Integrating robots into the Internet of Things

Cristina Turcu, Cornel Turcu and Vasile Gaitan

***Abstract*—**According to various reports, the number of robots used worldwide is constantly increasing. They are more and more present in different workplaces such as manufacturing, processing operations, dangerous areas, medical environments, military, inaccessible areas etc. Also, robots are able to do social works like assisting people with disabilities or even playing when toys are robotic techniques based. In our days ICT applications became more complex while including various technologies such as wireless communication, wireless or embedded sensor networks, virtual reality, artificial intelligence, cloud computing/storing etc. Due to the new IPV6 protocol every entity in this world could be uniquely identified and be a part of an infrastructure that enables connections between different entities (living or non-living), using different but interoperable communication protocols. Furthermore, everyday entities are becoming either source of information or consumer or both, having communication capabilities and being able to collectively solve complex problems. But, where are the robots? First developed as a tool, nowadays a robot can be integrated as an entity in the new paradigm of Internet of Things (IoT). Thus, in the IoT, a robot can be connected as a thing and establish connections with other things over the Internet. Despite some raised technical issues, the integration of robots within the IoT can offer great advantages in many fields, some of them presented in this paper where aspects related to the technologies involved in the transformation of the robot from a "tool" to a "thing" connected to the Internet of Things are presented.

***Keywords* —** Internet of Things, Internet of Things platform, Radio frequency identification, Robot.

I. Introduction

According to various reports and studies, the number and variety of robot applications in industry and our daily life is increasing. But many robots are specialized, being constrained to a limited number of operations. Also, if robots use only the information provided by their own sensors, the applications will be limited. Unfortunately, most of existing robots are not flexible enough to solve many complex tasks - for example, concerning dynamic environments [1]. But new benefits can be achieved through the application of new results from different research areas.

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Current research has worked on the development of new devices and services. The IPV6 new protocol, publicly launched in 2011, provides the spaces needed to accommodate a large influx of things onto the Internet, allowing for 2128 (approximately 340 undecillion or 340,282,366,920,938,463,463,374,607,431,768,211,456) addresses. As Steven Leibson puts it, "we could assign an IPV6 address to every atom on the surface of the earth, and still have enough addresses left to do another 100+ earths".

The Internet of Things (IoT) infrastructure allows connections between different entities (i.e., human beings, wireless sensors, mobile robots, etc.), using different but interoperable communication protocols and makes a dynamic multimodal/ heterogeneous network. In this infrastructure, these different entities (viewed as "things") have the ability to discover and explore one another, gather, provide or transmit information to IoT.

It is difficult to estimate the future evolution of IoT when it is expected that the number of devices online by 2020 ranges from 50 billion to one trillion [2]. Such potential can be exploited by robots. Still, in order to get there, new robots must address the need for unique identification and interoperability between them and other things from IoT, such as sensors, embedded devices, etc.

This paper is organized as follows. Section 2 introduces a brief description of the underlying concepts and various definitions of the concept of Internet of Things. Section 3 presents the theoretical background for the radio frequency identification (RFID) technology, considered a key enabler for the Internet of Things. Then, we address the issue of integrating robots in IoT. Finally, Section 5 presents conclusions.

II. Internet of Things

A. Definitions

At present, the definitions of "Internet of Things" are manifold; they vary depending on the context, the effects and the views of the person giving the definition. But before considering the definitions of this new concept called Internet of Things, we must first define the term of "thing". According to [3], in the IoT, "things" are classified in three areas: people, machine (for example, sensor, actuator, embedded devices, etc.) and information.

In Fig. 1, the three IoT visions are highlighted: Things-oriented, Internet-oriented and Semantic-oriented. From this illustration, it clearly appears that the IoT paradigm will be the result of the convergence of the three main visions addressed above [4].

