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Smart Monitoring of Potato Crop: A Cyber-Physical System Architecture Model in the Field of Precision Agriculture

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Abstract

In the last two decades an intense shift from advanced mechatronic systems to Cyber-Physical Systems (CPS) is taking place. CPS will play an important role in the field of precision agriculture and it is expected to improve productivity in order to feed the world and prevent starvation. In order to expedite and accelerate the realization of CPS in the field of precision agriculture it is necessary to develop methods, tools, hardware and software components based upon transdisciplinary approaches, along with validation of the principles via prototypes and test beds. In this context this paper presents a precision agricultural management integrated system architecture based on CPS design technology.

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Keywords: cyber-physical systems, precision agriculture, mechatronics, potato crop, wireless sensors network.

1. Introduction

In solving the food crisis at the beginning of the XXI century when the World population recorded in October 2011 was 7 billion people and with a projected global population surpassing 9 billion people by 2050 (Puiu, 2014), potato turns out to be a product of great importance. Potato is a valuable food, considered by FAO (2009) as an important pillar in improving safety food worldwide.

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Potato crop profitability can be achieved only by increasing the yield per hectare and production quality. In this context, modern technologies such as precision agriculture that are based on mechatronics engineering (Rad et al., 2014) should ensure productivity and high profitability of potato crops, in addition to environmental protection and natural resources preservation. In reality, the biggest problem with precision agriculture is in fact the amount of data acquired that can be difficult to interpret and very often overwhelming (Zhang and Pierce, 2013), but this issue is becoming less and less problematic as computing power and communication interfaces between different networked systems are becoming more powerful, more user friendly and less expensive. Today, precision agriculture is considered an application of Cyber-Physical Systems (CPS), the brand-new concept that rests on the foundation of theory of cybernetics, the practice of mechatronic design and the emergence of design and process science (Hancu et al., 2007; Lee and Seshia, 2011; Suh et al., 2011) as can be seen in Figure 1.

As a proof of concept, Nie et al. (2014) proposed a precision agriculture architecture based on CPS design technology that includes three layers: the physical layer, the network layer and the decision layer. The architecture can be used for different agricultural applications. Dong et al. (2013) presented a proof-of-concept for a CPS application called Wireless Underground Sensor-Aided Center Pivot (WUSA-CP) irrigation system. This system will provide autonomous irrigation management capabilities by monitoring the soil conditions in real time using wireless underground sensors. Mehdipour (2014) proposed a “Smart Pest Control” based on CPS in order to provide an infrastructure for monitoring rats in the agriculture field. However, from author’s knowledge there are no works in literature regarding the architecture of a CPS used for monitoring potato crop vegetation status. Therefore, this paper aims to provide such a solution.

The rest of the paper is structured as follows. In part two will be presented an overview of CPS architecture in order to understand the dimension and complexity of such systems. Based on the presented CPS architecture, a precision agricultural management integrated system architecture for monitoring the potato crop vegetation status will be described in part three. Advantages and disadvantages and implementation problems will be formulated and discussed, too. Finally, the paper ends up with the conclusions.

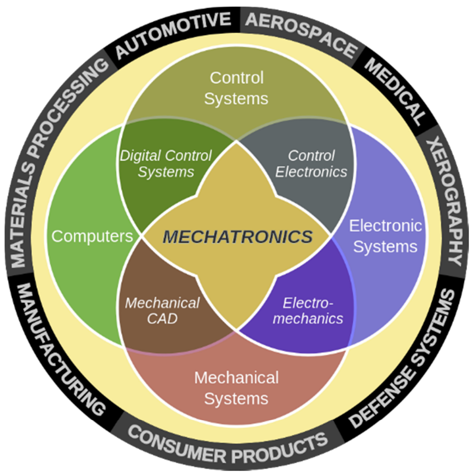

Fig. 1. Rensselaer Polytechnic Institute mechatronics model (Suh, 2014).

