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Review

Internet of Things in agriculture, recent advances and future challenges

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The increasing demand for food, both in terms of quantity and quality, has raised the need for intensification and industrialisation of the agricultural sector. The "Internet of Things" (IoT) is a highly promising family of technologies which is capable of offering many solutions towards the modernisation of agriculture. Scientific groups and research institutions, as well as the industry, are in a race trying to deliver more and more IoT products to the agricultural business stakeholders, and, eventually, lay the foundations to have a clear role when IoT becomes a mainstream technology. At the same time Cloud Computing, which is already very popular, and Fog Computing provide sufficient resources and solutions to sustain, store and analyse the huge amounts of data generated by IoT devices. The management and analysis of IoT data ("Big Data") can be used to automate processes, predict situations and improve many activities, even in real-time. Moreover, the concept of interoperability among heterogeneous devices inspired the creation of the appropriate tools, with which new applications and services can be created and give an added value to the data flows produced at the edge of the network. The agricultural sector was highly affected by Wireless Sensor Network (WSN) technologies and is expected to be equally benefited by the IoT. In this article, a survey of recent IoT technologies, their current penetration in the agricultural sector, their potential value for future farmers and the challenges that IoT faces towards its propagation is presented.

1. Introduction and motivation

The term "Internet of Things" (IoT) is a term first coined by a British visionary, Kevin Ashton, back in 1999. As the phrase "Internet of Things" reveals, the IoT paradigm will provide a technological universe, in which many physical objects or "Things", such as sensors, everyday tools and equipment enhanced by computing power and networking capabilities will be able to play a role, either as single units or as a distributed collaborating swarm of heterogeneous devices. Agriculture is one of the sectors that is expected to be highly influenced by the advances in the domain of IoT. The Food and Agricultural Organization of the United Nation (FAO) predicts that the global population will reach 8 billion people by 2025

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and 9.6 billion people by 2050 (FAO, 2009). This practically means that an increase of 70% in food production must be achieved by 2050 worldwide. The great increase in global population and the rising demand for high-quality products create the need for the modernisation and intensification of agricultural practices. At the same time, the need for high efficiency in the use of water and other resources is also mandatory.

One of the most promising concepts, which is expected to contribute a lot to the required increase of food production in a sustainable way, is precision agriculture (PA) (Zhang, Wang, & Wang, 2002). Precision agriculture aims to optimise and improve agricultural processes to ensure maximum productivity and requires fast, reliable, distributed measurements in order to give growers a more detailed overview of the ongoing situation in their cultivation area, and/or coordinate the automated machinery in such way that optimises energy consumption, water use and the use of chemicals for pest control and plant growth. At a higher level, having gathered information from many heterogeneous systems, well-evaluated scientific knowledge can be organised in the form of smart algorithms to provide a better insight into the ongoing processes, do the reasoning of the current situation and make predictions based on heterogeneous inputs, produce early warnings about potential dangers that threaten the cultivars, and improved automated control signals, based on plant responses (Kacira, Sase, Okushima, & Ling, 2005; Körner & Van Straten, 2008). The algorithms required to handle the distributed data in real time are far too complicated to run locally on a low-power Wireless Sensor Network (WSN) node. However, in the context of IoT, all the objects will be interconnected, and therefore the computational overhead can be easily shifted to the cloud or be distributed among more than one interconnected devices.

The greatly increasing interest in IoT in agriculture can be roughly seen in Fig. 1. The increase in the appearance of the term "IoT" along with the term "Agriculture" in the international scientific literature is rather indicative. These data motivated us to present an overview of the state-of-the-art research on IoT in its various forms, appearing in the agricultural sector, rather than a generic review. For this reason, a research methodology was adopted derived from the existing guidelines used by medical researchers, adapted and optimised for software engineering matters (Kitchenham, 2004). According to this methodology, a selection of recent literature was done, setting the year 2010 as starting point. The 2010 starting point year was determined because it is then when a significant number of publications appeared. Moreover, technologies and approaches before 2010 are quite obsolete at the time of writing the present manuscript. Other selection criteria included the multidisciplinary nature of a publication. Works utilising more than one technology in order to synthesise their solutions were considered as IoT-oriented; for instance, cloud and embedded devices/wireless sensors, or, works that make use of more than one type of end devices (things) within the same network. Having none of the aforementioned restrictions, the reviewed literature area would be too wide and out of the scope of this work. Moreover, this paper seeks to present research that adopts newer architectures, closer to the principles of IoT.

This paper begins with an introduction in the recent trends in the technologies, which represent the building blocks of IoT, such as the Radio Frequency Identification Radio Frequency Identification (RFID), wireless sensor networks, the addressing of the "things" in a common network, as well as the applications running on the cloud. Following the same categorisation, several works are presented, which incorporate one or more of the IoT aspects and focus on the agricultural sector. Some of the most popular hardware platforms, met in agricultural deployments, is also surveyed. The review closes with a discussion on future challenges and their effect on IoT spreading, which has effects on the adoption of IoT in the agricultural sector too.

One of the goals of this work is to provide the members of a multidisciplinary community, such as the researchers working on deploying innovative monitoring, tracking, decision support and control systems, with a handful manuscript that summarises the latest advances in embedded devices, sensor modules, wireless communication technologies, programming paradigms and cloud services suitable, or optimised, for use in agriculture. Some of the most common keywords appearing in the presented literature are presented in Fig. 2. High quality, peer reviewed conference and journal publications from the fields of computer and environmental sciences, engineering, as well as, decision, agricultural and biological sciences offered a rich repository of research works.

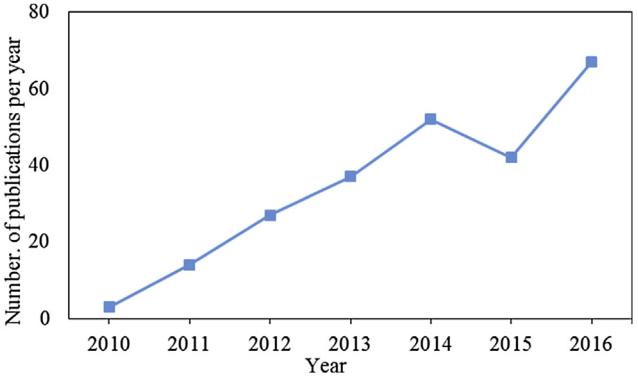

Fig. 1 – Evolution of the number of publications related to "IoT in Agriculture", as they appear in Scopus.

2. Internet of Things enabling technologies

The structure of IoT is based on three layers; namely, the perception layer (sensing), the network layer (data transfer), and the application layer (data storage and manipulation). Despite great improvements, IoT is still evolving, trying to obtain its final shape, as can be seen in several reviews (Atzori, Iera, & Morabito, 2010; Botta, de Donato, Persico, & Pescapé, 2014; Gubbi, Buyya, Marusic, & Palaniswami, 2013; Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012). As the term "Internet" implies, networking capability is one of the core features of the IoT devices. The internet as we know it today is mostly an internet of human end-users, while the IoT will be an internet of non-human entities, therefore a lot of machine-to-machine (M2M) communication will take place.