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Introduction to the Special Issue on IoT and Agriculture

We are on the verge of a new agricultural revolution. If we look at the extended agricultural sector, intended as the one cultivating plants and farming livestock, with the exception of mechanization and the introduction of chemicals (often referred to as the 3rd agricultural revolution) there have not been too many changes in the past few hundred years.

In fact, due to its intrinsic complexity and variability imposed by type, climate, soil, meteo, etc., looking after a living object (be it a plant, a fish or an animal) has been until now and for the past millennia probably characterized by success practices passed down from father to son. Such a view is supported by statistics like those published by the EU, showing for example that 93.7 percent of all farms are run by only family workers[1]: well established and stable business models, best known by the locals and refined over centuries of family trial and error.

Until recent years, challenges posed by climate change as well as globalization are undermining the stability of those models and the status-quo of agricultural businesses as there are many more factors that can influence the successful outcome of cultivations and farming. More meteorological extreme events, global warming, foreign pests and diseases[2], coupled with a global reduction of arable land[3] and an increase of population on earth[4], all point in one direction: the need for improved quality and quantity of agricultural monitoring data, for more insightful interpretation of cause-effect relationships, and for a more efficient and sustainable use of natural resources such as land, water, etc.

Needless to say, we think IoT technology has a huge role to play in such a landscape, as it can provide an unprecedented source of monitoring data at a very detailed granularity level; with huge amounts of data comes the ability to interpret it for a meaningful and business-viable purpose.

In this Special Issue we touch upon many of these subjects, spanning far and wide between technologies (best picks for wide range connectivity, edge computing, use of machine learning and artificial intelligence) and application domains (from optimized use of irrigation water to fish farming and aquaculture to dairy herds management).

Ensuring wide coverage in rural areas is one of the key enablers to foster innovation in agriculture. As opposed to Smart Cities, rural areas are characterized by customers who are struggling daily with low margins of running their businesses: covering wide areas for large operators has to be economically viable. Striking such a balance means that low-cost wide coverage can only be guaranteed for so called LPWANs (Low Power Wide Area Network technologies) such as LoRa, SIGFOX and NB-IoT, to name a few of the most popular ones, all of them characterized by a very low bit-rate supported, per connected customer's device. Having a thin pipe toward the public Internet means that transmitting raw data monitoring is not an option, especially if it consists of images or, even worse, videos. The article entitled "Energy Neutral Machine Learning based IoT Device for Pest Detection in Precision Agriculture" by D. Brunelli *et al.*, focuses on bridging competences on running a low-energy edge computing platform to process data close to the monitoring source and running on it lightweight algorithms trained for the detection of a particular pest, the codling moth, affecting apple orchard cultivations. In this way the LoRaWAN network can be accessed only to communicate a signal if and when the pest is recognized.

The performance of these networks as the numbers of connected devices per gateway grow are also subject of scrutiny. As mentioned above, operators will want to strike the right balance between infrastructure investment and fulfilling the needs of rural communities, knowing that this is a low-margin market where what matters is reaching big numbers thanks to the wide range of their connectivity networks. The article entitled "Internet of Things and LoRaWAN Enabled Future Smart Farming" by B. Citoni *et al.*, after introducing the design details of LoRa and LoRaWAN technology, sheds some light on state-of-the-art achievements and on limitations and bottlenecks of such a technology used in the AgriTech domain.

We already mentioned the need for ensuring that the use of technologies in an agricultural context is economically viable but can also support sustainable practices. The article entitled "Advancing IoT-Based Smart Irrigation" by R. Togneri *et al.* takes a deep cut at one of the most traditional application domains for which we have seen the use of IoT until now: the one supporting smart irrigation. The cost of irrigation water is still not a major concern, but it will not be this way for long given all the effects associated with climate change (droughts and more frequent extreme events are globally reducing the

ability of soil to retain water). But until volumetric water charges for irrigation become widely imposed, adoption will be limited to those contexts where there can be substantial electricity savings from reducing the amounts of irrigation water that need to be pumped. Given the wide variability solving irrigation problems faces, the article proposes a flexible architecture to easily connect IoT and Machine Learning (ML) components to build application solutions in a modular fashion. It shows results from pilot implementations run between Europe and Brazil.

Besides irrigation and precision agriculture, the most popular application domains are where IoT can indeed provide strong support to replace the need for human manpower monitoring, allowing farmers to monitor their farms (fish and livestock) without necessarily being physically present.

In this context, the article entitled "Precision Aquaculture" by F. O' Donncha and J. Grant illustrates how, combining partners' competences and assets from industry, technology and academia, it is possible to provide data-driven insights and decisions that promote ecologically sustainable intensification of aquaculture, taking the example of deployments in a number of fish-farms in eastern Canada.

From Canada to Ireland, moving from fish-farming to connected cows, with the article entitled "Connected Cows: Utilizing Fog and Cloud Analytics Toward Data Driven Decisions for Smart Dairy Farming" by M. Taneja *et al*., we step into the big issue of being able to monitor the health of cattle just by tracking the animals with some devices (such as pedometers or collars) and recognizing patterns that can be related to a particular condition which, if predicted and controlled early enough, can lead to substantial treatment cost savings. The solution illustrated in this last article is like the others, showing the benefits of being able to monitor environmental conditions through the use of low-cost IoT sensing devices and networks. What one does with collected data in terms of actuation and control and how successful the application can become in terms of business, is dependent on the competences of the domain experts to interpret the data and to the ability to relate outcomes to predictions that have a substantial impact on the farmers' bottom line. The more we see of such solutions to farmers' real problems at a sustainable cost, the more we will see the widespread adoption of AgriTech solutions which will accelerate a new data-based revolution in the agricultural sector.

To conclude, I would like to thank the authors and the reviewers for their contributions to this Special Issue and the Editor-in-Chief for the opportunity. It has been an insightful and interesting journey and the hope is that the final outcome will generate the same level of interest for the readers of the IoT community involved at various levels and with different roles in this fascinating application domain.

Biography

Raffaele Giaffreda (rgiaffreda@fbk.eu) is a chief IoT scientist at FBK CREATE-NET, Italy. He has worked in the telecom R&D environment since the beginning of his career, focusing in the last decade on IoT and related technology transfer activities. In his role, he is now responsible for setting research and innovation directions, acquisition of funding, and the execution of a number of collaborative projects in the IoT domain. He has worked in Italy and the United Kingdom (10 years), acquiring experience in both corporate telco environments (R&D of BT and Telecom Italia) as well as in a small research organization (CREATE-NET before its merger with FBK), where the ability to acquire funding was key to ensuring continuity of operations. He is a recognized expert with a substantial record of IEEE publications and conference presentations, a patent, and various book chapters and tutorials on IoT. He is an experienced speaker and chair of IoT related events, serves as an EU reviewer, and has served on the TPCs of a number of international conferences, and he is the Editor-in-Chief of the *IEEE IoT Newsletter*.

Footnotes

[1] https://ec.europa.eu/eurostat/statistics-explained/index.php/Agriculture_statistics_-_family_farming_in_the_EU.

[2] http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/1180172/.

[3] http://www.fao.org/3/i2280e/i2280e06.pdf.

[4] https://population.un.org/wpp/Publications/Files/WPP2019_Volume-I_Comprehensive-Tables.pdf.