An IoT Service-Oriented System for Agriculture Monitoring

Carlos Cambra[1], Sandra Sendra[1,2], Jaime Lloret[1], Laura Garcia[1]
[1] Universidad Politécnica de Valencia, Valencia, Spain
[2] Dep. of Signal Theory, Telematics and Communications (TSTC), Universidad de Granada, Granada, Spain
carcamb1@doctor.upv.es, ssendra@ugr.es, jlloret@dcom.upv.es, laugarg2@teleco.upv.es

Abstract—**Wireless Sensor Networks (WSNs), Internet of things (IoT) and aerial mapping are nowadays being used very much in agriculture. The challenge of joining those technologies requires a new and smart wireless network topology for devices communication. Problems like scalability and manageability are important challenges when there are many devices. This paper presents the design of a smart IoT communication system manager used as a low cost irrigation controller. The proposal is a powerful irrigation tool that uses real time data such as the variable rate irrigation and some parameters taken from the field. The field parameters, the index vegetation (estimated using aerial images) and the irrigation events, such as flow level, pressure level or wind speed, are periodically sampled. Data is processed in a smart cloud service based on the Drools Guvnor (a Business Rules Manager). The developed multimedia platform can be controlled remotely by a mobile phone. Finally, we measured the bandwidth consumed when the system is sending different kinds of commands and data.**

Keywords—*Data processing system; sensor data integration; Agro IoT; Wireless Sensor Network; Farming Data; SOA; Service Integration.*

I. Introduction

Smart technology deployed for modern farms grow together with the area of Precision Agriculture (PA). Public administration and farmers have access to many multimedia browsers and auto-guidance systems provided by agro-machinery manufacturers. There exist many additional sensors and devices which could add new and useful features to the agro-system if they could only be integrated with it. The Internet of Things (IoT) can help us to join all these elements. Our motivation to perform this research comes up because farmers demand a new multimedia platform to determine the most efficient decisions to manage and monitor their agricultural fields, especially for fertilizing tasks.

Common Agricultural Policy (CAP) 2014/2020 implements new points inside of the new term “Greening” [1]. This policy aims to obtain energy efficiency and the reduction of fertilizers in agriculture productions. These goals can be achieved by applying new technologies in farms with strong traditional thinking in growth methods, obtaining productions destined to human consumptions in a sustainable and healthy way, while decreasing around 70% the use of chemical herbicides.

All these issues require additional management tools and applications. It could be interesting to implement a direct integration in some few systems but it is nearly impossible to develop it on large scale fields as in the case of crop production systems. Information technology (IT) industry is aware of this problem and tries to solve it with Service Oriented Architectures (SOA), where each module exposes a standard interface for communicating with other systems. The current documentation and the tutorial are published on the official website [2]. Therefore, SOA principles should be investigated in a distributed smart agro big data environment. It is another emerging trend in software integration research that is suitable to be used in industry with Complex Processing (CP). Related literature demonstrates that there are many requirements for agriculture decision [3]. These requirements are focused on environment data collection for big data systems, vegetation index decision based systems and Wireless Sensor Networks (WSNs) using complex algorithm models or decision systems. Other requirements include scalability issues or ontologies for crop production systems. The quality and performance of new integration modeling systems should be addressed here as well [4]. Autonomous irrigation controller based on a timer is in most cases insufficient to satisfy the growing expectations put on the crop production systems. Research interests are nowadays focused on integrating aerial images, smart irrigation controllers and data originated by other sensors such as soil humidity sensors, temperature and crop aerial Normalized Difference Vegetation Index (NDVI) analysis. Methods based on combining visual data from several data sources like ground sensors or events between them are also an interesting research subject [5]. Scalability, effective management, and QoS in large and distributed monitoring systems are also important topics that must be taken into account.

