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ENHANCING PRECISION AGRICULTURE BY INTERNET OF THINGS AND CYBER PHYSICAL SYSTEMS

Abstract: R. Fresco, G. Ferrari. *Enhancing precision agriculture by Internet of Things and cyber physical systems.*

The recent advances in Internet of Things (IoT) and the proliferation of sensor platforms have allowed the implementation of different applications used to connect physical devices (Things) to the real world, enabling a multi cross domain and multidisciplinary data exchange.

The agricultural sector is also greatly benefiting from this progress with several advantages, including the optimal management of resources and the improvement of human labour (i.e., crop growth monitoring and selection, irrigation decision support, fertilizers, pesticide and agrochemicals application, etc.). Moreover, advancements in mechanization and GPS-assisted vehicle guidance in agriculture has established the concept of precision agronomy and precision farming, as well as automation in food production chain.

However, current systems still have significant drawbacks in areas such as flexibility, networking, standardization, robustness, skills' requirements and lack of real time data and actuation. A current trend is based on the interaction of machines and autonomous systems, in order to fit into cyber-physical production systems and enabling data collection and networked site-specific monitoring and control.

This paper explores all the cutting-edge challenges and solutions required to implement the digital agriculture framework, intended as the evolution from Precision Farming to connected, knowledge-based farm production systems, in a context where digital technologies are first-class elements for the automation of sustainable processes in agriculture.

Keywords: Internet of Things, sensors, cyber physical system, Agriculture.

Riassunto: R. Fresco, G. Ferrari. *Miglioramento dell'agricoltura di precisione tramite Internet delle cose e sistemi cyber-fisici.*

I recenti sviluppi dell'Internet delle Cose e la sempre piu' ampia diffusione di sistemi di sensori hanno consentito l'implementazione di diverse applicazioni che consentono di collegare i dispositivi tecnologici al mondo reale, con il vantaggio di ottenere uno scambio di dati eterogenei e multi-dominio.

Anche il settore primario dell'Agricoltura sta beneficiando di questi risultati con vantaggi che vanno dalla gestione ottimale delle risorse al miglioramento del lavoro umano (ad esempio sistemi di monitoraggio delle colture, sistemi di attuazione automatizzata dell'irrigazione, dosaggio mirato dei fertlizzanti, pesticidi e agrochimici e così via).

Anche l'evoluzione dei sistemi di meccanizzazione e di guida assistita da GPS per i veicoli in agricoltura hanno stabilito nuovi traguardi sia nell'evoluzione dell'agronomia e dell'agricoltura di precisione, sia nella produzione e controllo automatizzato della filiera agroalimentare.

Gli attuali sistemi però presentano alcune limitazioni in termini di flessibilità, collegamento, robustezza, di standardizzazione con le soluzioni IoT e difficoltà di apprendimento nell'utilizzo, nonché ridotto uso di sistemi in tempo reale e di agevoli procedure di attuazione.

Un trend attualmente molto interessante dello sviluppo tecnologico si basa sul concetto di interazione autonoma tra macchine e sistemi eterogenei, al punto da determinare l'impiego dei cosiddetti sistemi cyber-fisici, al fine di dare supporto al recupero di informazioni di monitoraggio e controllo legati specialmente al particolare sito agricolo.

Questo articolo si pone l'obiettivo di evidenziare tutte le soluzioni altamente innovative e allo stato corrente di sviluppo portando all'avanzamento della cosiddetta Agricoltura digitale, un raffinamento ulteriore del concetto più noto di Agricoltura di precisione. In particolare l'Agricoltura digitale mira allo sviluppo di una piattaforma integrata basata sulla conoscenza e su azioni autonome dei sistemi componenti, al fine di migliorare i processi di produzione in agricoltura e nelle aziende, con particolare attenzione a quelle particolari soluzioni tecnologiche che supportano processi di produzione sostenibile in Agricoltura.

Parole chiave: Internet delle cose, sensori, sistemi cyber-fisici, Agricoltura.

INTRODUCTION

Modern agriculture is facing tremendous challenges in order to build a sustainable future across different regions of the globe. Examples of such global challenges include: population increase, urbanization, an increasingly degraded environment, an increasing trend towards consumption of animal protein, and, of course, climate change. Global efforts will need to be addressed in a way that does not endanger the capacity of the agriculture sectors – crops, livestock, fisheries and forestry – to meet the world's food needs.

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As the global population approaches 9 billion by 2050 (Alexandratos & Bruinsma, 2012), the U.N. Food and Agriculture Organization (FAO) expects that demand for agricultural outputs is projected to increase by 60 percent from 2005/2007-2050. The prevailing demand will be for further kinds of food, including meat, fruit, and vegetables, as well as higher-quality and healthier food. However, one can observe an increasing competition for land and water in order to increase food production to feed a still growing population. On the other hand, there is a general agreement on the need to ensure sustainability of this increase (Galluzzi *et al.*, 2011).