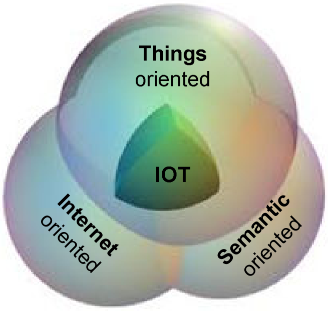

Fig. 1. The "Internet of Things" paradigm as a result of the convergence of different visions

Adopting the perspective outlined above, Table 1 presents several definitions of "Internet of Things".

Table 1. Definitions for "Internet of Things"

<table>
<tr><th>Perspective</th><th colspan="2">Definition of "Internet of Things"</th></tr>
<tr><td>Things-oriented</td><td>"Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts" [5]</td><td rowspan="2">"A world where things can automatically communicate to computers and each other providing services to the benefit of the human kind" [7]</td></tr>
<tr><td>Internet-oriented</td><td>"Interconnected objects having an active role in what might be called the Future Internet" [6]</td></tr>
<tr><td>Semantic-oriented</td><td colspan="2">"A world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" [6]</td></tr>
</table>

In fact, IoT can be simply considered as a shift in paradigm. "From anytime, anyplace connectivity for anyone, we will now have connectivity for anything" [8].

Even though a standardized definition of the "Internet of Things" does not exist, most of the definitions related to this vision have much in common, such as [9]:

- the ubiquitous nature of connectivity,
- the global identification of every thing,
- the ability of each thing to send and receive data across the Internet or the private network they are connected into.

As shown in [10], depending on the nature of things, different ways of connecting them to IoT will be used. Three major technology areas related to IoT offer three major options, as we can see in Table 2.

Table 2. Connecting things to IoT

Integrating things in IoT	Technology areas related to IoT
Identifying things	RFID
Sensing things	Sensors
Reading things	Embedded systems

Things in IoT should be identified by at least one unique way of identification for the capability of addressing and communicating with each other and verifying their identities [3]. In many research papers and reports, if the "thing" is identified, it is called "object". RFID technologies, shortly described in section 3, can be used to identify objects in IoT. In fact, RFID is viewed as a key enabler of the Internet of Things.

Accordingly, a robot can become a part of the Internet of Things (as a thing), as we can see in the fourth section of this paper.

B. *IoT Applications*

IoT applications will be used in a wide range of innovative areas, with the main fields of application as illustrated in Fig. 2 [11].

The CERPT-IoT [12] describes these application domains with indicative examples (Table 3).

Also, Beecham Research depicts a diagram (Fig. 3) that represents the IoT ecosystem in different industry sectors, such as, energy, healthcare, industrial, transportation, retail, etc. [27].

But the widespread adoption of the Internet of Things takes time and numerous reports identify business, policy and technical challenges that need to be tackled. Table 4 presents some of these challenges.

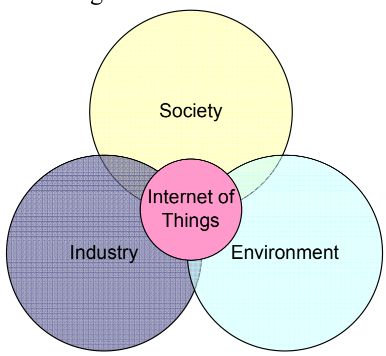

Fig. 2. The main IoT application domains

C. *IoT Platforms*

Currently, bridging the gap between the real and the virtual world is possible through developed IoT platforms. Next we shortly introduce some of these IoT platforms.

Pachube [13]) was published as an open real-time data infrastructure platform for the IoT, which manages millions of data points per day from thousands of individuals, organizations and companies around the world. Pachube's motto was "patching the planet". For example, Pachube was used as a tool for understanding the environment, for getting feeds from the stuff that has an electronic pulse and the means to communicate it to better understand what's going on around the world. Thus, one of the most dramatic demonstrations of Pachube's potential was visualizations of data that show radiation levels around the Japan and especially near the nuclear reactor. Now, Pachube.com has evolved into Cosm.com [14].

