IoT based End-to-End Farm Management System: An Approach toward Industry 4.0

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Abstract. The Industry 4.0 concept is a prominent trend expected to significantly affect the modernization of all industrial sectors. Since agriculture is a major sector of the primary industry, it is essential to integrate the Industry 4.0 technological advancements into the operational farm management in order ensure food security with regard to the climate change effects and the sustainable usage of environmental resources. Provided that the Industry 4.0 is strongly tied to the Internet of Things (IoT) technology, this paper presents an approach of employing a responsive and adaptive context sensitive IoT based system, capable of delivering a wide variety of operational services in order to facilitate end-to-end farm management. In particular, the proposed approach adopts a layered hierarchical structure enhancing the scalability and flexibility of agricultural operations. As proof of concept, the functionality of the proposed system was evaluated and some results regarding its performance are quoted.

Keywords: Industry 4.0; Internet of Things; Farm Management; Sustainability.

1 Introduction

The Industry 4.0 concept, which was originally introduced by the German National Academy of Science and Engineering (Kagermann et al., 2013), represents, as reported in the 2016 meeting of the World Economic Forum (WEF, 2016), a prominent trend expected to significantly affect the modernization of all industrial sectors (Xu et al., 2018; Pfeiffer, 2017) by promoting a framework for the integration of the entire production process into a "smart" digitalized environment. In this sense, since agriculture is a major sector of the primary industry, it is essential to integrate the Industry 4.0 technological advancements into the operational farm management, in order to address the excessive challenge of ensuring food security for the constantly

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increasing world population with regard to the climate change effects and the imperative necessity for long-term sustainable usage of environmental resources (Symeonaki et al., 2017; Sørensen and Bochtis, 2010).

Farm Management Systems (FMSs) are of fundamental importance for the accomplishment of successful farm management as they involve functions for planning, organizing, monitoring and controlling agricultural operations. To improve the performance of these activities in terms of sustainability, FMSs should be competent [8-10] to (Ozdogan et al., 2017; Deichmann et al., 2016):

i) Enact more efficient and sophisticated automated agricultural operations (such as cultivation, monitoring, irrigation, etc.) in complex environments and farm structures at lower costs,

ii) Provide effective and secure operating conditions both for the environment and agricultural stakeholders (such as farmers, agronomist engineers, policy makers, development cooperation professionals, etc.),

iii) Enhance the synergies among all agricultural stakeholders providing them with the ability to make decisions even on matters that are outside their areas of expertise.

Current FMSs are generally in accordance to a specific business model (Sørensen and Bochtis, 2010) and their operations do not exceed the limit of agricultural data monitoring as well as the delivery of selected control services through standalone applications, which are tightly integrated with each system since they involve closed specifications for commercial infrastructures and address to targeted end-users. This imposes some significant constraints concerning the interoperability of the FMSs as well as the semantic annotation of the numerous heterogeneous agricultural data that need to be handled by them. For this, a generalized approach of end-to-end farm management, based on the potent cross-industry cooperation of infrastructures, technologies, applications and stakeholders, is significant to be applied in accordance with the objectives and guidelines for the operative implementation of Industry 4.0 (Symeonaki et al., 2020), as depicted in Fig.1.

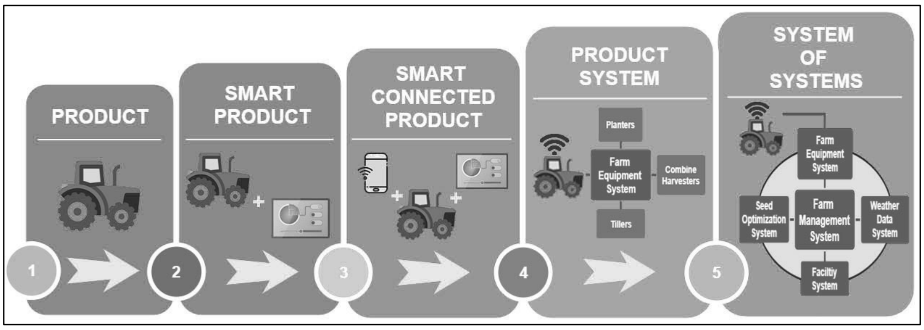

Fig. 1. Generalized concept of end-to-end farm management.