This paper shows how IoT, aerial images and SOA can be applied to large and smart farming systems, which should be scalable and easily configurable. It presents the design and development of the multimedia platform for precision agriculture (called PLATEM PA). It integrates an intelligent IoT irrigation system based on a mesh network using the new aerial mapping sensor included in AR Drones with HD cameras to monitor an area for growing crops (See Fig. 1). The captured video is used to control the irrigation system and the blocking of the sprayers, which may produce problems and crop death if they are not properly irrigated (See Fig. 2) [6]. The whole system is based on an 868 MHz wireless mesh network. The communication system lets the nodes transmit data up to 12 Km. Some previous contributions were described in [7].

The rest of paper is organized as follows. Section II describes the state of the art about the last technologies applied to agriculture, WSNs and aerial image mapping data. Section III describes the communication layers architecture, the Low Energy Consumption Wireless Mesh Network as well as the system operation. The entire data source is integrated on the context service where data is processed by a rule engine. It will be in charge of the matching rules, taking decisions and monitoring data, sending notification and computing statistics. The implementation is shown in Section IV. Section V presents the conclusion and describes the next steps in the development of PLATEM PA.

II. Related Work

Some time ago, autonomous irrigation controllers were designed using analog technology based on timers. In the most trivial case, an alarm event was detected with plastic bottles. If the bottle was full of water, the irrigation system was working well. If the bottle was empty, the system was incorrectly working due to false positives. Currently, most of the irrigation controllers can be manually programmed by mobile messages or smartphone applications. With high performance computers, additional features can be included, e.g. real time irrigation alarm detection and smart irrigation schedule according to the index vegetation or environment data. This section shows some of the existing works related to our proposal.

E. Playán et al. [8] described the evolution of irrigation controllers based on simulation models. They found two models. The sprinkler irrigation model, which is based on a ballistic model. The sprinkler sends the water to the drops, subjected to a velocity vector, wind vector and the force resistance. Another type is the crop model, which combines the soil water balance, crop growth, and crop yield by using mathematical equations implemented in a software application.

We focus this proposal on the real time image analysis of corn crops using smartphones or tablets to control the irrigation system. Sometimes the quality of water changes can include grit or clay that is not captured by the filter of the irrigation system. This may result in important problems due to the blockading sprinklers. It is necessary to solve this issue because the production during the summer period can suffer a drought in warm days. H. Z. Wang [9] explored the architecture using IoT based on heterogeneous sensor data. They proposed a design for implementing IoT in agriculture based on cloud computing. The design was based on a two-tier storage structure of HBase, which is a distributed database with high scalability. The access to the database using Map Reduce model was performed using a distributed programming framework. Hence, this design provided scalable storage, efficient data access, and facilitated other data processing tasks.

Captured images are used to estimate parameters usually measured by sensors. Depending on the quality of the video stream and the used algorithms, the system can classify vehicles, trace lane changes or even recognizing license plates. The system usually requires only one camera per monitored location. The aerial image, ground data sensor and environment data must be segmented and transformed into objects. Their behavior is recognized and tracked. An example of such a system was described in [10]. In this case, high multispectral cameras are used to monitor the vegetation index by bands reflection processed on normalized difference vegetation index (NDVI) measurement.

C. Cambra et al. [11] presented an analysis to determine the bandwidth requirements to transmit video in system applied to detect problems in the Coefficient Uniformity (CU) of an irrigation system. They also analyzed weeds conflicts on maize crop. The key idea of their work was to enhance the monitoring tasks with sensors or integrate them with the whole sensor network where the aerial sensors are just one type of sensors. Physical sensors are connected directly to first level nodes according to their location. Nodes create a hierarchical structure. According to the SOA paradigm, software should be delivered as loosely coupled and cooperating services, which should be described, published and easily discovered. In such environment, new applications called business processes can be created by composition of existing services.

Fig. 1. Weeds detection on maize crops using aerial video processing.

Fig. 2. Aerial video analysis detecting blocked sprinklers.

