INTERNET OF THINGS: A REVIEW OF APPLICATIONS AND TECHNOLOGIES

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Abstract

This paper presents the state-of-art of the Internet of Things (IoT), an enabler of new forms of communication between people and things, and between things. The main strength of the IoT concept is the high influence it has on everyday life by creating a new dimension to the world, similar to what the Internet once did. This paper describes the definitions of IoT and summarizes its main enabling technologies. The content includes the strengths and limitations of applications based on the IoT in logistics, transportation, healthcare, and environment and disaster. Finally, the open challenges of the IoT are debated to encourage more investigations into the domains.

Keywords: Internet of Things, IoT, limitations, strengths

Introduction

The term Internet of Things (IoT) (Huang and Li, 2010; Uckelmann *et al*., 2011) has been around for the past few years and is gaining recognition with the breakthrough of advanced wireless technology. Even though there are heterogeneous definitions on the interpretation of the Internet of Things, it has a corresponding boundary related to the integration of the physical world with the virtual world of the Internet. The IoT can broadly be defined as a global network infrastructure, linking uniquely identified physical and virtual objects, things, and devices through intelligent objects, communication, and actuation capabilities. In other words, the paradigm of the IoT is described as “any-time, any-place, and any-one connected” (Ryu *et al*., 2012). Its implication is based on technology that makes things and people get closer than in the old days.

In the perspective of “things”, numerous devices and objects will be connected to the Internet. Each individually provides data, information, or even services. The devices providing things can be personal objects we carry around such as smart phones, tablets,

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and digital cameras. Our daily environment, home, vehicle, or office connected through a gateway device can also provide “things” (Coetzee and Eksteen, 2011). Although Radio-Frequency Identification (RFID) is precisely the first idea that popped up, many more technologies such as sensor technologies, smart things, and actuators have also contributed, whereas machine-to-machine communication (M2M) and vehicle-to-vehicle communication (V2V) are the real applications in the market revealing the most benefits of the IoT (Atzori *et al*., 2010; Uckelmann *et al*., 2011).

The aim of this paper is to explore the development and the deployment of the IoT in significant application domains. The organization of the paper is as follows:- Section 2 describes the structure of the IoT; Section 3 presents a review of the existing application of the IoT categorized into the areas of logistics, transportation, healthcare, and environment and disaster; Section 4 is the discussion of the IoT applications based on its benefits and limitations; and Section 5 is the challenge of the IoT in those application domains.

The Structure of the Internet of Things

The Internet of Things can be viewed as a gigantic network consisting of subnetworks of devices and computers connected through a series of intermediate technologies where numerous technologies such as RFID, barcodes, and wired and wireless connections may act as enablers of this connectivity. Under the International Telecommunications Union (ITU), the perception of the IoT was structured as 4 dimensions of things, as illustrated in Figure 1 (Atzori *et al*., 2010; Coetzee and Eksteen, 2011).

Tagging Things

Real-time item traceability and addressability of RFID is what makes it stand at the forefront in terms of the IoT vision. RFID is gaining strong support from the business community due to its maturity, low cost, and low power. RFID acts as an electronic barcode to help in the automatic identification of anything attached. RFID tags are available in 2 types: active and passive. The active tags embedded within the battery on-board are widely used in retail, healthcare, and facilities management. The passive tags, containing no batteries, are powered by the reader and are more likely to be used in bank cards and road toll tags (Aggarwal, 2012).

Feeling Things

Sensors act as primary devices to collect data from the environment. Necessary data is provided via communications established

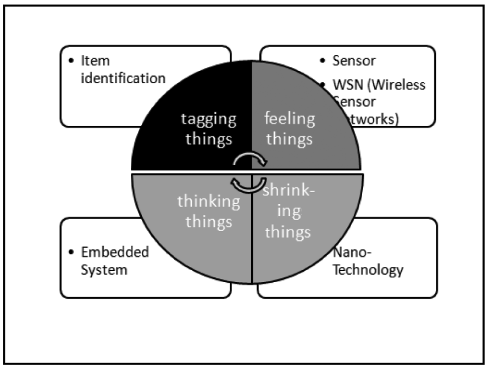

Figure 1. Four dimensions for the IoT (ITU)

between the physical and the information worlds (Vermesan and Friess, 2013). Recent advances in technologies make them consume less power with low cost and high efficiency.

Shrinking Things

Miniaturization and nanotechnology has provided the ability for smaller things to interact and connect within the "things" or "smart devices". A clear advantage is the improvement in the quality of life. For example, the application of nano-sensors for monitoring water quality at reduced cost, and nano-membranes for assisting in the treatment of waste water (Vermesan and Friess, 2013). In healthcare, its application can be seen in the diagnosis and treatment of diseases, including the diagnosis of HIV and AIDS, and in the prescription of nano-drugs for other diseases (Gubbi *et al*., 2013).