Different factors are related with the concept and the needs of innovation in agriculture. We mainly focus on three pillars: environment, biodiversity and public health. In the following, we outline their main characteristics.

The connection between **Agriculture and Environment** is a source of challenges and technological optimization.

Mankind gathers several benefits from intensive agricultural production, at the cost of a loss of the natural status of ecosystems. In fact, agriculture adds globally significant and environmentally detrimental amounts of nitrogen and phosphorus to terrestrial ecosystems (Vitousek *et al.*, 1997, Carpenter *et al.*, 1998). Deeper structural problems have also become apparent in the natural resource base. Water scarcity is growing. Salinization and pollution of water courses and bodies, and degradation of water-related ecosystems are rising. The soil, as basis for all agricultural activities, is also an interface between agriculture and environment. However, serious soil degradation, which threatens the productivity of the different soils, can be observed everywhere in Europe. Moreover, excessive fertiliser application can cause pollution risks for the environment, whereas insufficient fertiliser to replace nitrogen and phosphorus lost through intensive cropping can lead to soil degradation and loss of fertility.

This unprecedented confluence of pressures, as outlined by FAO (2014), determines the need for a strategy and a commitment about what sustainable agriculture means. A consequent conceptual model, proposed by FAO itself, emphasizes that agriculture system is an interface between two global systems: natural and human ones. This conceptual model is depicted in Figure 1.

The principles derived from this conceptual model can be summarized as follows:

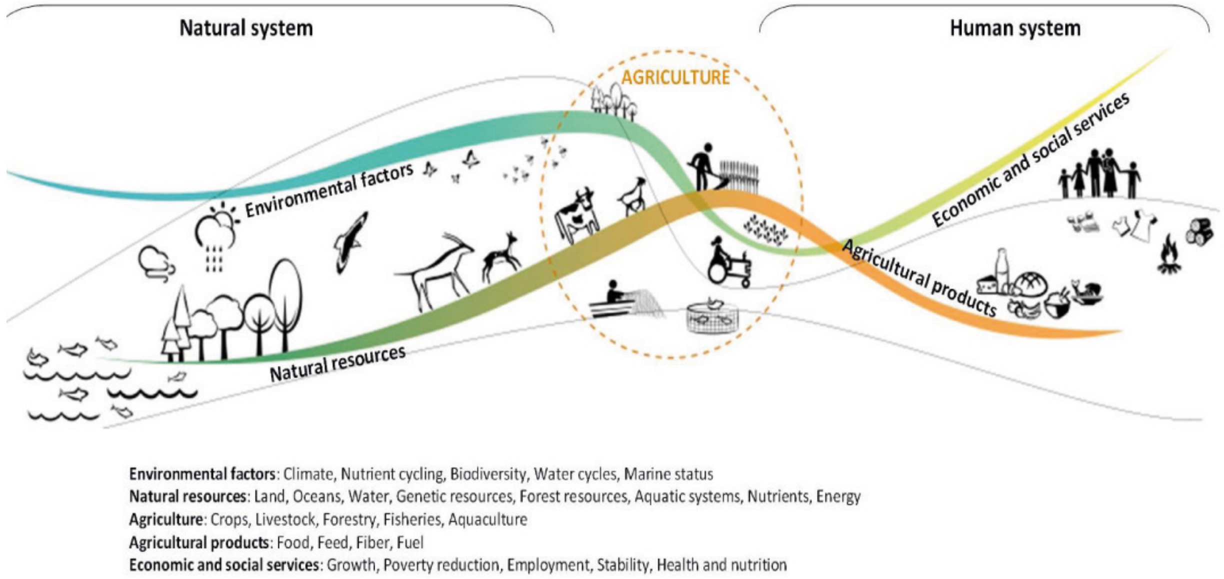
- conserve, protect and enhance natural resources;
- enhance the efficiency of resource use;
- improve and protect livelihoods and human well-being and health;
- enhance the resilience of people, communities and ecosystems;
- promote and improve effective governance.

In these terms, agricultural production systems need to focus more on the effective conservation and management of biodiversity and ecosystem services in order to address the double objectives of environmental sustainability and food security. At the same time, product quality requires increased attention.

The decreasing of arable land per person, as shown in Figure 2, can be considered as an indicator of the emergence of these issues in the entire world. These ones must to be faced with a long-term perspective that takes into account the lands and their people, putting the concept of sustainability at centre stage. Data are taken from FAOStat (2017).

Therefore, a modern agriculture needs to be addressed, as being directly and explicitly characterized by the adoption of production processes, technologies and tools derived from scientific advances, and results of the research and development activities.