Provided that the Industry 4.0 concept is considered to be a "collective" term through the establishment of a digitalized environment wherein physical and virtual objects can interconnect and interact autonomously along the entire value chain (Pfeiffer, 2017; Rojko, 2017), it is strongly tied to the technology of the Internet of

Things (IoT). In all industrial sectors, among which is agriculture, the IoT integrates the concepts of “Internet” and “thing” offering some key features such as heterogeneity, interoperability, high scalability, interconnectivity, object-related services as well as dynamic changes (Lakhwani et al., 2019; Madushanki et al., 2019; Talavera et al., 2017;). In particular, according to the IoT concept, an intelligent network, such as the Internet, is employed as a communication and storage infrastructure comprising virtual representation of the physical objects features and attributes. In this context the virtual objects act as central object information hubs, continuously acquiring and processing data from the physical environment in order to control operational processes remotely via the Internet (Bonneau et al., 2017).

This paper is keen to present an approach of employing a responsive and adaptive context sensitive IoT based system, capable of delivering a wide variety of operational services in order to facilitate end-to-end farm management. To this end, the proposed approach adopts a layered hierarchical structure consisting of an agricultural facility at the lower level and three cloud components distributed into the two higher levels. It is considered that such an approach will consequently enhance the scalability and flexibility of agricultural operations, by handling simultaneously large amounts of heterogeneous sensory raw data acquired remotely in multiple agricultural environments, and support the control of infrastructures as well as the making of critical decisions related to the optimization of agricultural production with regard to the sustainable development.

Subsequently to the introduction in Section 1, the rest of this paper is structured in five sections as follows. Section 2 overviews the architectural framework of the entire FMS while in Section 3 the operational functionality of the system is described in brief. In Section 4 the performance of the system is examined and some evaluation results regarding its performance are quoted in general. Finally, the paper is completed in Section 5, wherein the principal conclusions drawn from this work are discussed along with future directions for further research.

2 FMS Architectural Framework Overview

In the proposed architectural framework, the IoT acts as the enabling technology for efficient end-to-end farm management in order to ensure maximum agricultural production of optimum quality and increase the profitability of various agricultural production schemes. According to this framework the FMS consists of three main layers as depicted in Fig. 2 and overviewed forth below.

2.1 Physical Layer

The lower level points the Physical Layer, which involves a Wireless Sensor and Actuator Network (WSAN) integrated in an agricultural facility, consisting of a group of self-powered sensor nodes deployed in a mesh network topology with adequate communication range to cover a wide area. These nodes incorporate sensors that remotely acquire real-time data about various features concerning the cultivation, as well as actuators that interact with them, enabling the proper physical actions within the facility. The raw data acquired by the WSAN sensors are transmitted via wireless/mobile gateways, providing the required translation technologies and mechanisms among various protocols, to the next higher layer for being processed, managed, and stored. Subsequently, the gateways serve the transmission of feedback to the actuator nodes of the WSAN in order to control the equipment of the agricultural facility (i.e. irrigation valves, fertilizing sprinklers, illuminance and heating or cooling systems, autonomous machinery, foggers and humidifiers, etc.) and perform the required agricultural operations.