CPS Architecture

CPS can be described as smart systems that encompass computational (i.e., hardware and software) and physical components, seamlessly integrated and closely interacting to sense the changing state of the real world (Lee and Seshia, 2011). Cyber-physical systems are the product of a transdisciplinary engineering design process–mechatronics–that integrates electronic, software, computer, and motor control (Suh et al., 2014). These systems involve a high degree of complexity at numerous spatial and temporal scales and highly networked communications integrating computational and physical components as can be seen in Figure 2.

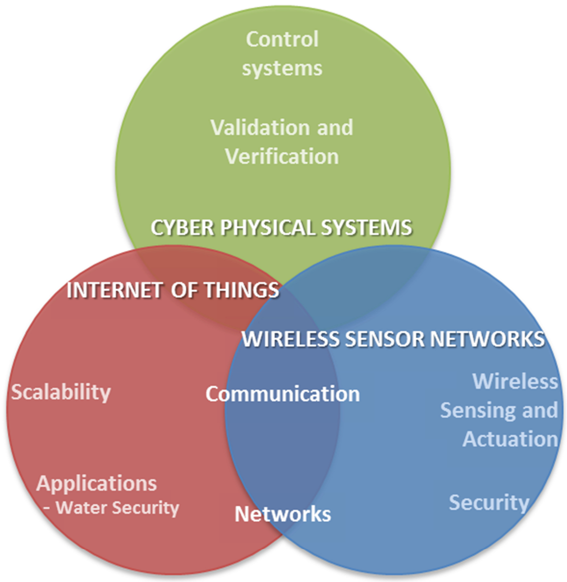

Fig. 2. Cyber Physical System model (ICRI, 2015).

Examples of CPS application areas include: the smart electric grid, smart transportation, smart buildings, smart medical technologies, next generation air traffic management, advanced manufacturing, precision agriculture, etc.

Under the architecture of Internet of Things (IoT) it is very hard to make a clear distinguish between CPS, Wireless Sensors Networks (WSN) and Machine to machine (M2M) technologies but CPS can be seen as an evolution of M2M systems. A very good presentation of the main differences and correlations among these four technologies in presented in (Mišić and Mišić, 2014).

Regarding their architecture, all these technologies share the same four major layers: sensing layer, networking layer, analysing layer and application layer. Usually, these layers will interfere with additionally security and privacy components. In Figure 3 is presented the four layer architecture along with a relevant example of its implementation in a real-life application - GoTa 4G system (ZTE, 2015).

In the case of CPS, the tight combination and coordination between physical and computational elements is more evidenced as can be seen in Figure 4 in the architectural model proposed by Mišić (2014) and Wu et al (2011). Analysing Figure 4 it is clear that a variety of issues need to be addressed at different layers of the architecture and from different angles of system design in order to obtain such an integration usually found in mechatronic systems (Tecaru et al., 2014).

Furthermore, in this dynamics information plays a decisive role. In references (Suh et al., 2014; Horvath, 2012) are outlined CPS design challenges.

In the CPS design, architecture establishment is the first and critical step, and is also the basis for research and development of CPS (Nie, 2014).

Based on the CPS architecture described above, next will be presented a precision agricultural management integrated system architecture for monitoring potato crop vegetation status.

The main purpose of such an integrated system is to provide an innovative solution for multispectral monitoring of potato crop based on mechatronic systems, in order to improve precision agricultural management, solution that will lead to overcoming bottlenecks identified in this area. The solution will take into account the four-layer architecture presented in Figures 3 and 4.