III. SYSTEM DESCRIPTION

This section presents the proposed solution. The proposal is based on a WSN connected to irrigation controllers. Layer 2 consists of a network coordinator middleware, a storage system and a multimedia platform browser (See Fig. 3).

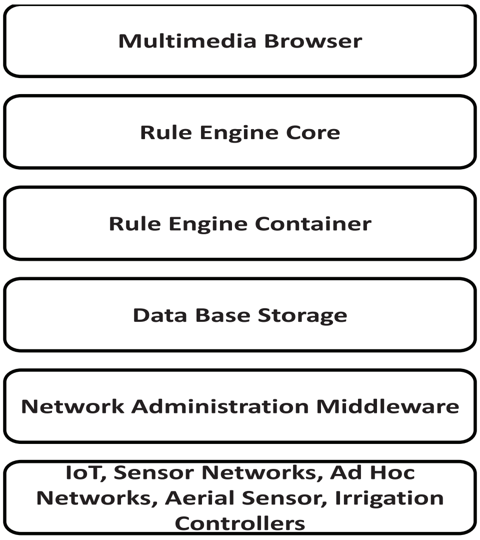

Fig. 3. Layered conceptual framework IoT data Integration Service Oriented Service.

The goal of PLATEM PA is to build a platform in order to offer services to the farmers through multimedia communication (Fig. 4). The proposal is adaptable and offers information about the weather of different places, lands conditions, and water requirements necessary for improving the farm efficiency. We propose to include the potential of mesh networks in a smart irrigation system to adapt the irrigation schedule in order to have a better agronomy decision system, to improve the efficiency and save resources. Moreover, intelligent channel assignment systems are taken into account to avoid interferences between them [12].

Irrigation controllers consist of a mesh network that operates at the 868 MHz ISM Frequency Band [13] as LoRa WAN [14] or Sigfox [15]. Irrigation controller and 868 MHz communication module are designed with low energy consumption technology that can work during one year, transmitting data up to 15 km.

Lora Alliance describes a LoRa WAN as standard specification of low consumption and wide bandwidth to use data acquisition devises thought to be implemented in the world IoT. LoRa WAN aims to provide secure bi-directional mobility, location and communication services for smart devices in mesh networks. Network Middleware is an implementation which is able to create a dynamic transmission based on Multi hop routes between the coordinator access point and several irrigation controllers. Sensor inputs can be used as well to gather environmental data from weather stations. Sensor probes collect data of soil moisture and the system functionality such as pressure and flow sensors. Fig. 5 shows the mesh network of irrigation controllers. It also includes the irrigation sensor events (pressure, flow and pH) and weather data. Any new monitoring scheme for event and danger detection [16] can be added easily.

Gathered data, i.e., data from the field and controller status are stored in a MySQL data base. The rule engine are in charge of getting decision and generating notifications taking into account previous data from sensors and status controller's analysis to match a possible rule to trigger. The visual user application is used to interact and executing actions in the system such as opening a hydraulic valve or showing data in regard to accumulated degrees-day temperature of a specific crop.

Modular mobile sensor devices gather data from any place. It is easy to connect, add and remove devices, which suppose a great advantage. Mesh networks increase the mobility of nodes because they allow communication without infrastructure. It benefits rural areas and landscapes where there is not electricity and, in most cases, without GSM or 3G coverage. We deploy a private radio network with dynamic routes inside the monitoring area. For example, irrigation controllers are working with a digital radio system with the 868 MHz ISM frequency band. The first part is the radio receiver, which has a low bandwidth and a data rate of 1,200 bits/sec. The narrow band is spaced in time and has more coverage range. The second part is a filter with a very narrow band reception, which is better for noise filtration.