Table 3. Description and examples of IoT application domains

Domain	**Description**	**Indicative examples**
Industry	Activities involving financial or commercial transactions between companies	Activities regarding development and inclusion of societies, cities, and people.
Environment	Activities regarding protection	Agriculture & breeding, recycling, environmental management services, energy management etc.
Society	Activities regarding development and inclusion of societies	Governmental services toward citizens and other society structures.

SenseTale [15] is an Internet of Things application that aggregates data from different sensors embedded in physical objects, mobile devices, electronic appliances and the environment. The live data coming from a sensor is used to create a story that can be shared with friends/family/external users through a social platform.

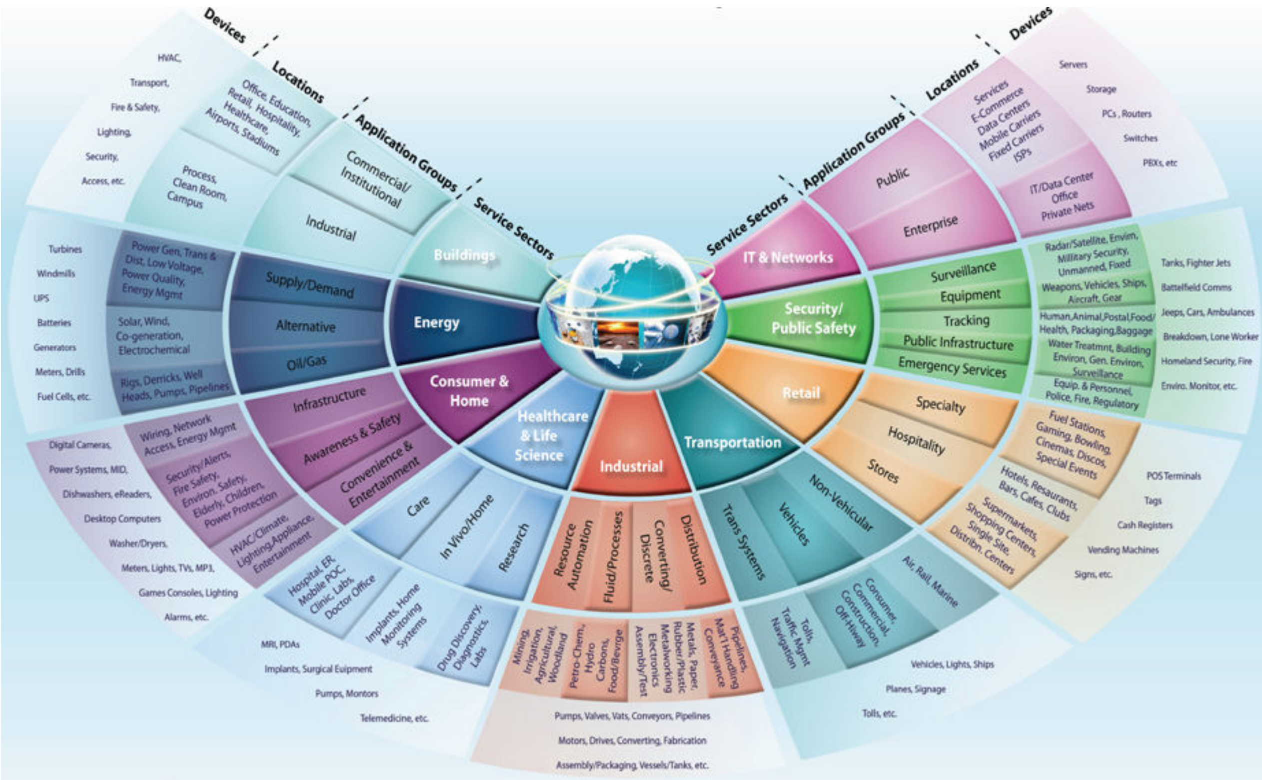

Fig. 3. The Internet of Things sector map [27]

Nimbits [16] is an open source service that allows people, sensors and devices to connect on the cloud. With such a tool any user can define points and feed different types of information into them. Data points have the capability to perform calculations, connect to social networks (Facebook, Twitter and Google Plus), store and share files/sensor logs/process diagram, generate alarms, statistics, etc.

