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Ontological requirement specification for smart irrigation systems: a SOSA/SSN and SAREF comparison

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Abstract. Precision agriculture is nowadays getting more and more attention in Europe. Due to the common water shortage problem, precision irrigation could become a key activity to save and use water in a more sustainable way. This paper builds upon an automatic irrigation system implemented as a context-aware system in which context is acquired thanks to a wireless sensor network. In such system, ontologies are used to solve integration problem of heterogeneous data provided by different types of sensors. Moreover, ontologies enable reasoning over these data to enrich the context. The automatic irrigation system will be installed on the pilot site of Irstea called AgroTechnoPole, located in Montoldre. The main goal of this paper is to analyze the SOSA/SSN and SAREF standard ontologies in regards to the ontological requirements that arise from the AgroTechnoPole use case.

Keywords: Ontologies, Adaptive Context-Aware, Precision Irrigation

1 Introduction

In the 21st century, economical and environmental challenges force local governments and citizens to improve processes and lifestyle habits to save precious and scarce resources. One of the most critical resources is water. Agriculture consumes the most water on a global scale [21]. There is a need to reduce water consumption while maintaining the crop quality.

In the agricultural domain, farmers need to observe natural phenomenon to decide appropriate activities to be carried out over the land. For example, farmers go to the farmland to examine the crop growth and state of the soil before making irrigation decisions. However, those activities are low-accuracy due to human lack of precision in observations and also the rapid changes of weather. Therefore, this reduces the yield and productivity.

Precision agriculture methods are intended to overcome this situation [18]: Digital technologies are used to monitor farming environments and optimize agriculture activities and production. Precision irrigation is also one of the critical activities in precision agriculture. Accordingly, demonstration and experimental sites for precision agriculture are emerging in the last years. For example, in the AgroTechnoPole experimental farm located at Montoldre, France, a smart irrigation system is being developed. The goal of such system is to capture the farm land data in order to activate an irrigation system in a precise and accurate way. This type of system, also known as adaptive context-aware systems, could benefit from semantic technologies like ontologies in order to harmonize, integrate and reason over data. In the particular case of the Montoldre site, an ontology is planned to be developed to semantically annotate the data and provide inference over it.

The goal of this paper is two-fold: 1) to extract ontological requirements for an irrigation context-aware system and 2) to analyze to what extent such requirements are covered by two well-known standard ontologies for the Internet of Things (IoT) domain. For extracting such requirements the Montoldre experimental-site set up, and data has been taken into account. The ontologies selected for the analysis are SOSA/SSN (the new version of the Semantic Sensor Network ontology) and SAREF (Smart Appliances REFerence ontology). The study is limited to such ontologies as they are well-known and adopted, available online, and overall due to the fact that there are proposed and developed within standardization institutions.

In order to provide the reader with insights about context aware systems, Section 2 provides a description of such type of systems and their typical cycle of processes. Then, the irrigation methodology to be applied in the Montoldre use case is presented in Section 3 before listing the ontological requirements extracted in Section 4. Section 5 shows the analysis of covered requirements and discussion. Finally, related initiatives are reviewed in Section 6 while Section 7 is devoted to the concluding remarks and future lines of work.

2 Cycle of processes for smart irrigation systems

A context-aware system "uses context to provide relevant information and services to users, where relevance depends on each user's tasks" [2]. Moreover, an adaptive context-aware system is a context-aware system that can "modify its behavior according to changes in the application's context" [5]. For example, a flood-aware system monitors a watershed to take decisions to send alerts about flood risk. It becomes an adaptive context-aware system, if it changes its monitoring schedule based on the flood risk [20].

The context of an adaptive context-aware system is considered as "any information that can be used to characterize the situation of an entity. An entity could be a person, a place, or an object that is considered relevant to the interaction between a user and an application, including the user and applications themselves" [2]. Two types of contexts can be defined: low-level context and high-level context [19]. The low-level context contains quantitative data such as sensor measurements from wireless sensor network. On the other hand, the high-level context contains qualitative data which is specified according to the application that used this content. An example of high-level context is the state of farming plots for a decision-making application: when the plot state is "dry", the application triggers irrigation actions.