Thinking Things

Embedded intelligence in devices through sensors has formed the network connection to the Internet. It can make domestic electric appliances realize intelligent control, for example refrigerators that can detect the quantities of various items and the freshness of perishable items. Embedded smart sensors may provide the means to communicate with users by sending alerts via the Internet connectivity. The connection can primarily be wireless or any other available communication, such as DSL, GPRS, WiFi, LAN, and 3G (Uckelmann *et al*., 2011). Smart things must not only communicate but must also be able to "...process information, self-configure, self-maintain, self-repair, make independent decisions, or even play an active role in their own disposal..." (Vermesan and Friess, 2013) which will change the way information is communicated from human-human to human-thing and to thing-thing.

Applications Based on the IoT

Some of the most important engines of the innovation and development of the IoT are its applications; otherwise public acceptance of the IoT will never happen (Coetzee and Eksteen, 2011). Based on the concept of the IoT, information generated from daily enabling objects in our environment can possibly communicate with each other. This information can drive many possible applications. Applications directly applicable or closer to our current living habitudes can possibly be categorized into the 4 following domains (Yang *et al*., 2012).

Logistics and Supply Chain Management

Traditionally, most of the logistics enterprises require manifold report tracking, along with the specific time and location to control the movement of goods. However, with the IoT society, the logistics commodity has changed greatly to become an autonomous society by a variety of applications available to support the needs. The systems in Li and Luo, (2010), Wei, (2011), and El-Baz *et al*., (2013) are logistics applications implemented to track the movement of goods in real-time. The data scanned from the tags of barcodes or RFID were transmitted to the logistics center or RFID receivers. Data were then transmitted through Wireless Sensor Networks (WSNs) (Li and Luo, 2010), GSM network (Wei, 2011), 3G network, or a new High Performance Computing (HPC) infrastructure through a broker (El-Baz *et al*., 2013) to be processed at the data center. The solutions in this domain are very promising since they have adopted comprehensive and diversified transmission protocols. Several devices such as RFID, Near Field Communication, and mobile phone can also act as data collectors,but they do have substantial limitations.

For example, supermarket chain management (Li and Luo, 2010) was developed based on a standard relational database, which can lead to a worrisome situation when dealing with a large volume of "things". The occurrence of incomplete information or missing information propagated from the communication distance of the mobile logistics information reader (Wei, 2011) and the data collision during transmission may alsojeopardize the results.

Not only are the applications to support the front-end and back-end operation essential, but the abilities to control and identify the next destination of goods/raw material are also indispensable. Real-time tracking of logistics entities using the combination capabilities of RFID, mobile devices, and the integrated browser interface was conducted (Lin, 2011). The position of objects was derived from GPS, WiFi, GSM, and GPRSThe overall detection accuracy of the geographical location was over 97% for moving entities and roughly 100% for the action-less entities. However, its hindrances are i) the detection of the geographical position function needed to support a variety of browsers, since different logistics users may use different mobile devices, and ii) the browsers themselves should have the ability to automatically detect and confirm on what positioning devices should be launched.

To increase the accuracy of the logistics process, not only the ability to detect the location of goods is desired, but the reliability of RFID signals is also essential, particularly in the environment where there is limited accessibility to the IoT infrastructure. The launch of AspireRFID (Soldatos *et al.*, 2010), an RFID middleware with a range of tools to facilitate RFID deployment (Soldatos, 2009) was a breakthrough. The integration of the Electronic Product Code (EPC) global based RFID architecture with Session Initiation Protocol (SIP) (Anggorojati *et al.*, 2013) to simultaneously detect locations and mobility management of RFID tags revealed the outstanding performance in cost consumption of tags registration and tracking.

In large logistics enterprises, the efficacy to automatically locate and move assembly parts has led to the adoption of robots. The infrared motion capture system or computer vision system with complex machine learning algorithms was basically used to control the navigation and object manipulation of robots. However, that feature of the proposed robotswas handled by RF-Compass and RFID (Wang *et al.*, 2013). Both the robots and the objects the robots will work on are embedded with an ultralow-power RF-compass and a low cost RFID as a replacement for WiFi-nodes. The RF-Compass could pinpoint the center position and the orientation of objects with 80-90% accuracy when robots were grasping objects. Even though this study demonstrates a low computation time when compared with machine-learning architecture, it has a limited line-of-sight detection and no proven evidence on handling small objects.

