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A Scalable Distributed System for Precision Irrigation

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***Abstract*—The level of adoption of Precision Agriculture (PA) technologies is still very different from one country to another and from one region to another in the same country. A major challenge is to develop PA from a best practice pursued by a minority of enlightened farmers to a widespread practice with sizeable impact on the use of environmental resources. One of the obstacles hindering PA is the lack of quantitative data readily accessible to farmers to guide their daily operations. In this paper, we present the information system developed within project POSITIVE to support and enhance precision irrigation across the whole Emilia-Romagna region. To this purpose, the POSITIVE information system establishes a service transforming satellite and sensor data into biophysical parameters and vegetation indices with full regional coverage. These data are automatically fed into a public irrigation advisory service (Irrinet+) thereby enabling precision irrigation and fertigation on a regional scale. Irrigation maps can be sent as advice to farmers or directly commanded to registered irrigation machines. The architecture of the distributed information system and the open protocols developed to achieve scalability and enable interaction of multiple heterogeneous components are reported in the paper.**

***Index Terms*—precision agriculture, scalable protocols, smart services**

I. Introduction

Precision Agriculture (PA) is a whole-farm management approach using information technology, satellite positioning data, remote sensing and proximal data gathering [1]. Nowadays, PA is both a necessity, for climate and sustainability reasons, and a development opportunity for farmers as well as for the machinery industry. However, the level of adoption of PA technologies is still very different from one country to another and from one region to another. Moreover, PA must develop into a widespread practice in order to provide benefits in terms of use of environmental resources, as mandated by Sustainable Development Goals. In many areas worldwide, including Mediterranean countries and northern Italy, water scarcity has become a recurrent problem, and agriculture is pointed to as the main water-consuming activity.

Leveraging the high resolution of the Copernicus satellites [2] and the diffusion of field sensors, project POSITIVE [3] has two main objectives. The first one is to establish a service that transforms satellite and sensor data into biophysical parameters and vegetation indices, so as to make them available on a regional scale as georeferenced maps to public and private services for management of precision agriculture. The second objective is to enable, on a regional scale, a precision irrigation and fertigation service, based on the Irrinet+ Irrigation Advisory Service [4].

In this paper, we present the information system developed to support water usage optimisation for irrigation efficiency across the whole Emilia-Romagna region as part of the POSITIVE project. For sake of scalability, such a system is distributed and service-oriented (Fig. 1). In particular, we focus on the POSITIVE Server, whose purpose is to collect and process satellite and sensor data, and to orchestrate the precision irrigation and fertigation process by managing farmer's requests and acting on irrigation machines. The POSITIVE Server is conceived to be replicated and further extended (e.g., by commercial players), in order to guarantee effective load distribution and scalability.

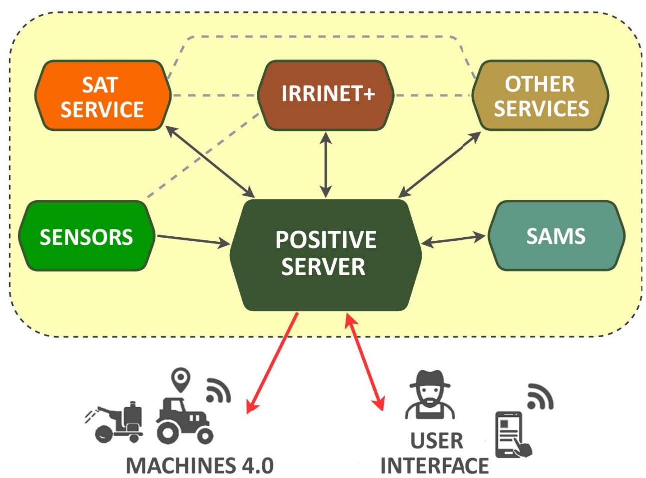

Fig. 1. POSITIVE information system.