Furthermore, a modern agriculture becomes the implementation of a social project, as specified in the results of ISDA conference on Innovation and Sustainable Development (Coudel *et al.*, 2013). In other terms, a project in which there are several steps to execute in order to create new links between research, economic stakeholders, civil society actors and policymakers.



Environmental factors: Climate, Nutrient cycling, Biodiversity, Water cycles, Marine status
Natural resources: Land, Oceans, Water, Genetic resources, Forest resources, Aquatic systems, Nutrients, Energy
Agriculture: Crops, Livestock, Forestry, Fisheries, Aquaculture
Agricultural products: Food, Feed, Fiber, Fuel
Economic and social services: Growth, Poverty reduction, Employment, Stability, Health and nutrition

Fig. 1 - Conceptual model for sustainable agriculture and environment (Source FAO, 2014).

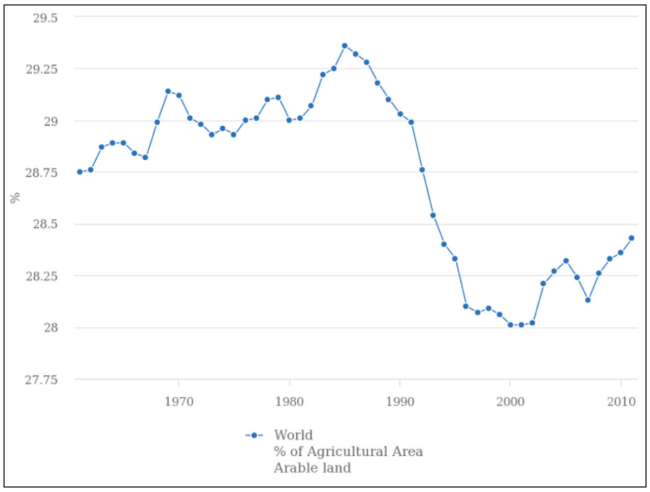


Fig. 2 - Arable land per person [1961-2011] source: FAOSTAT.

This is important given that we cannot consider agriculture in its unique function of production, but rather by how this production interfaces with the environment and society as a whole. The issues to address today are 'agriculture and health', 'agriculture and environment', 'agriculture and energy', 'agriculture and rural activities', and so on.

It is crucial to point out that a modern and sustainable agriculture is a responsibility for all participants in the system, including farmers, labourers, policymakers, researchers, retailers, and consumers. Each group has its own part to play, its own unique contribution to make to strengthen the sustainable agriculture community.

Often the connection between **Agriculture and Health** is not immediately clear, but if we consider the sprayed agrochemicals, the air quality, the food security and antibiotics used for animals, as well as nutritional quality and so on, many issues arise.

Health is intimately connected with the Agriculture and food and multifaceted interactions can be recognised (European Public Health Alliance, 2016).

Agrochemicals used in agriculture contribute to environmental degradation and pesticides are also an occupational threat extending to farm workers, their families and, potentially, inhabitants of areas exposed to their application on crops, on vineyards etc. Index of risk of damage from pesticide toxicity and exposure can be determined and some European modelling frameworks were assessed, like in the project HAIR (2017) and in the project FOOTPRINT (2017).

Pesticide risks are connected with the environmental degradation and the agricultural activities executed by the farmers. Pesticides are absorbed by crop and natural resources (i.e., water and soil) and they tend to be part as concealed substances in the food chain, with the increasing risk for both livestock and humans.

Furthermore, the most important point is related to antibiotics. A well recognized issue is related to antibiotics resistance (Thomas, 2012). The high level of antibiotic resistance can be associated with antibiotics overuse in both human and veterinary medicine. Intensive livestock systems and antibiotics use are also closely linked due to the cycle of antibiotics given to animals and from their products to humans.

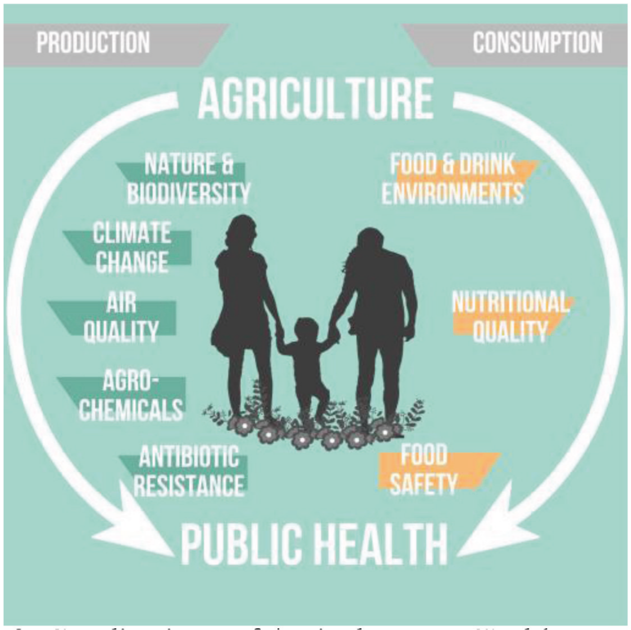


Fig. 3 - Implications of Agriculture on Health.