The review of the IoT applications in logistics (Table 1) indicates that, in order to maintain the effectiveness of the IoT, the system should at least comprise the following basic capabilities:

Autonomous control: Mechanisms to overcome limitations in the management and exploitation of millions of unreliable, non-autonomous things and of the corresponding data and information flows should be implemented. Instead of having a central control unit for decision making responsibilities, decentralized control of a multiplicity of smaller self-organizing units will be more efficient. The capability and possibility to render decisions independently will, as well, improve the robustness and increase the scalability of the process control.

Smart logistics entities: Each commodity in the logistics network is embedded with sensors to record information of items for fast updating of transactions of specific goods. Protection from thieves, andfast tracking and tracing of goods can alsobe autonomously triggered as alarm mechanisms by these sensors.

Unique addressability: Right product, right quantity, right time, right place, right condition, and right price are what are expected in logistics. Right product relates to accurate and appropriate information on a product which can be deduced from auto-ID, sensor information, or any other kind of linked information. Right time means that a product can be acquired anytime when needed. Right place refers to goods located independently of unreliable network connectivity. Effective data synchronization protocols and caching techniques are necessary to ensure the

Table 1. Summary of the IoT in logistics and supply chain management

Application	Technology/Technique	Strengths/Weaknesses
Supermarket chain management (Li and Luo, 2010)	• Tracking of goods in real-time via WSNs • Use mathematical model to track information on goods movements as well as automatically control of stock. • Technology: barcodes and RFIDs. • Database employed is a standard relational database.	Strengths • Ease of implementation Weaknesses • Inefficacy of database technology when handling big data.
Aspire RFID (Soldatos *et al*., 2010)	• Integration of the EPC global based RFID architecture with Session Initiation Protocol (SIP). • Technology: RFID, SIP. • Use SIP to detect location and mobility management of RFID tags.	Strengths • Reduces problem of limited accessibility of Global IP network. • Low cost consumption of tags registration and tracking. Weaknesses • Accidental propagation of infested traffic from LAN and Internet.
Logistic IoT Unified Information System (UIS) (Wei, 2011)	• Developed on ASP.NET. • Technology: GSM/RFID collection devices and GSM modem. • Data transmitted through Internet/GSM, mobile network.	Strengths • Supports both Internet and mobile network. Weaknesses • Incomplete or missing information from communication distance. • No specific handling for data collision.
Logistic Geographical Information Detection UIS (Lin, 2011)	• Combined capability of RFID, mobile devices and browser interface. • Locations of goods are automatically detected from mobile browser. • Technology: GPS, Wi-Fi, GSM, GPRS. • Supports various logistic mobile devices • Can operate without any extra positioning devices, only IoT mobile terminals are sufficient.	Strengths • High detection accuracy of over 97% for moving entities and 100% for still entities. • Provides several sources of location detection mechanism. Weaknesses • Location detection mainly depends on mobile browser. • Support for variety of logistic mobile devices is questionable.
A Logistic Mobile Application (ALMA) (El-Baz e*t al*., 2013)	• Technology: smart phone, 3G, HPC. • Supports variety of applications. • Operates on P2P based computing. • Large-scale server based.	Strengths • High performance. Weaknesses • Not suitable for small organization. • Limitation of 3G connection in some areas.
Robot navigation and object manipulation (Wang *et al*., 2013)	• Enables robots to perform more complex tasks in collaboration with other robots. • Technology: RF-compass, low-cost RFID, infrared motion capture system or computer vision. • Machine learning based algorithms	Strengths • Accuracy of 80-90% for grasping object. • Low computation time in comparison with standard machine learning algorithms. Weaknesses • No evidence on non-straight line of sight of robots. • Unproven record for handling small articles.

availability of information at the right place. The right price means the product price lies between the cost for information provisioning and the achievable market price.

ERP interface: Real-time access to the Enterprise Resource Planning (ERP) solution helps shop administrators to better inform customers about the availability of products and give them more product information in general.

Transportation

The development in transportation is presumed to be one of the factors to indicate the well-being of a country. That is why transportation problems are very challenging in the field of the IoT. A proposal on a road condition monitoring and alert application was initiated (Ghose *et al.*, 2012). Its main idea was to apply the principles of crowd sourcing and participatory sensing. The process began when the user identified the route he wished to take and marked some points as potholes in the smart phone's application. When the vehicle ran over the defined route, the accelerometer which continuously captured data would send raw data via the mobile network. Related features were then extracted to generate a confidence score to indicate the abnormalities of the routes by showing the plot of the potholes information. A distinct advantage was expressed from the adoption of the user's smart phone as a connector device with no additional cost applying on the existing hardware. Albeit, there remain issues with the upload and download process of the route-map which involves considerable network traffic and may induce vulnerability to the system. Moreover, the road condition classification is performed at the phone itself, is very time-consuming, and it may drain the battery of the mobile phone.