The network middleware (identified as layer 2) has the role to create the best route to communicate devices and add new nodes by the method of discovering neighbors with the best signal strength. With the study of this parameter, the best route to transmit the information is designed. The system also uploads some essential information to the database such as the battery status, the signal strength and the deviceID. When a packet is transmitted from the coordinator to the node endpoint, 2 bytes of this packet include the information about the signal strength. Carrier blank method is used to listen to the bursts during 1 minute. Nodes are able to discover nodes and provide dynamic routing up to 3 hops. During the data transmission, the transmitter emits during 10 msec. short periods of data, which improves energy saving.

The proposed solution for data computing is based on SOA principles in order to address flexibility and easily allow the integration of issues presented in crop production systems. It facilitates making quick and smart decisions. SOA is an architectural style that supports service orchestration. In particular, SOA defines the find-bind-execute paradigm to differentiate between service providers and service consumers and their loose coupling. We propose to apply this main paradigm to the intelligent farming system, instead of creating a direct relationship between the service provider (WSN, aerial crop analysis, irrigation systems and weather) and farmers (typically a person who produces cereals or group of them). All sensor data belong to the service cloud. Then, someone who acts as a service consumer explores the cloud in order to find a relevant service. It can bind to its endpoint and execute the service. Referring to SOA principles, a prototype solution for a mobile monitoring station has been designed.

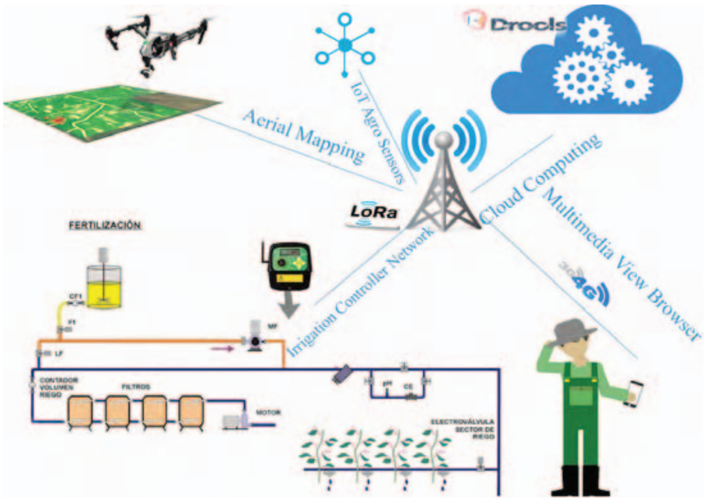

Fig. 4. PLATEM PA Visual concept

Fig. 5. 868 MHz Mesh Network with low energy consumption technology.