If one can address food security with a precision farming approach, farming will be made more transparent by improving tracking, tracing and logistics (EURACTIV, 2017). End users will determine the food quality themselves and this will give the key for farmers to achieve better good quality food, with the promotion healthier life-style.

Between **Agriculture and Biodiversity** there is a strong connection in terms of land degradation or more specific land cover/land use. Agricultural activities and grazing cattle on pasture can modify the soil, originating soil compaction and threats for plant biodiversity. Loss of landscape connectivity and, more generally, fragmentation in the landscape itself can occur (e.g., by creating smaller habitat patches) (Kettunen *et al.*, 2007).

Fragmentation in the landscape may also limit the ability of some wildlife species to move to new areas that can have suitable climatic conditions for them, especially during winter.

Only habitat corridors can be viewed as components of the landscape that facilitate the movement of organisms and processes between areas of intact habitat, recovering the functional connectivity of the landscape (Jomgman & Pungetti, 2004).

DIGITAL AGRICULTURE: FROM PRECISION AGRICULTURE TO KNOWLEDGE-BASED FARMING SYSTEMS

The need for a digital dimension

Advancements in last decades in mechanization and remote sensing have introduced the concept of precision agronomy and precision farming, as well as automation in the food production chain.

Precision farming and automation have already established paradigms in order to increase farm productivity, quality, as well as improving working conditions by reducing manual labour. All these factors play an important role in making farms sustainable (STOA, 2016). Moreover, many modern farmers already use high-tech solutions, e.g., digitally-controlled farm equipment like GPS assisted tractors, and even Unmanned Aerial Vehicles (UAVs) for monitoring and forecasting. There are partially and fully automatic devices for most aspects of agricultural functions, from grafting to seeding and planting, from harvesting to sorting, packaging and boxing, and livestock management. Even though the precision farming approaches can be effective and useful for farmers, after a proper training period, they typically tend to be calibrated only for a specific task, without bringing a holistic view of agricultural processes.

We need to point out that agriculture can be seen as a *dynamic system*, in which for every set of inputs it is mandatory to obtain a result or final/intermediate products: however, different conditions can alter the results (e.g., climatic conditions, soil quality, pests). The external factors that positively or negatively affect agricultural systems are numerous and often difficult to predict or to control. For this reason, predictive models cannot always guarantee the expected results. An integrated system of multiple functionalities with data collection and interpretation is absolutely required (Savale *et al.*, 2015).

Therefore, we think that real time dimension, given by sensing technologies, becomes the keystone for a relevant increase of the productivity against statistical and simulation models in agricultural processes.

Farmers need to know the status of their crops and actions for collecting data and real time monitoring *as a whole* are the best solutions to achieve innovation and, at the same time, sustainable productivity.

Furthermore, reliable detection, accurate identification and proper quantification of pathogens and other factors affecting plant and animal health are critical for monitor and control purposes, in order to reduce costs, trade disruptions and, sometimes, even human health risks.

A special interest in livestock management is determined by the livestock diseases, as well as plant pest. Both these aspects deserve international attention due to the potential for very serious and rapid spread, out of a national borders and serious socio-economic or public health consequences.

Transmissible diseases, which have the potential for very serious and rapid spread, regardless of national borders, which are of serious socio-economic or public health consequence and which are of major importance in the international trade of animals and animal product. For this purposes, FAO (1999) has focused on a new programme with two objectives: 1) to combat plant pests and diseases and 2) to fight livestock diseases. Once more, a keystone for this programme becomes real time surveillance and data collection in order to have early detection and monitoring the disease spread in order to manage it effectively. With these technological solutions (e.g., various types of wearable sensors), it is possible to understand the health status of animals and assess a so-called Livestock Information System (Ariff & Ismail, 2013) in order to monitor and trace all animal transactions and animal products, their disease during the time, the medicine usage, and so on.

The use of intelligent wireless sensor networks can make a difference also in crop management towards knowledge-based farm production systems.

Taxonomy of Digital dimension in agriculture

Precision Farming started when GPS signals were made available to the general public. Precision Farming enables vehicle guidance and site-specific monitoring and control. When combined with telematics and data management, precision farming improves the accuracy of operations and allows the managing of in-field variables. The objective is to give plants (or animals) exactly what they need to grow optimally, with the aim to improve the agronomic output while reducing the input (e.g., producing 'more with less'). In other words, precision farming improves the concept of a precision agronomy intended as a group of best practices for resource management.