The POSITIVE information system enables Scalable Operating Protocols (POSs), i.e., service-oriented precision agriculture procedures based on widely accepted standards, thereby allowing integration of heterogeneous information suppliers (sensor providers, service providers, etc.) and consumers (machinery manufacturers, farmers, public authorities).

The paper is organized as follows. In Section II, we survey related work on software architectures for precision

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agriculture. In Section III, we illustrate the architecture of the POSITIVE Server. In Section IV, we present the main POSs implemented in the project. Finally, in Section V, we summarize the paper and outline future work.

II. Related Work

Precision irrigation, including variable rate irrigation, has been widely studied and demonstrated, on a small scale. In the following, we briefly report on some significant works.

Kim *et al.* [5] designed and instrumented a wireless sensor network and a software for real-time in-field sensing and control of a site-specific precision linear-move irrigation system. The adoption of Bluetooth restricts the applicability of the proposed approach to small cultivated fields.

Most works on variable rate irrigation for precision agriculture investigated the use of fixed sprinklers, while in the paper by Aleotti *et al.* [6] a fully integrated platform was presented for a linear irrigation system. The proposed platform has a distributed architecture that includes a decision support system, a server node, a mobile application for user interaction, and embedded IoT devices that operate linear irrigation machines. Preliminary experiments were reported in tomato fields. Yet the platform was not designed to provide a service on a regional scale.

The SWAMP project [7] developed an IoT-based smart water management platform for precision irrigation in agriculture with a hands-on approach based on four pilots in Brazil and Europe. Experimental results show that the SWAMP platform is able to provide adequate performance for the pilots, but requires specially designed configurations and the re-engineering of some components to provide higher scalability using less computational resources.

Perakis *et al.* [8] designed CYBELE, a platform aspiring to safeguard that the stakeholders involved in the agri-food value chain (research community, SMEs, entrepreneurs, etc.) have integrated, unmediated access to a vast amount of very large scale datasets of diverse types and coming from a variety of sources, and that they are capable of actually generating value and extracting insights out of these data, by providing secure and unmediated access to large-scale High Performance Computing infrastructures. The CYBELE project (funded by the European Commission) started concurrently to POSITIVE. As soon as the CYBELE platform will be available, it will be interesting to test it in conjunction with the POSITIVE Server.

III. POSITIVE Server

The POSITIVE Server is the core of the information system being implemented. Its main activities are to collect and process satellite and sensor data, and to orchestrate precision irrigation and fertigation tasks by managing farmer requests and acting on agriculture machines.

A. Server Architecture

The main functionalities of the POSITIVE Server can be summarized as i) the query of inhomogeneous REST APIs for collecting data, ii) the interpretation, validation and processing of the collected data, iii) the exposition of a REST API for sharing raw and processed data. All these functionalities are supported by a flexible periodic task scheduler and a local database for storing part of the collected and processed data.

The Server architecture is layer-based, with three isolated and interconnected basic logical layers: API Layer, Business Logic Layer and Persistence Layer. Each layer is divided into functional submodules that can be deployed, tested and used independently.

The *API Layer* contains the mechanisms for communicating with the outside world. This layer implements the basic logic to handle input data, in order to route them to the appropriate function, and to handle and translate the output in a consumable format for the client. Among the functional modules of the API Layer, there are: the compress module, which contains the functions to decompress and compress data in file format like gzip; the endpoint check module, which deals with the high-level validity of incoming requests; and the routing module, which associates the endpoints exposed to the right server functions that manage them.

The *Business Logic Layer* is the logical layer in which all the processing functionalities are implemented, encoding the real-world business rules that determine how data can be created, displayed, stored, and changed. Among others, endpoint handlers or server routing modules have been implemented for managing the dialogue with the other services of the POSITIVE information system (Sat Service, Irrinet+, Sensors, and more). Each one is provided with mechanisms for authenticating the clients, checking the input data and formatting the output data, according to specific protocols. More complex processing functions, and also functions common to different sub-functionalities, are carried out within separate modules.