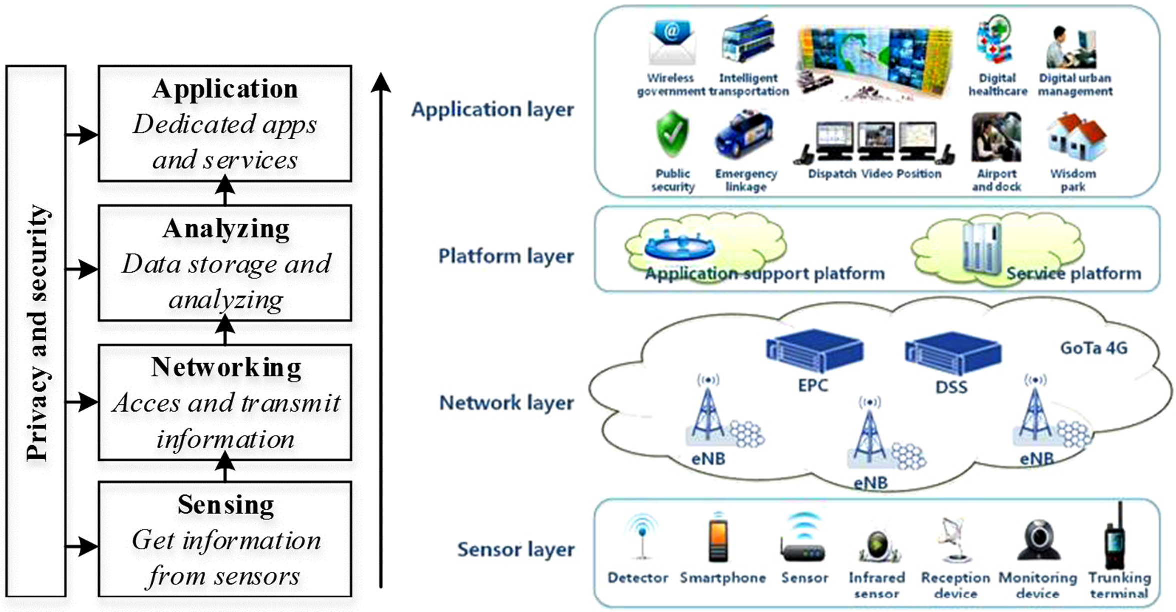

Fig. 3. Four-layer architecture of IoT, WSN, M2M and CPS.

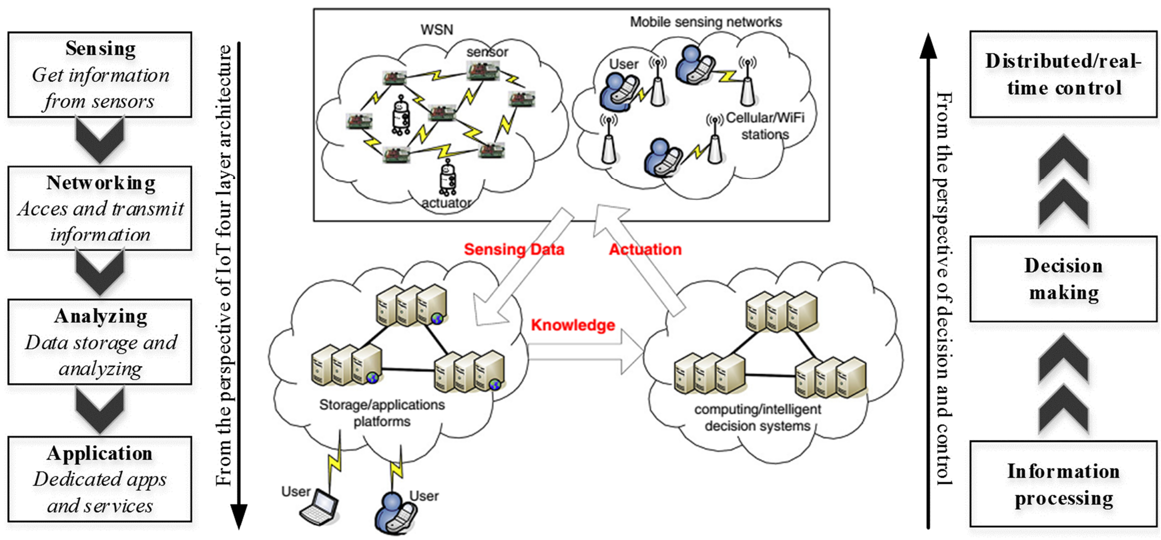

Fig. 4. CPS architecture model.