ThingSpeak [17] is an IoT application that allows users to store and retrieve data from things by exploitation of HTTP protocol over the Internet or via a LAN. ThingSpeak enables the development of different types of applications including location tracking and sensor logging applications. Also, there is a possibility of creating a social network of things with continuous status updates. ThingSpeak API complies with the performing of different calculi, such as timescaling, averaging, median, summing, and rounding. Furthermore, ThingSpeak allows using the cloud to store data and do calculations. Several data representations like JSON, XML, and CSV are used for integration of data into applications.

Table 4. Description and examples of IoT application domains

Perspective	Challenges
Business	Business models, standardization (on information sensing/ data transfer/ applications/service platform), IoT ecosystem
Policy	Re-allocation of radio spectrum, balance security and resilience, new legal definition of privacy, ethics delivery in the technological design of systems, services accessibility (mainly to humans with disabilities or special needs)
Technical	Scalability, interoperability, availability, networking, manageability, reliability, security and privacy, energy management

According to [18], "embedding real world information into networks, services and applications is one of the aims of IoT technology by using enabling technologies like wireless sensor and actuator networks, IoT devices, ubiquitous device assemblies and RFID".

The next section briefly describes RFID technologies.

III. RFID TECHNOLOGIES

Radio frequency identification (RFID) is an Automatic Identification and Data Capture (AIDC) technology that uses radio waves to automatically identify entities (people or objects), allowing the collection of data about them and storing that data into computer systems. Thus, RFID technology enables various entities to be uniquely identified in the Internet of Things. RFID technology is similar to barcode technology, a well-known and widely used AIDC technology. Although barcodes offer some advantages over RFID, (most notably their low cost), there are a number of characteristics particular to RFID which make this technology superior to barcodes in terms of (1) non-optical proximity communication, (2) information density, (3) two-way communication ability and (4) multiple simultaneous reading (the reading of more than one item at a time) [19].

The basic RFID system architecture (Fig. 4) [20] has three major components: contactless electronic tags to store unique identification data and other specific information, an RFID reader (to read and write these tags) and processing elements (application components) [28].

An RFID tag is attached to or embedded in the individual that is to be identified. Currently, RFID tags are widely used for tracking objects, people, and animals; all these entities can be connected as things in the Internet of Things. Tags fall into three categories: active (battery-powered), passive (the reader signal is used for activation) or semi-passive (battery-assisted, activated by a signal from the reader). Generally speaking, tag memory size can vary from 1 bit to 32 kbits and more. In certain tag types, the information on the tag is reprogrammable.

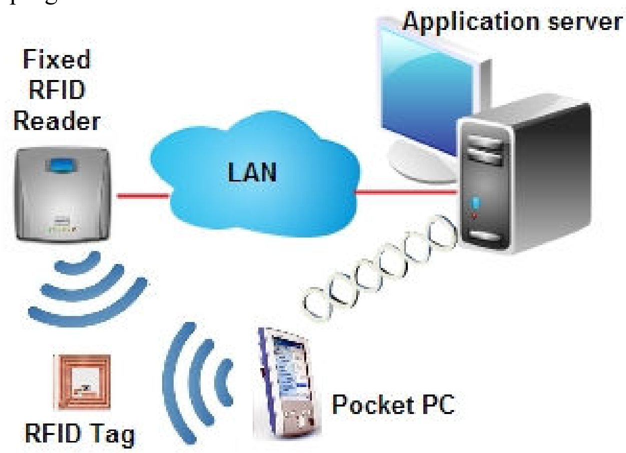

Fig. 4. The basic RFID system architecture

RFID reader is the device used to interrogate a tag. If the system uses RFID passive tags (which today are largely encountered), the reader generates an RF carrier wave that could power a tag if the tag is within its reading range. Based on a communication protocol, the tag sends back its data to the reader.