In irrigation, an adaptive context-aware system has three specific components. Firstly, a Wireless Sensor Network (WSN) plays the role of sensing and monitoring the plot environment. Secondly, a Decision Support Systems (DSS) could: a) send notifications to farmers to support them in the decision-making process; and b) automatically make decisions and control the watering system. Thirdly, watering devices are in charge of watering the soil in plots.

The processes of context-aware systems could be grouped and represented in a cycle of processes. This cycle is divided into four phases: 1) context acquisition; 2) context modeling; 3) context processing; and 4) context dissemination [14]. In adaptive context-aware systems, adaptation process must be considered as an element of the cycle of processes [19]. From our viewpoint, a fifth phase called "context exploitation" that includes the adaptation process should be added to the cycle of processes. In this sense, the adaptive context-aware cycle of processes for smart irrigation at Montoldre is depicted in Figure 1 and its five phases are described as follows.

- Context acquisition: during this phase the context-aware system acquires raw data from various sources. The primary source of data is raw measurement data collected from sensors in the field. In addition, some weather data (forecast or archive data provided by local weather station [17]) may be used to derive the crop growth stage. Any knowledge about the plot or the crop, provided by farmers and scientists, are also significant to improve the exactitude of the decision process.
- Context modeling: at this time raw data is annotated and integrated into the contextual system. These data will be structured and represented in a correct format to become low-level context. Ontologies is considers as the best candidate to model the low-level context including the concepts of deployment, network, sensor, measurement, plot and crop.
- Context processing: along this phase, low-level context will be processed in order to infer high-level context: this is a reasoning process. Rule-base or inference engine can be applied to reason over the context.
- Context dissemination: at this step the high-level context previously generated is distributed to external agents as other systems or users. Furthermore, when external agents are humans, the high-level context must be transformed to a human-readable format, for example by means of visualization techniques.
- Context exploitation: The high-level context is used by DSS process to run irrigation actions and control the watering system. Adaptation processes are also part of this phase. The contextual system can adjust the configuration of its components based on the context. For example, in a normal weather

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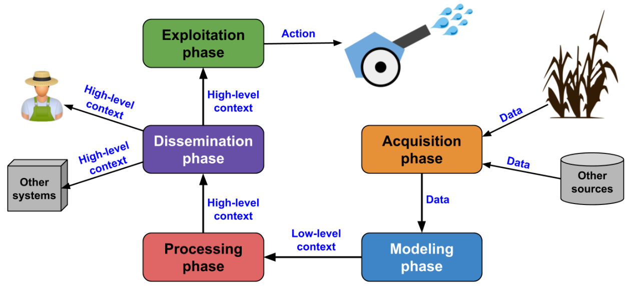

Fig. 1: Phases of the cycle of processes for a smart irrigation system

condition, the WSN observes soil humidity each day. However during a rainy period, the daily observation is unnecessary, then the WSN change its observation scheduling once a week until the termination of the rainy period.

3 Human Decision System for Irrigation Management: The IRRINOV use case

In this section, we present the IRRINOV®[4] method developed by Arvalis and its partners. This method proposes a guide for farmers to make irrigation decisions based on measurements of soil moisture sensors and pluviometers. The method is designed to answer the following questions: (1) When should the irrigation be started (i.e., when the watering devices should be installed on the plot)? (2) When should we start each irrigation turn? (3) When should the irrigation be stopped (i.e., when farmers could withdraw the watering devices)?

The IRRINOV method provides a set of decision tables and recommendations that allow farmers to manage their irrigation system on a single plot. Such method proposes numerous variants depending on the soil, plot and crop types. We will use the IRRINOV method of the region Limagne, this is, dedicated to maize crop plant on the clay-limestone soil [3]. Following IRRINOV guidelines, the measuring equipment includes:

- An IRRINOV measuring station composed of 6 Watermark probes to measure the soil water tension (tensiometer). Three Watermark probes should be placed at 30 cm depth in the soil, and the other three should be placed at 60 cm depth in the soil.
- A mobile pluviometer to measure the amount of water received by the crop during an irrigation turn.
- A weather station with a pluviometer to measure the quantity of water received by the crop during a rainfall.