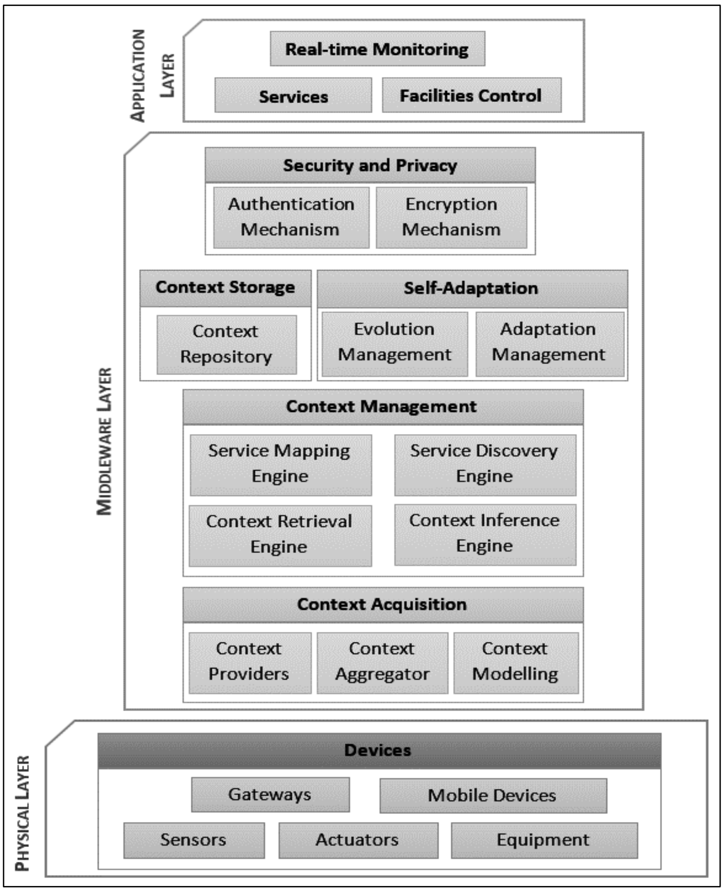

Fig. 2. End-to- End Farm Management System layered architecture diagram.

2.2 Middleware Layer

The Middleware Layer of the proposed architectural framework involves a context-aware middleware cloud acting as a Decision Support System (DSS) in order to provide context-aware services and actions. This component adopts the Infrastructure as a Service (IaaS) properties of cloud computing and is composed from several modules for acquiring, managing, and storing contextual data. Great importance is also given to the aspects of self-adaptation as well as security and privacy.

In particular the context acquisition module is responsible for the aggregation of the raw data which were obtained by the sensors of the facility's WSAN and their distribution among various providers (i.e. a weather station providing context related to environmental conditions such as temperature, pressure, humidity, etc.) so as to be converted into context. The context manager is responsible for managing requests from the context acquisition module, where contextual information is being obtained, as well as for correlating the contexts with the services which are specified by the service providers in order to identify the most suitable services and control actions for the relating context. The context storage module is highly required since context history can be essential for process planning, constituting a good source of knowledge for prediction of future actions to be undertaken and inference processes. Finally, the security and privacy module ensure the privacy of contextual information, through the execution of security functions which detect and monitor possible irregularities or unauthorized accesses to data. On top of that the self-adaptation module is responsible for diagnosing, locating and recovering any possible failures in the workflows.

2.3 Application Layer

The Application Layer of the proposed FMS consists of two cloud components which involve Software as a Service (SaaS) features. In particular in this layer all the required software applications for the interaction of end user with the FMS are provided, such as real time monitoring and facility equipment control. The applications are centrally hosted, accessed by users remotely and licensed on a subscription basis.

3 FMS Operational Description

In the proposed FMS approach sensor data, acquired by a Wireless Sensor and Actuator Network (WSAN) in an agricultural facility, are transmitted via a gateway as raw data to the context-aware middleware cloud where they are converted to context. These contextual data as well as the incoming rules provided by the services cloud (containing applications for the end user) are managed inside the middleware component to produce monitoring information, services and control actions (such as cultivation control). The context-aware middleware cloud responds back to the agricultural facility enabling the appropriate equipment to perform context-aware operations as well as back to the end users (farmers, agronomist engineers and agricultural products merchants) providing them with new context-aware services and monitoring information in order to take further assistive actions. In this sense the end user can operate the agricultural facility remotely via the cloud services (Fig. 3). It should be noted that this system's architectural framework may apply to more than one agricultural facility.