Lastly, the *Persistence Layer* includes the functions to connect with the database and access the data through CRUD operations (Create, Read, Update, Delete), and also the code of the logical models of the entities and the relations contained therein.

The server database is designed to be coherent, functional and extensible. The relational model uses also geometric data types, according to the GIS standards of the Open Geospatial Consortium [9]. The main entities fall into the following categories:

- *Plots*. We identify two main entities called Field and Thesis. The Field entity represents a plot of land, that is a well delimited portion of space, unambiguous and well identifiable. A Field is associated with one user and administrative and geographic information. Instead, a Thesis entity represents a subset of the field to which it belongs, and carries information about its cultivation cycle, such as crop type, soil working or irrigation method. This information characterizes a Thesis for a limited period of time and provides a history of the state of the plot.
- *Sensors*. For each type of Sensor that may be handled by the POSITIVE information system, we identify a different

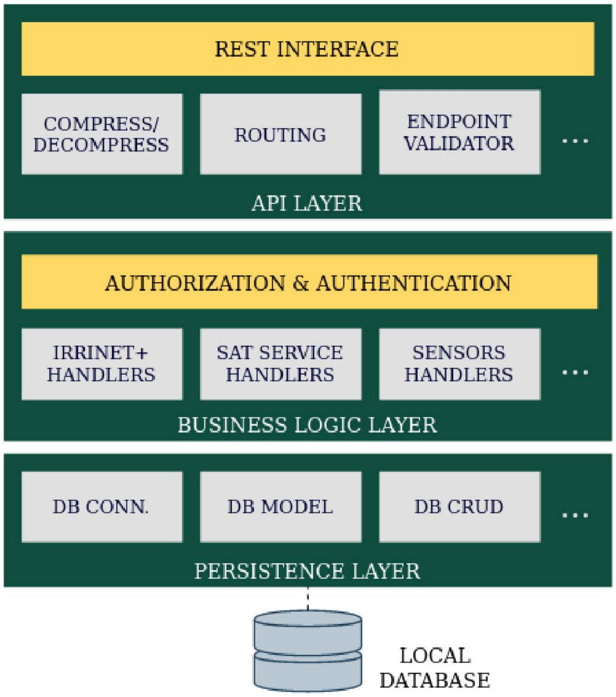

Fig. 2. Logical structure of the POSITIVE Server.

entity. Every sensor is identified by administrative data, like producer and model name. For each sensor data sample, a record is stored into the database. Each sample is also georeferenced by its own region of validity.

- *Remote Sensing*. For each active thesis in the database, the POSITIVE Server collects the most recent satellite data and keeps track of the last n acquisitions. The value of n can vary from thesis to thesis based on various factors, such as the type of terrain, the activities taking place on it, and more.

The POSITIVE Server is developed using the Go multi-paradigm programming language (also known as Golang) [10]. Go has been designed to enable creation of very efficient systems despite their complexity, in multicore and interconnected environments. Since scalability is a central objective of the POSITIVE project, Go is particularly suitable, thanks to its efficient implementation of high performance multiprogramming.

B. Data Flow Management

There are two main data flows within the POSITIVE information system. The first data flow, illustrated by the sequence diagram in Figure 3, is related to direct user interaction with the POSITIVE information system. In this case, the user is the owner of a cultivated plot registered to the Irrinet+ service, and wants to receive an irrigation advice based on the most updated satellite data. The POSITIVE Server may deliver complete information to the user (e.g., sensor data, irrigation advice), either periodically or on-demand.

In this context, on a daily basis the POSITIVE Server interrogates the Sat Service, which exposes REST endpoints, requesting the most recent vegetation data for all the plots registered to the service, extracting the perimeter polygon of each terrain from the database and formatting them correctly. Currently, using the products of the satellite acquisitions of the Sentinel-2 mission, the Sat Service processes and stores vegetation information in a grid of fixed parcels of 10m by 10m, spatially referenced in the UTM coordinate system. The Sat Service receives the polygon and returns a tesselated cover of the portion of land represented by the polygon, where each parcel is associated with the required value of vegetation index, such as the Normalized Difference Vegetation Index (NDVI) [11]. If necessary, the POSITIVE Server can perform conversion between UTM and WGS coordinate systems.