The next sections describe some setups of the IRRINOV method that should be taken into account for having a high-quality irrigation process.

[4] http://www.irrinov.arvalisinstitutduvegetal.fr/irrinov.asp

3.1 Setup about probes and sensor localization

The IRRINOV method specifies the localization of measuring equipment:

- The IRRINOV station should be located on a dominant soil (the main type of soil of the plot) and easily accessible. The location of this station depends on the irrigation system. The station should be placed between two sprinklers (i.e., watering devices in the IRRINOV method of the region Limagne) and at least 60 m from the edge of the plot. The Watermark probes should be located in two side-by-side planting rows as in the schema presented in Figure 2.
- The mobile pluviometer should be close to the IRRINOV station. Its height should be above the maximum height of crops and below the height of sprinklers. IRRINOV authors recommend that the pluviometer must be placed on a telescopic standing foot to keep it higher than the crops.
- The agricultural weather station should be close to the plot, far away from any buildings or trees, and at a specific height (below 2 meters which are the maximum height of the crops).

3.2 Setup about measurement frequency

The IRRINOV station and the mobile pluviometer should be placed in the plot when the crops reach the growth stage V2[5]. The measurement could start 2 or 3 days after the installation.

The watermark probes should be read once a week or every two or three days if weather becomes dry. Moreover, a Watermark probe measurement should be carried out:

- Before each planned irrigation turn, in order to confirm or discard the beginning of a new irrigation water turn.
- About 24 hours to 36 hours after each irrigation water turn to evaluate how effective the irrigation has been (avoid measurements less than 24 h after the end of irrigation, because the measurements are unstable).
- After significant rains to evaluate their effects. For example, if rainfall amount is under 10 mm then the irrigation water turn should not be modified.

The irrigation should stop when the crops reach the growth stage R5.[6]

3.3 Setup about validation of measurement value

To validate the measurement of Watermark probes, IRRINOV method establishes that the difference between the values obtained from probes at the same

[5] V2 is an ID defined in [1], and it is also named "5 leafs" according to the Arvalis growth stage classification

[6] R5 is an ID defined in [1], and it is also named "grain at 50% humidity" in Arvalis classification system

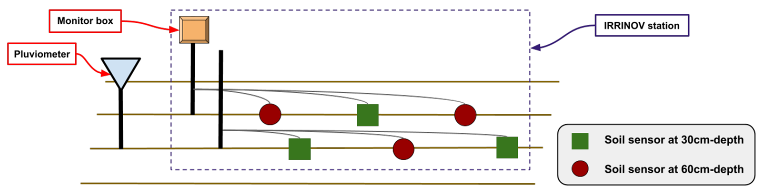

Fig. 2: layout of watermark probes and pluviometer in the maize rows

depth should not be more than 30 cbar. If the difference between probe measurements is above 30 cbar, it means that one of the probes is out of order and the farmer should go in the field to correct the probe installation.

To obtain the voltage in cbar, the value read on the probe should be multiplied by the correction coefficient which is specific for each batch of probes: For example, probes from 2003 have a correction coefficient equal to 1.7.

A difference of 10 to 20 cbar of tension between two probes located at the same depth is considered normal. For this reason, the IRRINOV method proposes to install three probes per level of depth. The IRRINOV guidelines suggest the farmer start an irrigation turn when two probes out of three have reached the threshold value. The value reached by two probes out of three is the one taken into account by the decision method. The abnormal values are not considered. It is worth noting that when the voltage value read from a Watermark probe is 199 cbar; there is a problem of contact between the Watermark probe and the soil.

3.4 Setup about decision tables

The IRRINOV method [3] proposes several decision tables to determine when should start the irrigation depending on soil type and crop growth stage.

The Table 1 determines when to start an irrigation turn for clay-limestone soil. This decision table is applied to maize crop when their growth stage is between V2 and V7.[7] In such table, cells contain the threshold of probes' measurement as mention in section 3.3.