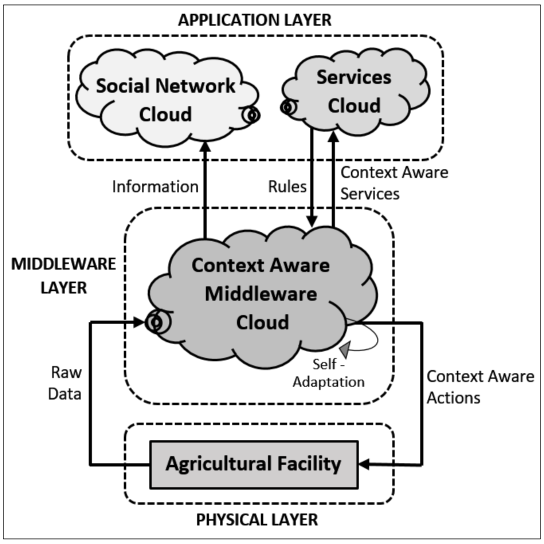

Fig. 3. End-to- End Farm Management System operational overview.

4 FMS Performance Evaluation

With the objective to validate the performance of the FMS a number of trials were conducted both in real and simulated environment for one agricultural facility environment. Testing the system allowed its proper analysis and evaluation in terms of health, operation, and performance.

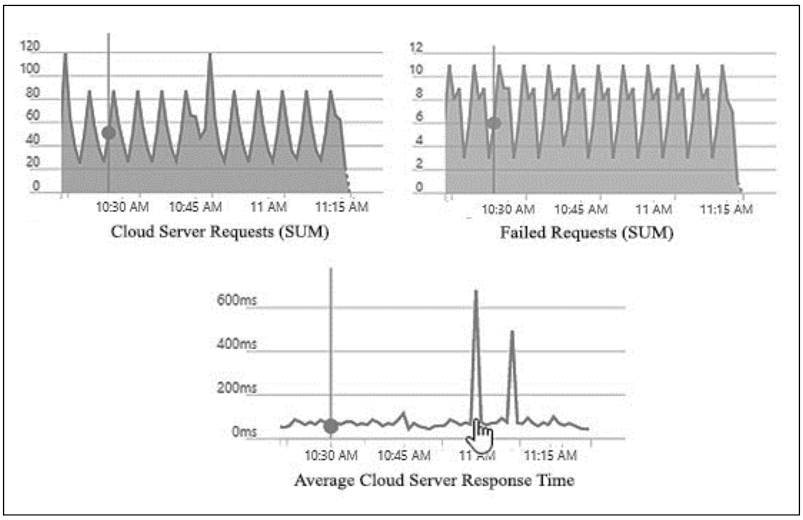

Fig. 4. End-to- End Farm Management System performance metrics.

In general, according to the outcomes provided by the metrics obtained during the tests as depicted in Fig. 4, the proposed FMS performs fairly satisfactory for controlling one agricultural facility environment since sensory data could be adequately acquired, processed, stored in the knowledge base, retrieved and disseminated to the applications of interest, resulting consequently into the proper actions. Nevertheless, the performance of the system is intended to be more thoroughly tested by evaluating additional parameters and integrating multiple agricultural environments for various cultivations and in distinct locations as part of future research.

5 Conclusions and Future Work

In conclusion, it is strongly believed that the proposed FMS architectural framework may support the integration of farm management toward the Industry 4.0 concept. It is in that regard that the introduced approach, based on the integration of WSANs into the IoT, has the benefit of being effortlessly adaptable, modifiable, and extendable for any application in any agricultural system environment no matter how complex it is.

Future work on the subject is intended to include an in-depth performance evaluation of the model through the integration of multiple agricultural facility environments with various cultivations and in distinct locations, in order to improve the interoperability and standardization of the proposed framework. For what is more, since the involvement of smart mobile devices and social networking was not taken into much consideration, these features are going to be included as part of the ongoing work.

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