RFID systems require software, network and database components that should enable information flow from tags to the organisation's information infrastructure, where the information is processed and stored. Systems are application-specific [21].

Worldwide, there is a large number of various RFID applications employed across a wide range of industries and this number is growing at a fast pace. Thus, RFID applications offer solutions for: 1) logistical tracking and tracing [22], 2) production, monitoring and maintenance, 3) product safety, quality and information , 4) supply chain [20], 5) access control as well as tracking and tracing of individuals, 6) loyalty, membership and payment, 7) healthcare, 8) sport, leisure and household, 9) public services etc. And, as RFID tags become cheaper and data flow more easily manageable, researchers estimate the increase of RFID-based applications in a wide variety of domains. The rapid penetration of RFID in different life areas presents opportunities for engineers concerned with developing RFID-based systems in an efficient manner and connecting more and more uniquely identified "things" to the Internet of Things.

Proving to be a low cost solution to uniquely identify things that should be connected to the Internet of Things, the RFID technology is viewed as a key enabler for the development of the Internet of Things, increasingly leveraging the power of the

IoT in various domains.

IV. Robots in Internet of Things

Next we consider the connection of the Surveyor SRV-1 robot to the Internet of Things. This robot, presented in Fig. 5, has several infra-red (IR) sensors (that can be used, for example, to estimate the robot's distance from obstacles), a digital video camera, WLAN 802.11b/g networking, etc. According to Surveyor Corporation, the SRV-1 robot is designed for research, education, and exploration [29].

Fig. 5. The Surveyor SRV-1 robot

In the Internet of Things this robot can connect as a thing. Thus, it can establish connections to other things over the Internet, either as a source of information and/or as a consumer. As an information consumer, the robot gains access to important information which it can gather in order to achieve certain tasks. Connecting robot to IoT as a source of information can considerably enhance, for example, the human-robot collaboration.

The considered robot can be connected to Internet of Things, either in an active or in a passive mode. In a passive mode, the robot is not connected to the Internet, but can be uniquely identified through an RFID tag. Other Internet-connected things with RFID reading capabilities can identify this robot and publish on IoT robot related information, e.g., robot localization information. In an active mode, the robot is connected to the Internet, allowing sending real-time information to the Internet.

In order to connect our robot to the Internet of Things, we consider two IoT platforms: Pachube (now Cosm) and ThingSpeak.

Fig. 6 presents the overall architecture of connecting the SRV-1 robot to Pachube platform. We attached an RFID reader and an additional power source to our mobile robot. We used an RFID tagged smart floor to enable the indoor localization and the navigation of the robot (Fig. 7). The smart floor is built with a dense, area-wide network of RFID tags, which are mounted underneath the regular floor covering. According to [30], these RFID tags which are invisibly attached to carpets or hard floors allow a robust navigation. While the mobile robot moves, the reader detects tags near the mobile robot. The robot estimates the position from the detected tags' positions and sends the coordinates values to Internet of Things platform as we can see in Fig. 8.