For large cities, problems such as finding parking spaces and waiting in line for toll-way payment can be cumbersome which promoted the idea of applying the license plate as a unique identity of the driver (Ren *et al.*, 2012). The license plate was captured by the recognition equipment whereas sensors embedded in the license plate would collect the information of the road surface. The data was then forwarded to calculate the optimal path and guiding passage for vehicles. The system is not only able to invoke traffic scheduling, vehicle positioning, and vehicle query for a passenger, but it also can locate the parking spaces in a nearby location. This design provides a variety of benefits to the driver in terms of managing highway automatic toll collection, avoiding busy traffic, locating parking spaces, and adding more security for the vehicle. A clear drawback, however, is that this design struggles to support too many functions which invokesa high cost and difficulties of implementation.

Electric vehicles, an important means to reduce both the fuel cost and the impact of global warming, have also gained considerable attention from drivers. Governments in many countries have supported research on systems to monitor the performance of lithium-ion (Li-on) batteries for electric vehicles (Haiying *et al.*, 2012). The system presented was designed to detect the functions of a Li-on power battery by deriving the driving situation from realistic working conditions for a driver so that the driver was able to get an idea of the route's status. This solution was embedded with many essential functions such as a dynamic performance test of the Li-on battery, remote monitoring with on-line debugging, and error correction that could significantly reduce the maintenance cost. For as much as the underlying issue of such a design is the battery life, the extensible functions of age-tracking and end-of-life predictions of the battery should be bundled so that a fading battery can be tracked to assure the readiness, reliability, and security of electric vehicles.

Safety supervision in the distribution of hazardous or valuable goods is imperative for shipping companies. A study to master the operation of an entire fleet from a command center in real-time was conducted (Shengguang *et al.*, 2013). Each vehicle was embedded with GPS to form a multi-hop network for the command center to share the perception of the drivers. A combination of an RFID reader and 3G video surveillance was used to monitor the status of the goods, whereas temperature and humidity sensors in the vehicles were used to detect the quality of the transported goods. If indicators exceeded the limit, an alarm would be raised. Other unpredicted events such as driver fatigue or unauthorized access were also detected and forwarded to the command center. This design has achieved effectiveness in road traffic safety and travel reliability. The limitations are that the adoption of several technologies in this design will increase the cost of both deployment and support. Moreover, the location of vehicles can be inaccurate when vehicles are moving at high speed or approaching blind spots for GPS.

The IoT applications in transportation which have been reviewed are summarized (Table 2). From those, it can be concluded that the underlying system should at least include the following system units:

Vehicle System: the main components of a vehicle system are:

i) GPS system: This system is mainly responsible for receiving comprehensive information such as location, time, and weather from satellites. It is not only amap embedded with resources about major cities and road information, but it also gives a fast and accurate GPS positioning, even if the satellitesignal is poor; and

ii) Wireless communication system: GPS and RFID data are forwarded to a control center through the Internet. Data will then be displayed on electronic mapsat the monitoring center to facilitate the management ofreal-time scheduling.

Station System: The station subsystem generally consists of a communication module and control module. The former includes the GPRS receiver, which is responsible for receiving and decoding the transmitted data packets from the monitoring center. The latter is a communication interface module to receive data and display real-time transit vehicle information.

Monitor Center: The collected information is transmitted to the communication equipment through the Internet. Then, the communication equipment will send the received information to the real-time database system to compare with the data of events. The collaboration ofreal-time data in the database and GIS technology means that the road traffic information can be integrated for visualization.

Healthcare

Improvement in human health and well-being is the ultimate goal of any economic, technological, and social development. The rapid rise in the aging of the populations is one of the macro powers causing great pressure on healthcare systems. A solution to solve the difficulties in accessing healthcare for people in rural areas of developing countries (Rohokale *et al*., 2011) was implemented. A person registered with the rural healthcare center (RHC) was requested to wear an active RFID sensor to detect any change in the normal parameters. If those parameters exceeded certain values, information would be cooperatively routed to the RHC doctor. In an environment without the Internet, the mobile network facility could be utilized to convey the information. This approach is proven to be a reliable critical healthcare application that continuously monitors and controls the health parameters of humans.

The other approach was the integration of clinical devices in the patient's environment (Jara *et al*., 2012) which allowedthe user to use a mobile phone to transmit health data to medical centers. A home gateway was located at the patient's house to connect to the Internet while the mobile personal health device acted as an integration of medical devices from different vendors. The system continuously analyzed the vital signs from the patient to detect anomalies. The noticeable flaw of the system is security threats and attacks in the mobile network; although GSM has adopted encryption as a protection mechanism, as it is wide-spread in nature, interception of the information transmitted is possible.