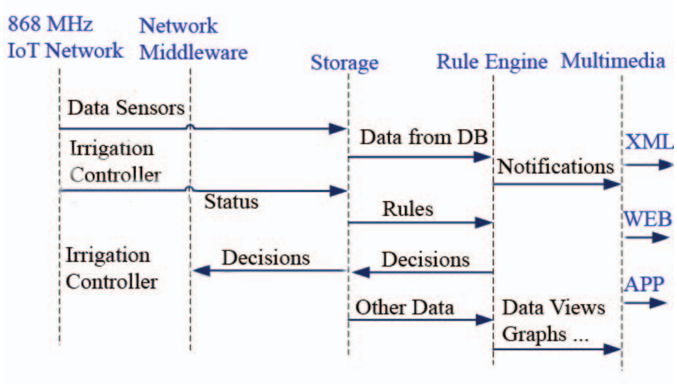

Fig. 6. Data annotation processing path

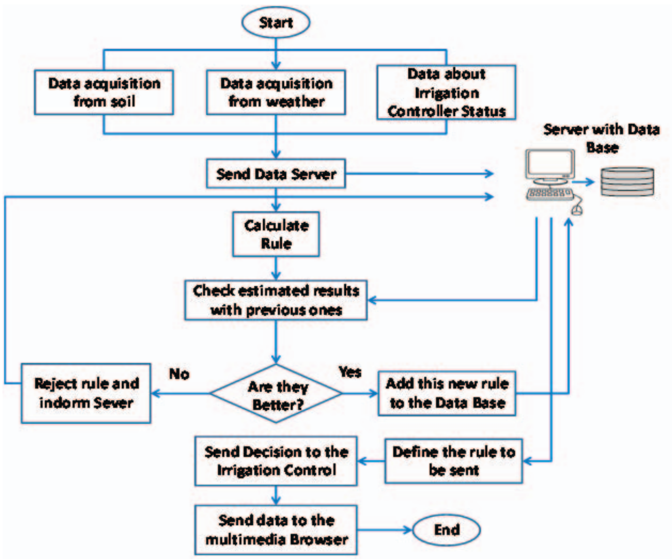

Fig. 7. Flow Diagram of PLATEM PA Operation

The server has three main components. The first one is an application that is able to register the external sensor data in the system. The only requirement for a device or application to register and become a data source is to send the values according to the specified format which depends to the type of sensor.

The next part introduces the Drools Guvnor business management based on the Rete pattern matching algorithm [17]. It provides the basis for a more efficient implementation that might check each rule with facts in a knowledge base, firing the rule, if necessary. There are several benefits of this algorithm such as reducing or removing the redundancy or allowing an efficient delete of memory when facts are retracted. We called rule container to the part of data base where the rules of the system are saved. There are inside entities to contain the parameter rules of the system irrigation functionality, the agronomy parameter rules and the weather rules.

The system needs to get experiences and create new relationships between rules. Each rule contains two main sections: the conditions section and the actions section. Declarations start with the rule keyword followed by the name of the rule. Fig. 6 shows the process and exchanged packets performed by the system to implement the different rules, monitor data and, finally, show data through the multimedia platform. Fig. 7 presents the flow diagram of PLATEM PA Operation.

IV. Experimental Scenario

In order to test our system, in this section we implement the rule that detects the potential fungus attack. This section also shows the resulting overlapping layers obtained by the gathered images and, finally, we check the consumed bandwidth of each node during different operation phases.

Firstly, Fig. 8 shows the *PossiblePesticideEvent* rule which is able to detect the potential fungus attack in a part of the field, concretely area 1. Rule conditions determine when the action has to be implemented. In this example, two events must occur: accumulated degree-day temperature is 1300 ºC and five days ago rain sensor storage 5 litters/m^2. In our historical data base crops ago, fungus appeared when barley has 1300 ºC life and the environment has a high humidity level. When all conditions are fulfilled, the new event is created. The last line of the actions section inserts this event to the rule engine. In this way, the new event can be used by other rules. Rules give the user a great flexibility in combining low level events into higher level events which should trigger proper services or notify the user. Drools Guvnor provides a user-friendly interface for building rules so the user does not have to know all the language details, e.g., possible fungus attack detected on humidity air data changes. Integration with services layer was also tested thanks to sensor data and notification services. Complex events add several additional dimensions to the monitoring process. It was proven that in the test scenario, the decisions based on extra assumptions are more accurate.

On the other hand, one sensor usually is not enough to make the right decision and take the specified action. We used several sensors as temperature, humidity air sensor and rain sensor. When using the combination of those events the false calibration rate decreases. In order to detect some real-life context events, rules were written in special Drools domain and specific language.

The experimental scenario comprises the context service that may occur barley fungus attack through the context service model to detect humidity air in a 1300ºC barley life. In the following example, the rule engine automatically starts to select possible rules and conflicts and identify two possible rules that can be triggered. The rule showed in Fig. 8 has been tested in this case. Checking historical of accumulated degree-day temperature and humidity air sensor rules of specific crop zone conclude that the scenario is perfect to fungus attack.

PossiblePestEvent triggers and creates new farmer notification to prepare a pesticide sprayer application in few days and irrigation program will be pause during 7 days. After sprayer application we can check the effects of fungus attack by aerial tools (satellite image or UAV Image) that provide PLATEM PA.