CPS Architecture Model for Monitoring Potato Crop Vegetation Status

Precision agriculture management consider, among other things, also the monitoring of the crops vegetation status. This is done by calculating and interpreting vegetation indices based on spectral data collected by specialized acquisition systems (Ola et al., 2013). In this context in Figure 5 is presented the CPS architecture for monitoring potato crop vegetation status. The layers of architecture will be described below:

Physical layer - used for information acquisition process. Information will be collected by means of sensors at ground level, human work and two innovative systems: Multispectral Terrestrial Mobile Mechatronic System (MTMMS) and Multispectral Autonomous Aerial Mobile Mechatronic System (MAAMMS). These two innovative systems will provide a solution for farmers with limited financial possibilities for monitoring potato crop vegetation condition based on multispectral investigation techniques. All measurements will be georeferenced using GPS satellites and will contain information regarding the hydric and thermal stress, soil properties, level of chlorophyll, pH, nitrogen, potassium, phosphorus, etc.

Network layer – wireless communication is an indispensable technology for precision agriculture (Luculescu et al., 2014). The central element in such a network is the node (mote) and is the results of a complex hardware and software integration design. Designing network nodes is not an easy task but in the proposed architecture the information obtained from MTMMS and MAAMMS will be transmitted via an Acquisition, Processing, Storage and Transmission System for Multispectral Information (APSTSMI), an innovative solution that provides the basic tool for collecting data from the field. APSTSMI is a special system designed for being integrated with the two mechatronic mobile systems and to provide the entire range of information required in decision layer.

Decision layer – optimal decisions will be obtained using an Innovative Technology for Multispectral Monitoring of the Vegetation Status of Crops (ITMMVSC). This technology will use artificial intelligence techniques, containing GIS elements on which agricultural information is overlapped, offering through a friendly user graphical interface a valuable decisional tool in what means today precision potato crop management (Puiu et al., 2014). This system will create, store, analyse and process spatial information distributed through a computerized process regarding soil type, nutrient levels and correlate them with a certain plot of field. Moreover, will enable viewing, understanding and interpreting data in many ways. In this way, by monitoring inputs and outputs of crop, farmers will determine what areas of the field are profitable or not and what steps can be taken to increase profits in affected areas.

Application layer - this layer will provide solutions to incoming problems based on information processed and stored locally but also from knowledge bases obtained from other location where similar situations occurred. In this way that farmers can follow the evolution of certain parameters of interest and take the appropriate decisions in order to increase agricultural productivity.

It is expected that the proposed architecture to:

1) Increase the agricultural management with major economic impact;
2) Protect the environment and to preserve the natural resources in a more efficient manner;
3) Optimizing the use of water resources by careful monitoring the crop vegetation indices regarding the hydric stress;
4) Obtain large and quality productions due to the integrated management system;
5) Optimizing the chemical inputs (fertilizer and pesticides) by knowing the right doses and moments when to be used;
6) Increase the sustainability of agricultural systems;
7) Provide a low cost solution for the farmers with limited financial possibilities that can be easily implemented in practice.

2. Conclusions

Potato crop for future generations will require practices, processes, and systems that are sustainable (economically, environmentally, and socially). In this context, this paper presented a precision agricultural management integrated system architecture for monitoring vegetation condition of potato crop based on CPS architecture and design technologies. The proposed system allow farmers to follow the evolution of certain parameters of interest and take appropriate decisions in order to increase agricultural productivity. Implementing such a system is not an easy task and requires knowledge of potato crop, management strategies, processing and visualization of information technologies, etc. in order to be viable in practice. Finally, the concept presented in this paper will represent the start for others researchers in the field of precision agriculture.