In the early 2010s, Precision Farming was enriched by the advancement of new technologies such as cheap and improved sensors, actuators and micro-processors, high bandwidth cellular communication, cloud-based ICT systems and big data (Kassim, Mat & Harun, 2014). This set of technologies forms the basis for the Smart farming/agriculture concept and methodology.

In Figure 4, a representation of the incremental evolution of technology applications in Agriculture is shown. In this figure, a classification, related to the advancements intended as a set of intermediate and incremental steps, is also shown. We can consider an 'overall box' that captures the idea of the principal scenarios of the digital dimension of modern agriculture.

Drones, remote sensing, intelligent decision support systems and Cyber physical systems add a further step in the leveraging process of the modern agriculture. In other words, they increase core features of what can be considered, as a whole, digital agriculture (CEMA AISBL, 2017).

A **drone**, in a technological context, is an unmanned aircraft. Drones are more formally known as Unmanned Aerial Vehicles (UAVs) or Unmanned Aircraft Systems (UASs). These aircrafts are equipped with an autopilot using GPS and a standard point-and-shoot camera controlled by the autopilot.

UAVs/UASs may be remotely controlled (by human operators) or can fly autonomously through software-controlled flight routes in their embedded systems, working in conjunction with onboard sensors and GPS.

The integration of drones and Internet of Things technology has created numerous applications: drones working with on-ground IoT sensor networks can help agricultural companies monitor land and crops.

According to MIT (Anderson, 2014), drones can provide farmers with three types of detailed solutions. First, seeing a crop from the air can highlight irrigation problems, soil

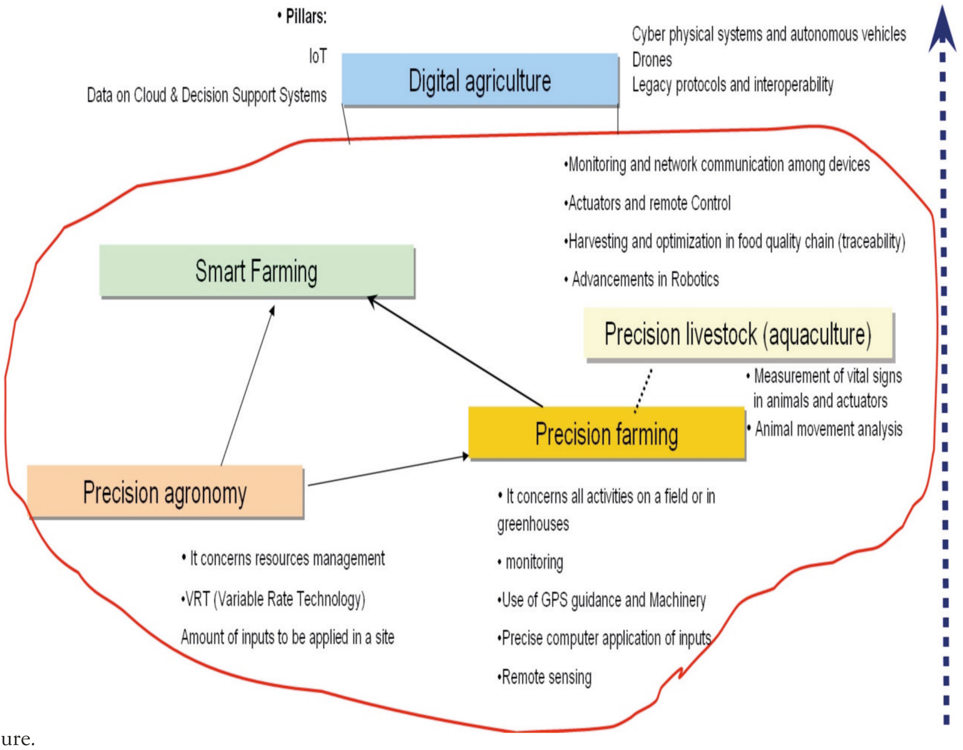


Fig. 4 - The digital dimension in Agrıculture.