The gathered and processed data images are represented in Fig. 9. Source data layers, such as satellite layer, provide the GPS coordinates of the digital terrain model to geo-locate the areas. The next source layer, NDVI, is the result of the vegetation index calculation algorithm, which decides how is the health of the plant, the stress hydric, or over hydric, by gathering aerial mapping images from UAV or Satellite. The computational result layer is able to create differential classification zones where irrigation controllers have different parameters such as water and fertilizer for each zone. Finally, CAD irrigation layer can be used to elaborate maps and redesign the area.

The last test performed was to check the consumed bandwidth per node during the different phases (Fig. 10 and Fig. 11). We performed two different tests. The first one was more focused on basic tasks as starting and stopping the system and sending data. In this case, Fig. 10 shows that the biggest value of bytes/s is registered when we manually open a valve, although the time is very short. The task that generates bigger amount of data as a function of the time is the data sending. The second test (Fig. 11) was focused on obtaining data during sending commands to modify the program contained in the programmer.

```
rule "possible-pesticidefungus-areal"   Fungus Rule Storage in DB
when
   AccuTemp(value<1400°C) || (value>1250°C)
   AccuWeeklyRain(valuerain >3 l/m2)                        Conditions
   HimidiyAirDayEvent(valueairhum > 75%, this after $hum)
then
   PossiblePesticideEvent e = new PosiblePesticideEvent(new DateTime())
   insert(e)            Farmer Notification(Pesticide task is required
   end                  in area 1)
```

Fig. 8. Rule engine example (Fungus attack Conflit Set)

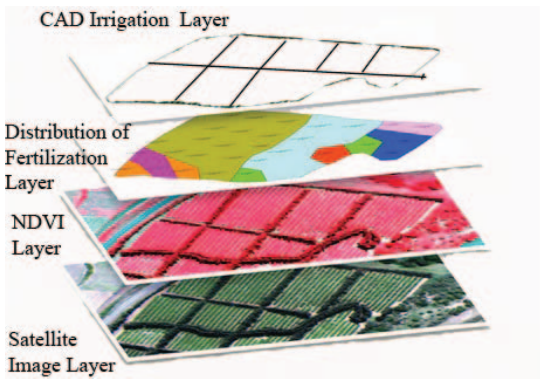

Fig. 9. Layer Overlapping (System irrigation project layer, Index vegetation layer, Post processing sectorized layer.

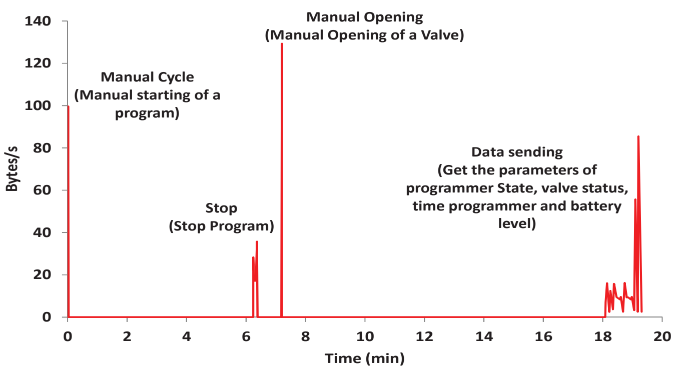

Fig. 10. Bandwidth consumed by a node during basic tasks.

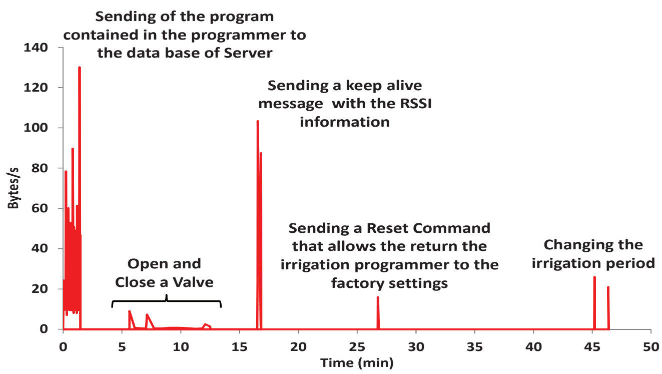

Fig. 11. Bandwidth consumed by a node when sending control commands.