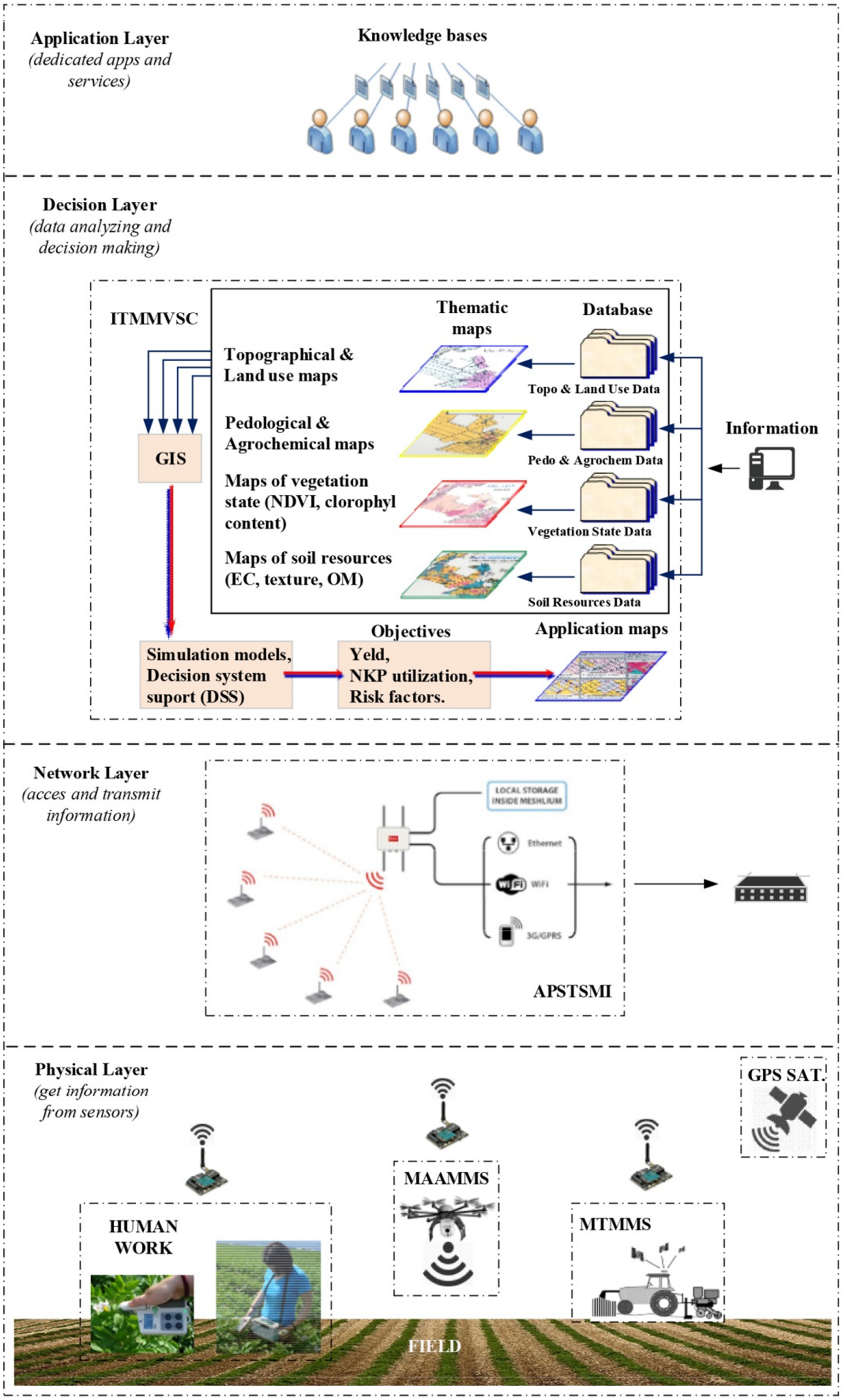

Fig. 5. CPS architecture for monitoring potato crop vegetation status.

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