Table 1: Water turn duration for maize growth stage between V2 and V7

	9 to 10 days	6 to 8 days	below 5 days
$Probe30$	30 cbar	50 cbar	60 cbar
$Probe60$	10 cbar	20 cbar	20 cbar
total	40 cbar	70 cbar	80 cbar

[7] V7 is an ID defined in [1], and it is also named "10 leafs" in the Arvalis growth stage classification

Let's define two variables $Probe30$ (and $Probe60$) that represent the value reached by two probes out of three probes at 30 cm depth (and at 60 cm depth).

The first column of a decision table should be read as "If the plot has a water turn duration fixed between 9 and 10 days" and "when two probes at 30 cm depth out of three ($Probe30$) are above the value 30 cbar and when two probes at 60 cm depth out of three ($Probe60$) are above the value 10 cbar" or "when the total ($Probe30 + Probe60$) is above 40 cbar", then an irrigation turn should start. Note that for this particular decision table the two first lines are redundant because the last one due to the fact that if $Probe30 > 30$ and $Probe60 > 10$, then $Probe30 + Probe60 > 40$.

3.5 Automatic Irrigation System

Based on the IRRINOV human-oriented decision method, we would like to implement an adaptive context-aware system for automatic irrigation. The automatic system integrates the IRRINOV guidelines and will be deployed on the AgroTechnoPôle of Irstea. The AgroTechnoPôle contains an experimental farm located at Montoldre where researchers can test their prototypes such as robots, machinery, and wireless sensor network. On this experimental farm, a weather station Davis Pro 2 is available for air and weather measurements. Moreover, a significant number of sensors are deployed in the field to monitor moisture and temperature of the soil.

The data about localization mentioned in section 3.1 should be acquired during the context modeling phase to build the low-level context.

The frequency guidelines expressed in section 3.2 can be used to define the communication and measurement frequencies of the network nodes, which are part of our context-aware system. Note that detection of some rainfall or irrigation events can trigger some measurement actions. Thus the output of the two pluviometers will activate the measurement of the soil moisture nodes.

The guidelines proposed in 3.3 can be translated into rules to validate the data stored during the context acquisition phase.

The decision table presented in section 3.4 could be translated by a set of rules that look like:

If (8 $<$ WaterTurnDuration $<$ 11) and (GrowthStage $<$ V7) and ((Probe30 + Probe60) $>=$ 40), then (Irrigation state is true)

These rules are part of the context processing phase that will deduce from the low-level context the high-level one. Note that the value of GrowthStage is a qualitative value that should be taken from a hierarchical list. Thus a specific function should be defined to evaluate the "$<$" operator.

4 Ontological requirement extraction

The goal of this section is to present ontological requirements of the adaptive context-aware system in the Montoldre use-case. To determine such requirements, we have studied the IRRINOV method to identify its input and output data. We also analyze all the information needed to evaluate the quality of an irrigation process. In addition, several exemplary data gathered from the experimentations in Montoldre are taken into consideration. The following ontological requirements have been extracted:

R1. Deployment: the devices involved in agricultural systems, for example in an irrigation scenario, might be deployed in different ways depending on the station of the agricultural year and the crop rotation due to a three-field system. In this sense, the model needs to include deployment information. This requirement includes two sub-requirements due to the spatiotemporal nature of agricultural deployments:

R1.1. Deployment time: the temporal aspect of deployment needs to be represented.

R1.2. Deployment location: the geographical aspect of a deployment needs to be represented.

R2. Plot: a deployment might involve one or more platforms in which the devices are placed. The description of the plot includes the geometry of the plot, the water turn duration for this plot and the size of the plot.

R3. Network configuration: the sensor network deployed in an agricultural scenario follows a specific network configuration. As a side note, every device connected to other devices of a network and possess a unique address in that network is called a node on the network. In our use case, the connections between sensor nodes and other nodes in the network should be represented. This requirement could be split into four sub-requirements:

R3.1. Network topology: the connections between specific nodes should be represented.

R3.2. Network communication: the communication protocols used between nodes in a network should be described.