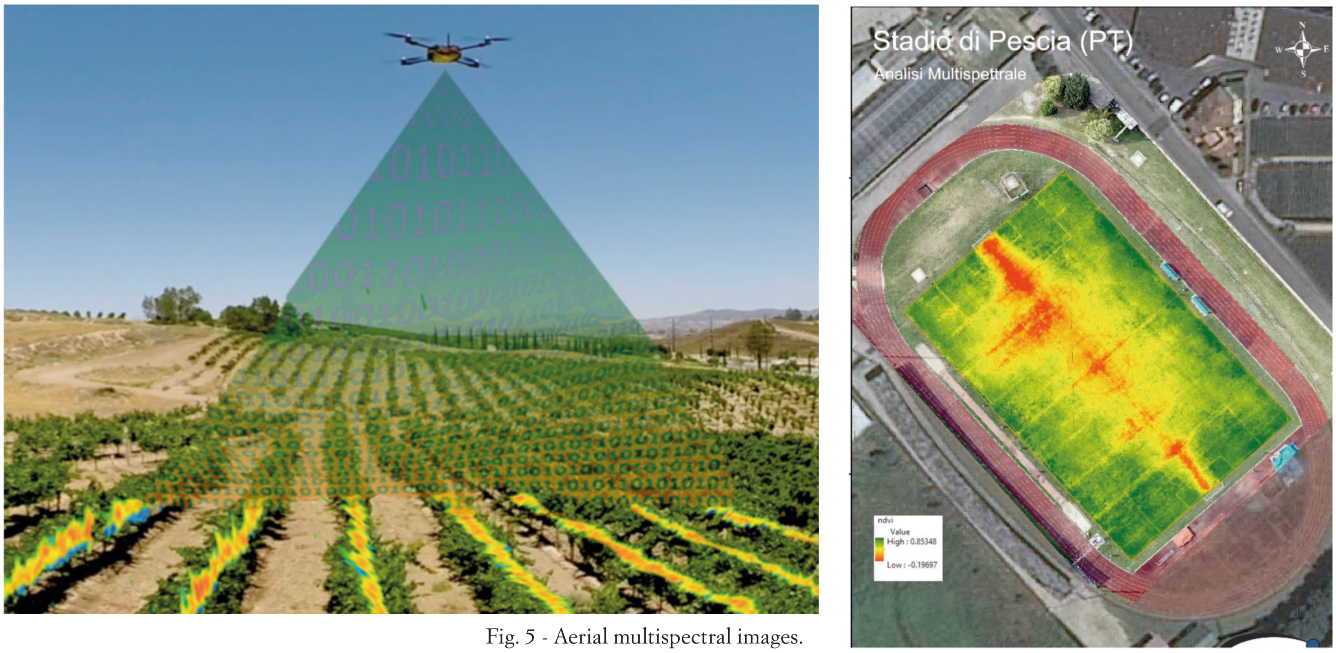


Fig. 5 - Aerial multispectral images.

variation and even pest and fungal infestations that are not apparent at eye level. Second, airborne cameras can take multispectral images (as in Figure 5), capturing data from the infrared, as well as the visual spectrum, which can be combined to create a view of the crop that highlights differences between healthy and stressed plants in a way that cannot be seen with the naked eye. Finally, a drone can survey a crop every week, every day, or even every hour. This set of images can be combined to create a time-series animation, showing changes in the crop, revealing issues or opportunities for better crop management.

It is apparent that a similar approach can be also applied to the environment and biodiversity analysis. This approach can establish a new trend towards an increasingly data-driven agriculture.

CYBER PHYSICAL SYSTEMS FOR AGRICULTURE DOMAIN

Mechanization is quite typical in agriculture. However, the advancements in robotics and autonomous systems, coming from artificial intelligence and embedded systems applications, will lead to a further evolution in agriculture. As explained before, a drone is itself a flying robot, but a significant evolution will really happen when a generation of embedded intelligent ICT robotics systems will be applied. These systems can be interconnected, interdependent, collaborative, autonomous and can provide computing and communication, monitoring/control of physical components/processes in various applications.

In other words, considering the interaction with the physical world (including human users), these systems assume in important role in capturing data, typically intended as intelligent sensor networks of (autonomous) systems with specific sensing and actuating capabilities.

In fact, cyber and physical world cannot be considered as two different entities, but they are closely correlated with each other after integration of sensor/actuators in the so-called cyber systems.

Cyber systems became responsive to the physical world by enabling real time control emanating from conventional embedded systems, thus leading to the concept of **Cyber Physical System** (CPS) (Shi *et al.*, 2011).

A CPS can be interpreted as the "integration of computation with physical processes." For instance, it uses sensors and actuators to link the computational systems to the physical world. There were considerable challenges in CPS, particularly because the physical components of such systems have introduced safety and reliability requirements qualitatively different from those in general-purpose computing: therefore, standard abstractions in computing have to be adapted. Moreover, physical components are qualitatively different from object-oriented software components and concurrency is intrinsic. An evolutionary extension of the state of the art in computing was and still is necessary.

In CPSs, the joint behavior of the "cyber" and "physical" elements of the system is critical - computing, control, sensing and networking can be deeply integrated into every component, and the actions of components and systems must be safe and interoperable.