A non-contact health monitoring system (NCHMS) (Yang *et al.*, 2012) was another choice of the IoT healthcare service which is more convenient for users. The system monitored the user's facial expressions, postures, and sounds. The monitoring system collected the user's data through digital cameras, microphones, and other equipment. The feature extraction, expression recognition, and classification were performed at the server. The variations in the user's facial expressions, postures, and sounds were used as identifications to classify if the user was in danger or had a disease. If any of these parameters changed, the system determines the necessary treatment, reminds the user, and notifies the hospital and related persons. The system demonstrated promising strength in terms of ease-of-use. But the adoption of a camera as a collector device can cause difficulties in actively synthesizing images for transmission, as well as the angle of the images captured. As for the microphone, recognition of the voice could also suffer from the clamor in the environment. Another

Table 2. Summary of the IoT in Transportation

Application	Technology/Technique	Strengths/Weaknesses
Road Condition Monitoring and Alert system (Ghose *et al.*, 2012)	• Crowd sourcing and participatory sensing based application. • Technology: accelerometer, smart phone, GPS (future). • Classifier based algorithm. • When a route is chosen, a confidence score for the area marked and the pothole information will be plotted on mobile.	Strengths • Reduces cost by using smart phone as a connector device. Weaknesses • Many uploads and downloads of GIS data can induce network traffic • Ease of security attack. • Time consuming for classification.
License plate Identification (Ren *et al.*, 2012)	• Uses license plate as unique identifier. • Locates optimal path and guiding passage for vehicles. • Automatically invokes traffic scheduling, vehicle positioning, and vehicle query. • Technology: RFID, recognition equipment.	Strengths • Automatically suggests optimal path, locating of parking spaces and added security for vehicles. Weaknesses • High cost and difficulties in implementation.
Remote performance monitoring system and simulation testing (Haiying *et al.*, 2012)	• Monitors the status of Lithium-ion power battery of electric vehicle. • A simulation of identified route for bus drivers. • A performance test of battery pack, battery modules, and battery systems. • Technology: GPS, RFID.	Strengths • Online debugging and error correction can significantly reduce the maintenance cost. Weaknesses • no support for age tracking and end-of-life predictions of battery
Transport vehicle monitoring system based on IoT (Shengguang *et al.*, 2013)	• Real-time administration of the entire fleet from the command center. • Technology: GPS, RFID, 3G. • Monitors status of goods through RFID tags attached to goods. • Combines various capabilities of technologies: vehicle electronic sensors, mobile communication technology, navigation systems, smart terminal equipment, and the information network.	Strengths • Effective road traffic both for safety and reliability. Weaknesses • High cost implementation • Weak signal when vehicles are moving at high speed or approaching blind spots for GPS

serious drawback is the machine learning technique, normally involved with time-complexity in the analysis of the large volume of the learning data set.

The IoT applications in healthcare which have been reviewed aresummarized (Table 3). In a nutshell, solutions for healthcare should at least involve the following capabilities:

Tracking and monitoring: All patients should be tracked and monitored with any wearable WSN devices at all times seeing that sensors can effectively generate health signals as an enhancement with the communication capacity;

Remote service: Telemedicine and remote diagnosis are necessary to provide emergency detection and first aid for patients with congenital diseases;

Information management: Information regarding health such as medication, therapy, and advice for patients should be distributed through the value chain; and

Cross-organization integration: The integration of hospital information systems should be extended to patients' homes and other hospital chains.

Environment and Disaster

At present, natural and accidental disasters are taking place more frequently. To lessen the effects of natural disasters, technologies in the IoT could play a crucial role in alerting before disasters happen, and in disaster recovery after they have ended.

A heritage site monitoring system, namely the Health Monitoring and Risk Evaluation of Earthen Sites (HMRE2S) model (Xiao *et al*., 2013), was conducted to monitor environmental information of cultural sites.

Table 3. Summary of the IoT in healthcare

Application	Technology/Technique	Strengths/Weaknesses
Rural Healthcare Monitoring and Control system (Rohokale *et al*., 2011)	• Based on Opportunistic Large Array utilizes the cooperative transmission of the ad-hoc network nodes. • Technology: RFID, Internet, mobile network. • Data will be routed via internet to the gateway through RHC doctor. • Basic data of patient will be stored in server for comparison.	Strengths • Provides options for both Internet and mobile network. Weaknesses • Interception of information transmitted. • High computation cost for patient parameter comparison.
A knowledge acquisition and management platform (Jara *et al.*, 2012)	• An integration of a home gateway and a global connectivity to support other medical devices. • Technology: EPR, Pro-active monitoring and alerting, Remote diagnosis and RS232 and Bluetooth Health Device Profile (HDP) etc. • The system continuously analyses the vital signs from the patient to detect anomalies.	Strengths • Offers a function of plug and play. Weaknesses • Reduction in performance of input devices when compared with others such as Serial Port Profile.
Non-contact health monitoring system (NCHMS) (Yang *et al*., 2012)	• Analyze the user's facial expressions, postures, and sounds as input data. • Technology: camera, microphones, and other equipment. • Classification and recognition based algorithm.	Strengths • Convenient to users. Weaknesses • Time consuming and threshold dependable. • Cost complexity of input devices.