In this case, the actions that implies bigger bandwidth are the sending the programming contained in the programmer to the data base of server with maximum values of (130 Bytes/s) and sending the keep alive messages with the Received Signal Strength Index (RSSI) to the server (108 Bytes/s) although this action is very short.

To understand the advantages of using LoRa WAN, we have compared a LoRa WAN and a Zigbee network. While Zigbee cannot communicate beyond 1,160 m., LoRa WAN can send commands at distances up to 12,300 m.. A crop fields can have an extensions of 5 hectares. Zigbee is not a suitable solution for that. Regarding to the consumed bandwidth, its requirements are very similar.

V. CONCLUSION

This paper describes the way that communication technologies and intelligent context-service systems provide autonomous decision without human interactions. It uses LoRa WAN network protocol, which provides a long distance communication with very low energy consumption levels. Recent studies on mesh network [18] show the easy adaptation of Wi-Fi protocol to connect devices without infrastructure but it has high energy consumption.

In this paper, we demonstrated the potential of IoT networks on PA. Results demonstrated that the use of 868 MHz mesh networks is the best solution for data acquisition in farming systems. Our context service proposal is based on SOA principles and tools that can enhance the modern agricultural systems and allow the precision agriculture. The flexible composition of smart agricultural services, like smart and efficiency irrigation season inside of farmer community, is a great advantage for irrigation turns and for saving energy and water. The system events and data processing rules can be extended during the development process. The irrigation services are described to demonstrate the capabilities of the proposed system. We also show the future opportunities of such services in the domain of agricultural decision systems. This IoT architecture and the way of taking decisions could be adapted to many other applications such as emergency rescues [19] among others.

The crucial part of further development works will be the development of a standard communication protocol between irrigation devices, like ISOBus [20], for agro-machinery. Moreover, in the first evaluation we have discovered that different irrigation controller makers cannot communicate between them or with stations water pumps by using private communications protocols, thus, in future works, we want to design a standard irrigation communication protocol in cooperation with main irrigation manufactures, which will include new secure systems [21][22].

REFERENCES

[1] Common Agricultural Policy (CAP) 2014/2020.Available at: http://ec.europa.eu/agriculture/policy-perspectives/policy-briefs/05_en.pdf [Last accessed: October 27, 2016]

[2] JBoss Drools Integrated to SOA. Available at: http://planet.jboss.org/post/the_jbossesb_drools_integration_in_the_jboss_soa_platform [Last accessed: October 27, 2016]

[3] S. ZhongFu, D. KeMing, Z. FeiXiang, and Y. ShouYi "Perspectives of research and application of big data on smart agriculture", Journal of Agricultural Science and Technology, 2013, Vol. 15, No. 6, pp. 63-71.

[4] N. Zapata, R. Salvador, J. Cavero, S. Lecina, C. Lopez, N. Mantero, R. Anadon, and E. Playan, “Field test of an automatic controller for solid-set sprinkler irrigation” Irrigation Sciences. 2013, Vol. 31, No.5, Pp.1237-1249.

[5] E. Raymond, Hunt Jr. W. Dean Hively, Stephen J. Fujikawa, David S. Linden, Craig S. T. Daughtry and Greg W. McCarty “Acquisition of NIR-Green-Blue Digital Photographs from Unmanned Aircraft for Crop Monitoring”, Remote Sensing, 2010, Vol.2, No.1, Pp.290–305.