R3.3. Node status: the status of a node such as active and inactive, should be represented. This information is essential for example in the sensor data acquisition quality control.

R3.4. Node role: the role of a node such as an end node or a routing node, should be represented.

R3.5. Node location: the precise locations of sensors need to be represented. This requirement is more detailed than R1.2 as in the case of the IRRINOV method, specific guidance about the distance between nodes is provided. In this sense, this requirement refers to the exact location of nodes so that the distance between them could be calculated, rather than generic locations.

R4. Device: specific agricultural oriented devices as well devices used in other domain should be represented. These devices might be further classified as sensor or actuators; however, it is not necessary for all the devices involved in the network to belong to one of these types. The following list of devices corresponds to the Montoldre use case and it does not intend to be exhaustive in the agricultural domain:

– Sensors: Weather station; Tensiometric probe (Watermark); Pluviometer.

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– Actuators: Irrigation gun.
– Sink node: all sensor nodes send data to the sink node.
– Server: corresponds to a local server based on Linux that support part of the DSS.

Taking all this into account, this requirement could be further specified leading to the following sub-requirements:

R4.1. Sensor: sensors should be described.

R4.2. Actuator: actuators should be described.

R4.3. System compondency: compondency relation between devices should be represented.

R4.4. Domain specific devices: agricultural domain oriented devices are needed to be represented, for example, soil moisture sensors, pluviometer or IRRINOV station.

R5. Measurement: the observations made by sensors should be represented in the model including values of the observation, units of measures and time-related information about the observation, for example, when was it observed or to what period does the observation corresponds to. In particular, the following units of measurements need to be represented in the use case at hand: Millimetre (mm), Centibar (cbar), and Watermark unit of measure (the Watermark soil moisture measure ranges from 0 to 200.) which is transformed to cbar. In addition, Celsius degrees (ºC), Decibel-milliwatts (dBm) and Millivolt (mV) are usually needed in a broader scenario for data integration in irrigation systems.

Taking all this into account, this requirement could be further specified to represent use-case specific unit of measurement needed:

R5.1. Domain specific units of measurement: concrete units of measurement are needed for the use case at hand, for example, the Watermark specific units.

R6. Property: specific agricultural oriented properties as well properties also used in other domain should be represented. The following list of properties corresponds to the Montoldre use-case and it does not intend to be exhaustive in the agricultural domain: Soil moisture; Water received during irrigation; Temperature of the soil; Temperature of the air; Ambient humidity; Precipitation; Plant growth stage.

Taking this into account, this requirement could be further specified to represent use case specific properties needed:

R6.1. Domain specific properties: concrete properties to be observed or act upon are needed for the use case at hand, for example, the soil moisture or the water received by the plot during the irrigation activity.

R7. Feature of interest: in most of the cases, when observing a property it is needed to represent the entity for what such property is observed. For example, when measuring temperature, one might distinguish whether it is the temperature of a room or a person. This entity is usually referred to as the feature of interest. Considering IRRINOV method, this requirement could be further specified as follows:

R7.1. Feature of interest depth: in the specific case of IRRINOV method the depth of the plot part being observed is an essential factor. Therefore the specific location of the feature of interest should be taken into account considering not only general location or geographical coordinates but including also the depth. Please note that, according to IRRINOV method, the critical value is about the depth of the soil, not the location of the sensors. While in some scenarios the location of the sensor will coincide with the depth of the soil is observed, it can not be taken for granted that will always be the case, for example, if radar oriented sensors are used.

R8. Action: in the case of the Montoldre use case the action "irrigation" is needed to be represented.

R8.1. Domain specific actions: for the Montoldre use-case, the action "irrigation" is needed to be represented including the parameters such as the time interval during which the action has to be carried out and the quantity of water needed to be released. Note that the IRRINOV method does not provide guidelines on the amount of water that should be spread by the irrigation system.

R9. Crop: in farm irrigation methods, as in particular in the IRRINOV case, the crop growing in the field to be irrigated represent essential information as it affects the method calculations. Moreover, the date when the crops reach a growth stage depends on the type of cultivar of the crop. This information should, therefore, be represented.