The environmental information such as temperature, humidity, and light were collected via an intelligent monitoring system. This experiment was claimed to provide accurate results but generalization for other sites may not be applicable since it explored only a small heritage site. For larger cultural sites, the accuracy remains questionable.

Another contribution to global warming is the smart environment which increasingly has attracted interest from society. A smart heat and electricity management system (Kyriazis *et al*., 2013) was presented to monitor real-time electricity usage of buildings and individual appliances where smart meters were used as data recorders. When the power consumption of those objects was above the limit, users would be promptly informed of such a deformed situation.

Considering disasters, waste from an oil depot can cause a terrible disaster to the environment because it is easy to set ablaze and explode. A surveillance system for safety management of an oil depot was introduced in China (Du *et al*., 2012). The sensing layer of the system consisted of RFID tags and non-explosive personal digital assistants (PDAs) to identify and interact with the key facilities in the oil depot. 3G was used as the communication layer to forward the data from the worksite to the Internet, where users accessed the safety management information via an enterprise intranet. This IoT based safety management information system was proven to be stable since it was actually deployed in 2 oil depots with 24 PDAs and 100 RFID tags.

The IoT applications in environment and disaster which have been reviewed are summarized (Table 4). The conclusion can be drawn that the prime featuresof solutions should at least be equipped with the following features:

Environment sensors: Intelligent sensors for the humidity, temperature, and pressure in the air are not calamities will serve as front-end devices togather as well as process contextual information from the environment. The built-in fault detection and diagnostic capability is also actuated through the convergence of the global industrial system;

WSN and mobile communication: The sensor nodes will be utilized for providing senses without the users' intervention. The wireless network of the sensor nodes would help sense the environment and objects around and communicate to other things. Essential pillars are WSN and advanced mobile communication technology (3G and 4G) which can provide uninterruptable high-speed communication; and

Participatory sensing applications: The utilization of each person's mobile phone, vehicle, and associated sensors as automatic sensory stations can help in capturing a multi-sensor snapshot of the immediate environment. By combining these individual snapshots in an intelligent manner, it is possible to create a clear picture of the physical world that can be shared and, for example, used as an input to the smart environment services decision processes.

Discussion on IoT in Applications

Under the vision of the IoT, applications can be fully automated by configuring themselves when exposed to a new environment. The intelligent behavior driven by the system can autonomously be triggered to seamlessly cope with unforeseen situations. However, the applications in the above domains can deliver more analytical results if the following hindrances are properly taken care of.

Apparently, the major players of collection in the above application domains are RFID and GPS. RFID is one of the most convenient devices to transmit and receive data via radio frequency without wires and at the lowest cost. Some RFID devices can only be used within the industry due to the range of the electromagnetic spectrum (Coetzee and Eksteen, 2011). A clear disadvantage of its technology is the reader collision which may occur when the signals from 2 or more readers overlap or many tags are present in a small area. Although many systems use an anti-collision protocol to enable the tags to take turns in transmitting to a reader, this problem remains. Another strong barricade is that the global standards of RFID are not yet established (Haiying *et al*., 2012).

As for GPS, it is recognized as an excellent tool for data collection in many environments where users can generally see the sky and are able to get close to the objects to be mapped. GPS requires a clear line-of-sight between the receiver's antenna and several orbiting satellites. Anything hiding the antenna from a satellite can potentially weaken the signal to such a degree that it becomes too difficult to achieve reliable positioning. Obstructions like buildings, trees, crossways, and other obstructions that block sunlight can effectively block the GPS signals where the potential could be seriously reduced (Guo *et al*., 1995; Vermesan and Friess, 2013).

Since the communication infrastructure of the IoT can be any network available within the range, hence a mobile ad-hoc network which allows people and devices to seamlessly form a network in areas without a pre-existing communication infrastructure seems to be a better choice. The more convenience, the more applications, and the more network services it supports, the more opportunities for active attackers as well as malicious or misbehaving nodes to create hostile attacks. These types of attack can seriously damage basic functions of security, such as the integrity, confidentiality, and privacy of the node. Currently, the security goal in mobile ad-hoc networks can only be achieved through cryptographic mechanisms. These mechanisms are generally more susceptible to physical security threats than fixed wired networks. Besides, standardized communication interfaces and distributed control intelligence within an industry network remain disorganized (López *et al*., 2012).