Industry and Government in United States have posed CPSs at the centre of the engineering research agenda since 2007 and, since 2010, the European research and industrial community has focused on CPSs as paradigms for the future of systems (Lamnabhi-Lagarrigue, Di Benedetto & Schoitsch, 2014). The general interest demonstrated by industry is strong. This is intuitively clear by taking into account that the most relevant features and pillars in CPS derive from: embedded systems, wireless sensor networks, IoT, communication protocols and all interactions between them. Addressing the challenges and opportunities of CPS requires a large consensus in foundational concepts, as well as a shared understanding of the features and technologies unique to CPS. NIST has established the CPS Public Working Group (2016) as an open forum to foster and capture inputs from those involved in CPS, both nationally and globally with incremental releases for a CPS framework, as depicted in Figure 6.

CPS can be considered a new frontier of systems characterized by autonomous behaviour. In fact, one of the major challenges in future robotics is to design systems that can collaborate with each other. This is radically different from classical robot automation in which industrial robots, protected by fences, carry out repetitive tasks. In this context, precision agriculture is a highly relevant application domain that is going to be subject to disruptive innovations (Cürüklü, Martínez-Ortega & Fresco, 2017). The effects of climate change are already influencing access to arable land and world population growth needs to be taken into account. Environmental degradation is also occurring and the change of strategies in agriculture are unavoidable. Therefore, there is a real risk of food shortage in the future if we do not develop autonomous systems that can collaborate to solve real-world complex problems.

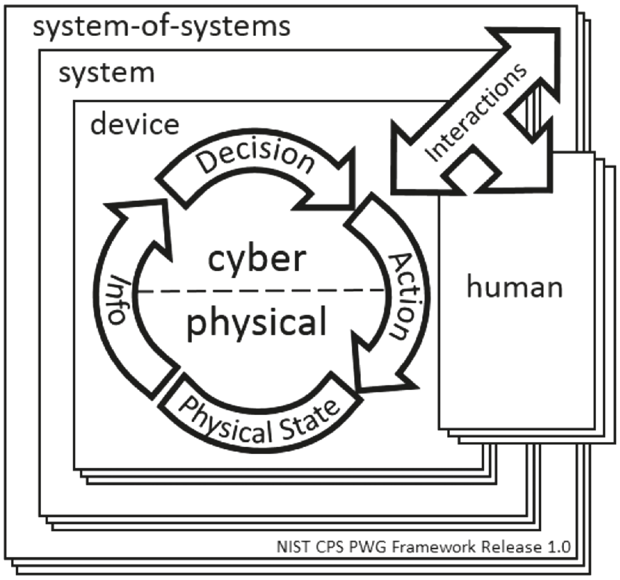


Fig. 6 - CPS framework conceptual model.

Fig. 7 - Aggregate technologies and systems in farming environment.

A farmer must have full control and knowledge of data about his/her activity. In this sense, decision support and cooperating autonomous systems, as shown in Figure 7, are relevant to optimize and obtain sustainable processes in agriculture.

CONCLUSIONS

Modern agriculture is facing tremendous challenges in order to build a sustainable future across different regions of the globe. Examples of such global challenges include: population increases, urbanization, energy scarcity, increasingly degraded environment, increasing trend towards consumption of animal protein, and, of course, climate change. Global efforts will need to be addressed in a way that does not endanger the capacity of the various agriculture sectors – crops, livestock, fisheries and forestry – to meet the world's food needs.

All the technologies explored in this article can contribute to optimize agricultural processes. However, it is also necessary to change many agricultural practices (e.g., reduction of fertilizers or chemical treatment with the real application of alternative strategies): technology and automation can support and reduce human burden necessary to accomplish this (Manyika *et al.*, 2017). An ever increasing trend is to create multidisciplinary dialogue with all involved stakeholders in order to make a difference and realize an effective enhancement and research actions with a tangible societal impact, taking into account the need to simplify human and system/machine interfaces and interactions

REFERENCES

ALEXANDRATOS N., BRUINSMA J., 2012. *World Agriculture Towards 2030/2050: The 2012 Revision*, ESA Working Paper No. 12-03, U.N. Food and Agriculture Organization, June 2012.

ANDERSON C., 2014. Agricultural Drones, Relatively cheap drones with advanced sensors and imaging capabilities are giving farmers new ways to increase yields and reduce crop damage. *MIT Technology Review magazine*, May/June 2014 issue. Available online: https://www.technologyreview.com/s/526491/agricultural-drones/

ARIFF M.H., ISMAIL I., 2013. Livestock information system using Android Smartphone, In: *IEEE Conference on Systems, Process & Control (ICSPC).* IEEE Computer Society: 154-158. doi: 10.1109/SPC.2013.6735123.

CARPENTER, S.R., CARACO, N.F., CORRELL, D.L., HOWARTH, R.W., SHARPLEY, A.N., SMITH, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Applications* 8: 559-568.