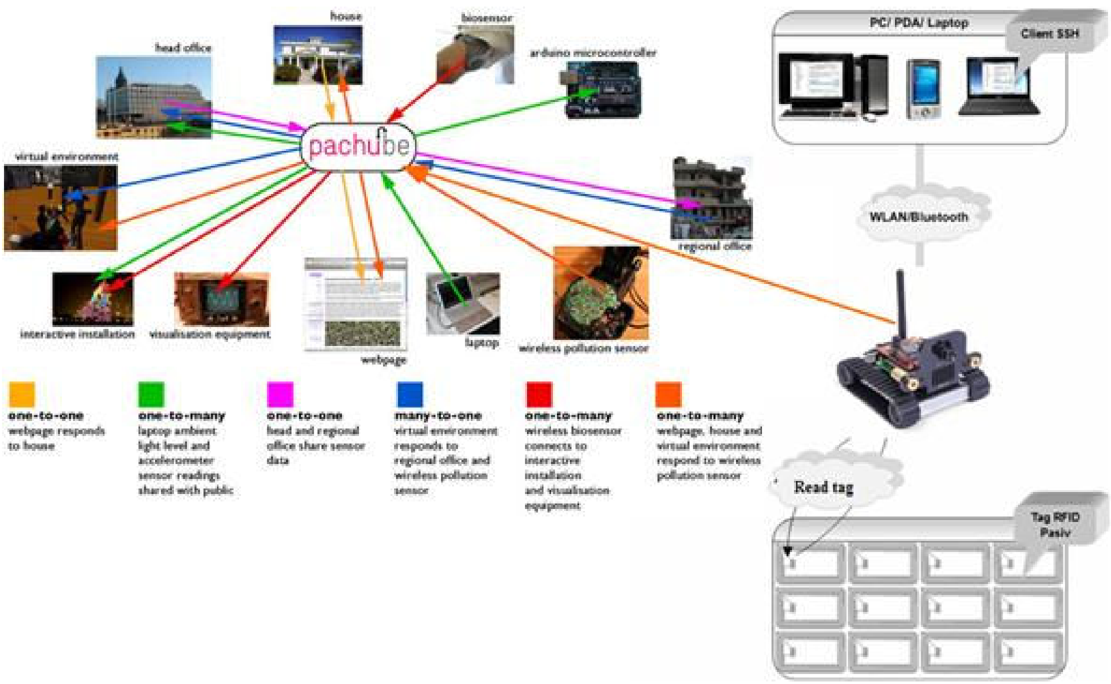

Fig. 6. Connecting SRV-1 to Pachube platform

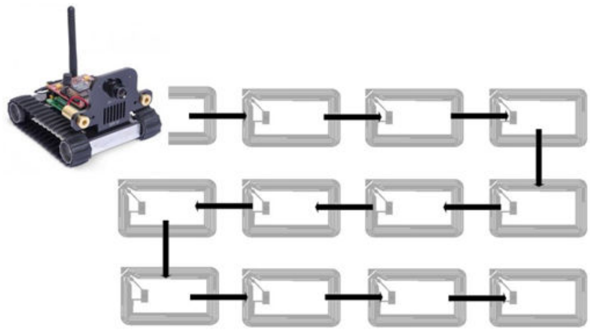

Fig. 7. Robot navigation

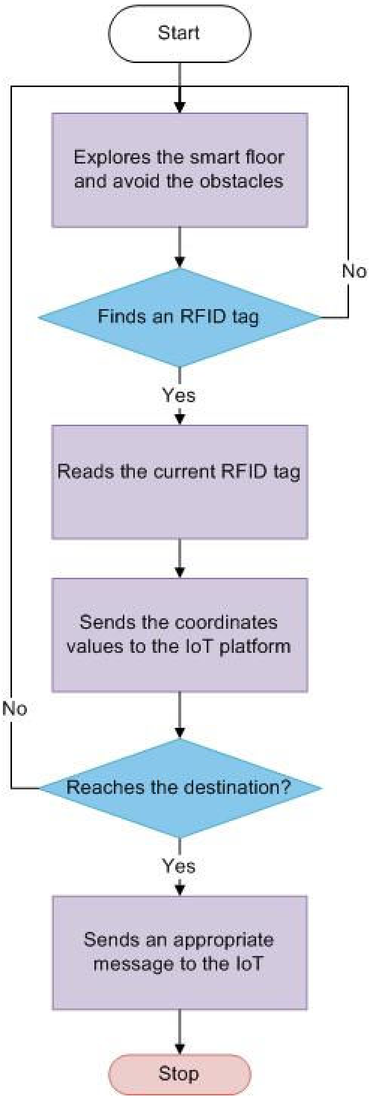

Fig. 8. Dataflow of robot navigation

In order to evaluate the presented system, we conducted extensive experiments using various tags and different tag positions. We found that this localization and navigation system is robust to the external environments, such as, light condition, surface condition of floor, dirts on the floor, etc. Also, it is easy to scale up the work space and number of robots.