5 Ontological requirement analysis

As the number of elements involved in the IoT landscape is constantly growing, new solutions arise to cope with their heterogeneity and to ease interoperability between platforms, ecosystems and devices. In this sense, numerous ontologies have been defined to cover the IoT domain in many ways [8].

While there is a wide range of models for IoT ecosystems and devices description, this work focus on the coverage of the use case at hand by official ontologies proposed by standardization bodies. For this reason, we choose the Semantic Sensor Network Ontology (SOSA/SSN) and the Smart Appliances REFerence ontology (SAREF).

The SSN [4] was proposed by the World Wide Web Consortium (W3C) and has been broadly adopted worldwide. In oder address the omissions of original SSN, the joint W3C and OGC Spatial Data on the Web Working Group has developed a new version of the SSN including a module called SOSA[8] (Sensor, Observation, Sampler and Actuator), among others, providing a new modular version of the SSN[9] ontology. This new version, called SOSA/SSN, extends the SSO Pattern (Stimulus Sensor Observation Pattern), implemented in the previous version, by including classes and properties for actuators and sampling. The

[8] http://www.w3.org/ns/sosa
[9] http://www.w3.org/ns/ssn

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three major components of SOSA are "sensors and observations", "samplings and samples" and "actuators and actuations".

SAREF[10] is a reference ontology for smart appliances that focuses on the smart homes, and provides an important contribution to enable semantic interoperability in the IoT being adopted by European Telecommunication Standardization Institute (ETSI) as a Technical Specification [6]. This ontology provides a core model for IoT that could be extended and adapted in order to cover specific domains. SAREF focus on the representation of appliances and devices together with their functions, commands, services, states and profiles. In addition, in the latest version, the ontology consider the representation of measurements coming from sensors.

In what follows, a coverage analysis of the ontological requirements by the SOSA/SSN (including all modules) and SAREF ontologies is presented providing the mappings between requirements and ontology elements. Then, a discussion about the requirements covered and open issues is drawn.

5.1 Ontological requirement coverage

Table 2 presents the relation between the requirements extracted in Section 4 and the ontology elements defined in SOSA/SSN and SAREF ontologies. In this table, each requirement is represented in a row where the first column from the left identify the requirement itself and the information in the second and third columns represent the coverage by the SOSA/SSN and SAREF ontologies respectively as follows: (a) an empty cell indicates that the requirement is not addressed by the given ontology; (b) if the requirement is covered, then the ontology elements from each ontology are included in the cell using the prefix of the ontology and the identifier of the element (note that these elements might be classes or properties); (c) an integer number between parenthesis identifies side notes about the documentation provided in a given ontology that could be useful for the requirement at hand, regardless whether it is covered or not.

As shown in Table 2, some requirements are not directly addressed by the analyzed ontologies; however, their documentation include guidelines about how to address them. In this sense, regarding R1.2, R3.5 and R7.1, it should be mentioned that SOSA/SSN documentation suggests the use of geoSPARQL [15] to model geographical information (Note (1) in the table). It is worth noting that the correct representation of R3.5 and R7.1 are of particular importance as such information is taken into account during the IRRINOV method calculations, as shown for example, in Figure 2.

Regarding R5, SOSA/SSN documentation proposes to link to the Quantities, Units, Dimensions and Data Types Ontologies (QUDT, [9]), the Ontology of Units of Measure (OM, [16]) or the RDF extension mechanism for UCUM (Unified Code for Units of Measure) datatype [11] (Note (2) in Table 2). For the case of SAREF, the OM ontology is used as a suggestion for covering this aspect (Note (3) in Table 2).

[10] http://w3id.org/saref

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Table 2: Requirement coverage by SOSA/SSN modules and SAREF.