As far as the IoT dealing with more objects, the volume of the data generated and the processes involved in the handling of those data become critical. The ability to

Table 4. Summary of the IoT in Environment and Disaster

Application	Technology/Technique	Strengths/Weaknesses
Safety management information system for oil depot (Du *et al*., 2012)	• Technology: RFID, explosion-proof PDAs, 3G. • IoT technology is adopted to monitor the process of the routine works. • Software adopted: Oracle for storing business data, others are encapsulated as web service for reuse.	Strengths • Proven record in real depot sites. Weaknesses • -
Health Monitoring and Risk Evaluation of Earthen Sites (HMRE2S) (Xiao *et al*., 2013)	• Evaluate healthy level of the earthen sites by applying the concept of artificial antibodies to identify unusual environmental factors. • Technology: intelligent environment monitoring system which collects temperature, humidity, light, etc.	Strengths • Self-detection based on immune system. Weaknesses • Result is unlikely to be generalized to large heritage sites.
Smart heat and electricity management transportation (Kyriazis *et al*., 2013)	• Real-time electricity usage on the energy consumption of buildings and individual appliances. • Technology: smart meters for electricity consumption and mobile sensors.	Strengths • Weaknesses. • Not applicable yet.

extract content from the data becomes even more crucial and complex, especially when dealing with bigdata. A variety of technologies and factors involved in the data management of the IoT such as data collection and analysis, data migration and integrity, sensor networks, and complex event processing are not yet convincing (Vermesan and Friess, 2013).

Advancement and Hindrances in the IoT

The realization of the advancement in the IoT indicates sustainable applications forming a smart environment for humans where a plurality of challenges can be raised.

The first challenge was driven by embedding intelligence into things. To enable things and devices to learn and become smarter, more autonomousthings are required to share and exchange experiences with other things.

The second challenge refers to the management of heterogeneous device platforms in a decentralized way. To make a relationship with other devices, those platforms willarrange the device coordinators via their social behavior. Furthermore, pertinent issues with respect to end-to-end security, privacy, and trust also need to be addressed.

Moreover, a lot of techniques are required within and across different levels of the IoT-based systems; for example, hardware-coded security at the device level, and security and privacy in storage at the data level. Reputation, trust, and privacy profiling of things and providers are also techniques to prevent information inference.

The thirdchallenge refers to the support for scalable data and information management through rich metadata structures that capture the social aspectsof things. Real-time analysis of data will generate potentially valuable knowledge from the information flowsof the exponential amount of data.

However, there are other significant challenges which introduce a wide gap between the technology and applications in business in the IoT which cannot be neglected such as:

Unappealinginitial investment: This is a primary hindrance of mass volume adoption. For example, when suppliers want to adopt RFID for tracking goods, the initial investment cost is unacceptable for business. Besides, users do not yet trust the services provided by the IoT applications vendors, as experienced from a huge failure initiated from the deployment of the IoT Google Heath System (Wamba and Chatfield, 2010); and

Unavailable devices and service integration: Even though there is a lot of promising technology available for the IoT applications, there are very few services which can be integrated. Users need to contact several vendors if they want to deploy a complete system. Therefore, an assimilated system design framework is crucial to integrate scattered subsystems and devices for more valuable services (Lee *et al*., 2010).

Forwarding the IoT

For the IoT to achieve its vision, a number of challenges need to be overcome. These challenges range from standardization, communication, and security to data volume (Coetzee and Eksteen, 2011; Vermesan and Friess, 2013).

Standardization

There are numerous efforts towards standardization in several principal areas such as RFID, EPCglobal, M2M, as well as applications, since standards are required to allow global interoperability to change this “Intranet of Things” into the more complete “Internet of Things” (Vermesan and Friess, 2013).

The integrated environment is the origin of the success to run a multiplicity of user driven applications and connect various sensors and objects. Complex and interconnected IoT applications can be supported greatly by open Application Programming Interfaces at various system levels (Agrawal and Vieira, 2013). On one side, the vertical solutions of vendors based on their own technologies are not ready. On the other side, a dynamic global network infrastructure requires self-configuring capabilities. Appropriate channels should be provided for developers to deliver new applications and combine information generated by several IoT devices to produce new added value. Interoperable protocol is also a powerful communication tool in providing access to information, media, and services to synergize the open, global network connecting people, data, and things.

