAE schema, but they can also be enriched with other qualities part of other ontologies to apply the abstract pattern to the particular case.

Then, in the application logic, we defined what the thing would do in practice and when. Let's consider the Raspberry Pi 3, to make an example: it can post a new Event, "New Location Available", to be executed every Property "Scan Interval" value. Both the reasoner and the location monitor are subscribed to the location event. The alarm monitor, instead, is subscribed to the Alarm events that the reasoner module can throw. The subscription pattern is unique for all subscribers, so that environment extensibility is granted, provided that new devices auto declare themselves following the PAE schema.

Device discovery is also possible exploiting the ontology. In fact, discovery types are limited only by the programmer and the environment, since SPARQL queries like `SELECT ?t WHERE {?t rdf:type td:Thing}` are easily extensible to include further characteristics of things to be detected. Thing effective availability (e.g. `wot:isDiscoverable` DataProperty), location, protocol accessibility are very easy to obtain by filtering parameters as well as discovery for things throwing specific events and so on.

IV. Conclusions and future works

In this work, a truly smart and hand-held RFID system working at the frequency of 2.45 GHz, with the function of localization of tagged entities, both moving and static, has been developed. The demonstration of its functionality has been accomplished with the detection of tags positions even in harsh electromagnetic environments, allowing a continuous localization of users at hospitals or rest homes and an early diagnosis and care of age-related illnesses that can be unambiguously associated with the iteration of certain movements and habits.

Concerning the transition from IoT to WoT, research work is still in its early stages. In this work we suggested a possible way of implement an environment accessible through standard protocols like HTTP and WebSocket. Semantic representation of thing descriptions allowed us to create an environment fully discoverable, while the subscription mechanism of the SEPA enabled a real time event processing. The application of those concepts to indoor position monitoring lead us to a real working application, which in the future we plan to extend to other devices and enrich with a smarter reasoning module. Finally, a complete evaluation of performances is expected to give interesting results on the limits of interoperability in the WoT.

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