CEMA AISBL, 2017. Digital Farming: what does it really mean? European Agricultural Machinery, February 2017. Available online: http://www.cema-agri.org/page/digital-farming-what-does-it-really-mean

COUDEL, E., DEVAUTOUR, H., SOULARD, C. T., FAURE, G., HUBERT, B. (EDS.), 2013. Renewing innovation systems in agriculture and food: How to go towards more sustainability?. Wageningen Academic Publishers, Wageningen.

CPS PUBLIC WORKING GROUP, 2016. Framework for Cyber-Physical Systems Release 1.0. Available online: https://s3.amazonaws.com/nist-sgcps/cpspwg/files/pwgglobal/ CPS_PWG_Framework_for_Cyber_Physical_Systems_Release_1_0Final.pdf

CÜRÜKLÜ B., MARTÍNEZ-ORTEGA J.F, FRESCO R., 2017. Adaptive Autonomy paves the way for Disruptive Innovations in Advanced Robotics, *Ercim news* 109: 25-26.

EURACTIV, 2017. EU Farming getting smarter, Special report, 20-24 March 2017. Available online at: http://eurac.tv/7fMa

EUROPEAN PUBLIC HEALTH ALLIANCE (EPHA), 2016. Agriculture and public health - Impacts and pathways for better coherence. EPHA Strategic Document, May 2016.

FAO, 1999. Manual on Livestock Disease Surveillance and Information Systems. FAO Animal Health Manual, Rome.

FAO, 2014. Building a common vision for sustainable food and agriculture - Principles and approaches. U.N. Food and Agriculture Organization, Rome, ISBN 978-92-5-108471-7.

FAOSTAT, 2017. http://www.fao.org/faostat/

FOOTPRINT, 2017. Footprint project website: http://sitem.herts.ac.uk/aeru/footprint/

GALLUZZI, G., VAN DUIJVENDIJK, C., COLLETTE, L., AZZU, N., HODGKIN, T., 2011. Biodiversity for Food and Agriculture - Contributing to food security and sustainability in a changing world. In: *Workshop of Food and Agriculture Organization of the United Nations (FAO)*, Rome, 2011.

HAIR, 2017. Harmonised environmental indicators for pesticide risk (HAIR), project website: http://cordis.europa.eu/project/rcn/73844_en.html

JOMGMAN R., PUNGETTI G., 2004. Ecological Networks and Greenways: Concept, Design, Implementation. Cambridge University Press.

KASSIM M.R.M., MAT I., HARUN A.N., 2014. Wireless Sensor Network in precision agriculture application in Computer, *International Conference on Information and Telecommunication Systems (CITS2014)*, IEEE Computer Society: 1-5.

KETTUNEN M., TERRY A., TUCKER G., JONES A., 2007. Guidance on the maintenance of landscape features of major importance for wild flora and fauna - Guidance on the implementation of Article 3 of the Birds Directive (79/409/EEC) and Article 10 of the Habitats Directive (92/43/EEC). Institute for European Environmental Policy (IEEP), Brussels. Available online: http://ec.europa.eu/environment/nature/ecosystems/docs/adaptation_fragmentation_guidelines.pdf

LAMNABHI-LAGARRIGUE F., DI BENEDETTO M.D., SCHOITSCH E., 2014. Introduction to the special theme cyber-physical systems. *Ercim news* 94: 6-7.

MANYIKA J., CHUI M., MIREMADI M., BUGHIN J., GEORGE K., WILLMOTT P., DEWHURST M., 2017. A future that works: Automation, Employment, and productivity. McKinsey Global Institute, January 2017.

SAVALE O., MANAGAVE A., AMBEKAR D., SATHE S., 2015. Internet of Things in Precision Agriculture using Wireless Sensor Networks, *International Journal Of Advanced Engineering & Innovative Technology* 2(3): 1-5.

SHI J., WAN J., YAN H., SUO H., 2011. A survey of Cyber-Physical Systems, In: *International Conference on Wireless Communications and Signal Processing (WCSP)*, IEEE Computer Society: 1-6.

STOA, 2016. Precision agriculture and the future of farming in Europe. Scientific Foresight Study, IP/G/STOA/FWC/2013 -1/Lot 7/SC5, December 2016, European Parliament. Available online: http://

www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf

Thomas, S., 2012. Antibiotic Use in the Animal Agriculture Industry: Potential Threat to Public Health. *Sanford Journal of Public Policy*, January 2012. Available online at: https://sites.duke.edu/sjpp/2012/antibiotic-use-in-the-animal-agriculture-industry-potential-threat-to-public-health/

Vitousek P.M., Mooney H.A., Lubchenco J., Melillo J.M., 1997. Human domination of earth's ecosystems. *Science* 277: 494–499.

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