Communication Infrastructure

Things generated by devices can join networks and facilitate peer-to-peer communication for specialized purposes. They can increase the robustness of communications channels and networks by forming ad-hoc peer-to-peer networks in disaster situations to keep the flow of imperative information going in case of telecommunication infrastructure failures. Therefore, the integrity and stability of the infrastructure is crucial to provide reliable services.

The overall cyber-physical infrastructure (e.g., hardware, connectivity, software development, communications, and specialized processes at the intersection of control and sensing) are considered as the compositionality of cyber-physical systems. The network aspects may consist of Wi-Fi, IP networks, and mobile computing. Those can bring a stream of technologies such as cloud, things, and mobiles. The convergence of main driven platforms with wired and wireless broadband connections will strengthen the cloud to connect intelligent things that can sense and transmit huge amounts of data to create services. Cloud stimulates a global infrastructure for everyone to create content and applications for global users. Besides, networks of things are globally connected and maintain their identity online. This global infrastructure allows mobile connection to be available for services and businesses at anytime and anywhere leading to a globally accessible network of things, users, and consumers (Agrawal and Vieira, 2013).

Security, Privacy, and Trusts

As technologies and systems are incorporated, security remains a preponderant concern to lower system vulnerability and protect essential data, sincethe communication channel in the IoT is not only from human to machine but also from machine to machine where the guarantee on access control, authorization, privacy, and protection from malice is a prime requirement for the IoT acknowledgement.

In regard to its wireless and ubiquitous infrastructure, the IoT is vulnerable to lashing malicious attacks. The attacks generally aim to control the physical environments or obtain private data. Therefore, the IoT should autonomously tune itself to different levels of security and privacy, while not affecting the quality of service and quality of experience. The security should not only ensure the data stored in the platform but should also cover the transmission of messages from devices (sensors, actuators, etc.). Specific mechanisms to ensure the availability of the infrastructure should vindicate the Internet attacks such as denial of services and compromised nodes. The most eligible protective action during attacks on the IoT-based infrastructure should be focusing more on assisting operators thanon coping with automatic protection (Uckelmann *et al*., 2011).

Although most of the IoT has achieved a security trust through Public Key Infrastructures, decentralized and self-configuring systems can be considered as alternatives. Not only cryptographic mechanisms are required but technologies such as homomorphic and searchable encryption are also potential candidates for developing such approaches. Besides, more self-managed IoT is wanted to serve the heterogeneity and diversity of the devices/gateways. Self-managed IoT may employ machine learning to process and share data without the information content being accessible to others. Technologies of decentralized computing and key management, as well as soft identities designed for specific contexts or applications, will be more essential to the IoT's privacy (Vermesan and Friess, 2013).

Data Collection and Acquisition

Data collection from sensors, identification, and tracking systems are very crucial for real-time processing. There remain several complexities of process involvement, as well as doubts in standards and filtering techniques.

Data generated by the IoT devices from different vendors and different domains usually have different features. In most cases, not all data are significant, thus the identification of smart objects is imperative. In the back-end, many more techniques such as new intelligent methods based on semantic technologies and tools for processing and analyzing historical and on-site data with the different qualities are gaining high attraction.

The first level of the IoT data manipulation is mainly dealing with decoding data noise where specific filter mechanisms are welcome. Even though automatic identification helps to avoid mistakes from manual data entry, the corresponding data needs to provide a high level of accuracy upon the data quality standards agreed. While the new mechanisms of data aggregation aimto reduce the amount of transmission data and to taper the utilization of energy, sensor nodes such as fuzzy-based and evaluation on quality of aggregation remain doubtful (Gubbi *et al*., 2013).

Big Data

One significant aspect in the IoT is the large number of things being connected to the Internet, each one providing data. Mechanisms to store and assure the validity through scalable applications remain a major technological challenge.

Each record of raw RFID data generally contains EPC, location, and time and is at least 18 bytes long. To extract valuable data from such big data, a data mining approach based form of data management and event processing are indispensable. Not only are the data always massive, distributed, time-related, and position-related, but they are also heterogeneous andare distributed on resources with limited capabilities. The fundamental centralized data mining and preprocessing architecture may not be comprehensible to support data stored indifferent sites. Yet, a multi-layer mining model, distributed data mining model, grid based mining model, as well as a data mining model from multi-technology integration should be consideredas alternatives (Bin *et al*., 2010).

Although the IoT has to overcome huge barriers to gain trust from society, it has illustrated a distinguished potential to add a new dimension to the application in logistics, transportation, healthcare, and environment and disaster by enabling communication between smart objects. Therefore, the IoT should be considered as a part of the future Internet in which everything can connect in a network where objects can interact with each other. The development of several issues will make the IoT a complete solution. Hence more research in the application of the IoT is imperative. Once successfully implemented, the reduction of human efforts will benefit the quality of life as well as business.

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