The online database service Pachube offers the considered robot the power to share, collaborate, and make use of information uploaded on the web. Thus, it can make real-time charts, embed graphs of the data on websites, and send real-time alerts to other devices, such as a cell phone [24].

Also, we take into account the integration of our robot in Internet of Things through ThingSpeak (Fig. 9), an open application platform that enables meaningful connections between robots and people [25].

Fig. 9. Connecting SRV-1 to ThingSpeak platform

Although ThingSpeak is very similar to Pachube, there are some differences between them, among which a more easily to use interface for displaying data. Also, because ThingSpeak allows using the cloud to store data and do calculations, this could add powerful capabilities to our robot, which has limited memory and processing resources. Thus, the cloud could be used for highly impressive algorithms and functions, for processing many resource-consuming tasks and returning the results to the robot [25].

Applying RFID technologies to the robotic area provides solutions to some problems, e.g., connecting an RFID-based robot to the IoT in passive or active mode, indoor or outdoor localisation, etc. The adoption of RFID technology offers a great flexibility in the dynamic environment at a low cost. Thus, we can consider our robot with RFID identification capabilities that is connected to the IoT, viewed as an IoT thing. This robot could identify RFID-tagged entities from its own environment, e.g., entities that are not connected to the Internet, and publish the information related to these entities on the IoT. Thus, the robot allows the connection of these entities in the IoT in a passive mode, with these entities viewed as things in IoT.

IoT applications need to know the physical location of things. Connecting an RFID-based robot to IoT allows the development of a tracking system and high resolution scanning for indoor or outdoor environments. This robot can work in different physical environments that raise some problems to other systems, e.g., based on computer vision. Using IoT facilities, the robot can update the information of interest in real time. Other things in the Internet of Things can access this information when needed, without any time or geographical limitations. Also, the robot can get the information of interest from other things connected to IoT.

The integration of robots within the Internet of Things can offer great advantages for many domains, such as, ambient and assisted living (health, intelligent home), supply chain, etc.

But, although the integration of robots within the Internet of Things could bring great benefits, this evolution towards IoT raises some technical issues, among which [26]:

1) different intercommunication and interoperation standards;
2) different radio interfaces and media access;
3) different resources management;
4) different encryption;
5) different publication and subscription of devices;
6) different privacy and security standards;
7) different business model.

In order to integrate all types of devices, extensible standards and protocols are required, suitable for the "Internet of Things".

V. Conclusion

The Internet of Things, a world-wide network of interconnected objects, can be considered an evolutionary process, rather than a completely new one. “From anytime, anyplace connectivity for anyone, we will now have connectivity for anything” [8].

Researchers estimate that new innovative applications will emerge in the near future to exploit the connectivity and accessibility of everything connected to IoT.

RFID technology is viewed as a key enabler for the development of IoT infrastructure. Thus, RFID provides any thing connected to IoT with the capability of being uniquely identified.

Robots can offer viable solutions for anytime, anyplace connectivity for anything, enabling the development of IoT. In fact, connecting robots to IoT allows them to connect to other things in IoT, such as, external processing units (e.g., clouds) and external sensors (e.g., temperature sensor), to receive useful information for achieving various tasks. Also, other things from IoT can access robots’ capabilities, such as, sensing, processing, and acting. In this manner, robots can be perceived as belonging to the Internet of Things. However, there are still some challenges for worldwide IoT adoption, from infrastructures improvement to standardisation.

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