Requirement	SOSA/SSN	SAREF
R1 Deployment	ssn:Deployment	
R1.1 Deployment time		
R1.2 Deployment location	(1)	
R2 Plot	sosa:Platform	
R3 Network configuration		
R3.1 Network topology		
R3.2 Network communication		
R3.3 Node status		saref:State
R3.4 Node role		saref:Task
R3.5 Node location	(1)	
R4 Device	ssn:System	saref:Device
R4.1 Sensor	sosa:Sensor	saref:Sensor
R4.2 Actuator	sosa:Actuator	saref:Actuator
R4.3 System componency	ssn:hasSubSystem	saref:consistsOf
R4.4 Domain specific devices		
R5 Measurement	sosa:Observation (2)	saref:Measurement saref:UnitOfMeasure (3)
R5.1 Domain specific units of measurement		
R6 Property	ssn:Property	saref:Property
R6.1 Domain specific properties		
R7 Feature of interest	sosa:FeatureOfInterest	
R7.1 Feature of interest depth	(1)	
R8 Action	sosa:Procedure	saref:Function saref:Command
R8.1 Domain specific actions		
R9 Crop		

5.2 Discussion and open issues

In the following, the insights extracted from the ontological requirement coverage analysis presented before are detailed. First of all, it should be mentioned that the two analyzed ontologies have been defined as general ontologies covering top-level concepts that should be specialized by other ontologies developed for specific use-cases. In this sense, it is not a criticism about the lack of coverage of requirements R4.4, R5.1, R6.1 and R8.1 as they refer to domain-specific knowledge. However, it is important to define and take such requirements into account to drive the development of extensions or new ontologies for the agricultural use case. More precisely, the requirements provided in this work would represent a valuable input for the development of a SAREF extension for the agricultural domain.

Main observation is that none of the analyzed ontologies allows the description of the network configuration (R3), topology (R3.1) and communication lines (R3.2).

For modelling different deployments (R1) in which devices might be involved the SOSA/SSN ontology provide some coverage considering deployments, platforms as well as system componency. However, while there is a recommendation to represent geographical information linking to other ontologies, it does not address the temporal characteristic of deployments needed to be represented in the agricultural domain. SAREF on its side, do not consider the representation of different deployments. Therefore, we can claim that none of the models fully address the spatial-temporal deployment information (R1.1 and R1.2).

Focusing on the action that a device might carry out (R8), it should be mentioned that each model provides a suggestion to model them. In this sense, SSN approach is more related to algorithms, workflows, etc. including information about the input needed and output generated. SAREF model is oriented to the functionality the devices are designed for including practical information as the commands that could be executed, for example, "open" and "close". However, none of the models represents web oriented information about where this action can be executed, or the data could be retrieved, that is, no one allows the representation of web services or web thing description.

The crop representation (R9) deserves a special mention for this study. While in Table 2 it is indicated that this requirement is not covered by the analyzed ontologies, some clarifications should be done for the SOSA/SSN ontology. In this case, one might argue that this information could be modeled as a characteristic of a feature of interest, where the feature of interest would be the plot being observed. However, it could be also considered that this information is related to the platform that hosts the sensors, that could also be a given plot. Taking all this into account, developers should first decide to which entity is more accurate to attach such information and then, define probably new domain properties to express the possible values of the crop types.

Related to the crop representation, we should mention the need for representing plant growth state (R6.1). This information could change from plant types and from different classifications systems. In this sense, resources for defining controlled vocabularies and mapping between concepts, for example SKOS,[11] should be considered to model this issue.

Regarding open issues for the representation of the Montoldre use case, even though it has not been defined as an ontological requirement, it is worth noting that the SAREF description of `saref:Profile` about `saref:Commodity` could be of interest to represent the water waste or saving achieved by the smart irrigation system. In this case, water would be the `saref:Commodity`.

Finally, another issue to be covered, that could be represented in another level of knowledge representation, for example using rules, is the definition of problems based on measurements. For example, an observation higher than 200 in a watermark sensor is considered an indicator of functioning problems.

6 Related work

There exist several context-aware systems using ontologies for representing data and rules. For example, we can mention the work described in [7] where an ontology supporting precision agriculture applications is presented. This ontology, developed in OWL, intend to model the knowledge needed by a Decision Support System including knowledge about plant characteristics, pant state, environmental parameters, sensor, and actuators

[11] http://www.w3.org/TR/skos-primer

Paper submitted to the 9th International Semantic Sensor Networks Workshop – SSN 2018.
See https://ssn2018.github.io/ for the reviews, if available,
and a link to the final version if this contribution was accepted.