[6] A.J. Garcia-Sanchez, F. Garcia-Sanchez, J. Garcia-Haro, “Wireless sensor network deployment for integrating video-surveillance and data-monitoring in precision agriculture over distributed crops”, Computers and Electronics in Agriculture. 2011, Vol. 75, No. 2, Pp, 288–303.

[7] C. Cambra, J.R. Diaz, and J. Lloret, "Communication Ad Hoc Protocol for Intelligent Video Sensing using AR Drones", In proc. of the IEEE Ninth International Conference on Mobile Ad-hoc and Sensor Networks (MSN 2013), Dalian (China), Dec. 11-25, 2013.

[8] E. Playán, R. Salvador, C. López, S. Lecina, F. Dechmi, and N. Zapata, “Irrigation Controllers driven by solid-set Sprinkler and crop simulation models”, In proc. of the 1st CIGR Inter-Regional Conference on Land and Water Challenges, Bari, Italy. Septembr, 2013.

[9] H. Z. Wang, G. W. Lin, J. Q. Wang, W. L. Gao, Y. F. Chen, Q. L. Duan, "Management of Big Data in the Internet of Things in Agriculture Based on Cloud Computing", Applied Mechanics and Materials, 2014, Vols. 548-549, pp. 1438-1444.

[10] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[11] C. Cambra, J.R. Díaz, J. Lloret, Deployment and Performance Study of an Ad Hoc Network Protocol for Intelligent Video Sensing in Precision Agriculture.” Lecture Notes in Computer Science. 2015. Vol. 8629, Pp.165-175.

[12] D. Yiltas-Kaplan, S. Durukan-Odabasi, P. Kirci, An Interference-Aware Channel Assignment Scheme for Wireless Mesh Networks, Ad Hoc and Sensor Wireless Networks, Volume 30, Number 3-4 (2016). Pp. 183-199

[13] S.Hellan & F. Storvik, "Europe ISM Band rulthr es"Application Note ANO50. Available at: http://www.ti.com/lit/an/swra146b/swra146b.pdf [Last accessed: October 27, 2016]

[14] Lora Alliance. Available at: https://www.lora-alliance.org/What-Is-LoRa/Technology [Last accessed: October 27, 2016]

[15] Sigfox tecnical features. Available at: https://www.sigfox.com/ [Last accessed: October 27, 2016]

[16] T. Kawakami, N. Fujita, T. Yoshihisa,and M. Tsukamoto, “An Evaluation and Implementation of Rule-Based Home Energy Management System Using the Rete Algorithm”, The Scientific World Journal, 2014, Vol. 2014, Article ID 591478, Pp. 1-8.

[17] M. Martinelli, L. Ioriatti, V. Federico, M. Benedetti, A. Massa, "A WSN Based Solution for Precision Farm Purposes". IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2009). Cape Town, (South Africa), July 12-17. 2009. Pp. 469-472.

[18] C. Cambra, S. Sendra, J. Lloret, L. Parra, "Ad hoc Network for Emergency Rescue System based on Unmanned Aerial Vehicles", Network Protocols and Algorithms, 2015, Vol 7, No 4, Pp. 72-89.

[19] ISO Bus 11783. Agricultural Industry Electronics Foundation. Available at: http://www.aef-online.org/en/about-isobus/what-is-isobus.html [Last accessed: October 27, 2016]

[20] B. Djellali, A. Chouarfia, K. Belarbi, P. Lorenz, Design of Authentication Model Preserving Intimacy and Trust in Intelligent Environments, Network Protocols and Algorithms, Vol 7, No 1 (2015). Pp. 64-83

[21] J. L. Tornos, J. L. Salazar, J. J. Piles, Secure Trust Management with Source Routing Protocol for MANETs, Network Protocols and Algorithms, Vol 7, No 2 (2015). Pp. 42-59

[22] F. Bagci, Energy-efficient Communication Protocol for Wireless Sensor Networks, Ad Hoc and Sensor Wireless Networks, Volume 30, Number 3-4 (2016). Pp. 301-322.