Another application using ontologies in the crop cultivation domain is the approach presented in [12]. The method presented in this work combines a domain ontology and a task ontology. Both are implemented in OWL. The domain ontology represents soil, seed and agricultural machines while the task ontology is about planting processes such as soil selection, seed selection, fertilization, and irrigation. In this regard, we can also mention the ontology presented in [22] for hilly citrus production. In this case, authors present an agricultural ontology specialized in hilly citrus, also it reuses some terms from AOS (Agricultural Ontology Service) ontology. The ontology includes citrus nutrient imbalance modeling, hilly citrus fertilization modeling, and hilly citrus irrigation and drainage modeling.

It is worth noting that the ontologies mentioned in such approaches are unavailable online, or at least the ontologies' locations are not provided in the papers. Therefore, it is impossible to: 1) reused them and 2) check whether in their implementation standard ontologies are reused.

However, the goal of the present study is not to provide an ontology for irrigation context-aware systems nor to review existing ontologies in the agricultural domain. The objective of this work is to analyze standard ontologies in the IoT domain candidate to be reused in a smart irrigation system. In this sense, we can mention the work presented by [13] where ontology alignment between SSN and SAREF ontologies are analyzed, proposed and applied to a specific device description. It is worth noting that such analysis considers the first version of SSN instead of the new ontology SOSA/SSN.

Finally, the new SOSA/SSN and SAREF ontologies have been analyzed in the work presented by [10]. This work presents a set of alignments between the SEAS ontology and the above-mentioned ontologies. In this case, the objective is focused on the adoption of best practices and patterns implemented in the SEAS ontology in SAREF in order to ease its maintenance.

In summary, up to authors' knowledge, there are no reference studies about the use of standard IoT ontologies for the agricultural domain.

7 Conclusions and future work

The main contributions of this paper are: 1) a set of ontological requirements for adaptive context-aware systems in the agricultural domain. The requirements are extracted from the pilot site in Montoldre, and a specific irrigation methodology knows as IRRINOV; and 2) a preliminary analysis of the requirements coverage by two well-known standard ontologies: SOSA/SSN et SAREF. It is the first step for designing an ontology to support the adaptive context-aware system to be developed in Montoldre. This work also represents a valuable contribution for the ongoing extension of SAREF for the agricultural domain (SAREF4AGRI).[12]

As already shown, some requirements are not covered by SOSA/SSN and SAREF, as they are too specific for the domain at hand. It is clear that the two

[12] https://portal.etsi.org/STF/stfs/STFHomePages/STF534

analyzed ontologies are top level and should be specialized for particular cases. The future lines of this work would pass, on the one hand, by specializing the SOSA/SSN ontology in a new ontology, on other hands, by contributing to the SAREF4AGRI extension.

Moreover, there are independent domain requirements not covered by none of the ontologies, for example, the network characteristics. In this case, a search for existing ontologies representing networks should be carried out. If there are no suitable ontologies for this case, we propose to extend SOSA/SSN in the ontology supporting the Montoldre use-case.

In order to build the ontology to cover the Montoldre use-case, it is clear that several ontologies should be combined. Inevitable, there are parts not covered by any of the ontologies and overlapping parts between ontologies. In this sense, it is essential to map data from Montoldre use-case to the SOSA/SSN and SAREF ontologies to assess which one is more suitable for the task at hand. Other ontologies about network and service web should also be considered such as the Web of Things[13] and the oneM2M ontologies.[14].

Finally, it is necessary to form a set of rules-based integrated into the adaptive context-aware system for irrigation in agriculture. This rules-based is a critical element to transforms the IRRINOV human-oriented decision guide into an automatic irrigation system.

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[13] https://www.w3.org/TR/wot-thing-description/#vocabularyDefinitionSection
[14] http://www.onem2m.org/technical/onem2m-ontologies

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