The POSITIVE Server checks whether the received information is updated with respect to the previous one, which depends on the transit of the satellite in favorable weather conditions and on the update frequency that it guarantees. Based on the data acquired from the Sat Service, the POSITIVE Server interacts with the Irrinet+ REST API to upload the vegetation information in its decision model. The POSITIVE server takes care of processing the satellite data (e.g., conversion between coordinate systems, plot contour manipulation and refinement) in order to produce a final representation acceptable and integrable by Irrinet+.

Once the map with vegetation data has been obtained and validated, Irrinet+ proceeds to integrate them into its decision model encompassing multiple factors, such as crop type and development stage, soil information, delivered irrigation, weather information with evapotranspiration assessment, cultivation growth model, other available sensory information. The POSITIVE information system, working alongside with Irrinet+, is therefore able to return for each registered plot an irrigation advice map refined on the basis of vegetation information obtained from satellite imagery. A satellite-based approach is deemed essential to provide enhanced irrigation advice with full coverage of large areas (like the Emilia-Romagna region).

The irrigation advice is expressed through a water volume spatially distributed across the plot in 10m x 10m parcels. The advice can be sent to the farmer, leaving to him/her the responsibility to actuate irrigation, or directly to irrigation machines in Machine-To-Machine fashion, provided that these machines are suitably equipped and have been registered to the service. The POSITIVE Server processes the irrigation map and transforms it into a plan suitable for direct use of connected irrigation Machines 4.0.

The second data flow concerns the collection, processing, and use of any additional sensor data related to the plots registered into the POSITIVE information system. The POSITIVE Server acquires these data, typically on an hourly basis. The acquisition rate can be selected according to the specific features of the considered sensor. Local sensors for terrain and vegetation status are increasingly being used in agriculture (e.g., soil humidity, olfactory sensors, temperature,

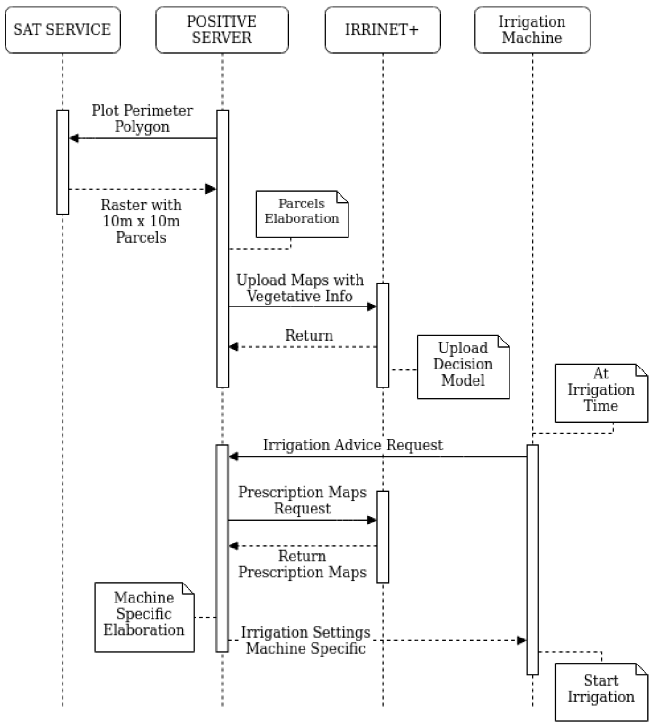

Fig. 3. Sequence Diagram of the data flow producing a machine-specific irrigation recipe.

etc.). These sensors, by definition, only measure local properties (compared with the global satellite coverage), but when available they provide complementary information helping to refine the developmental model of the crop and thus its water needs. Local sensors may be connected to dedicated proprietary servers that expose a simple REST API. In this case, the POSITIVE Server periodically queries those servers, with well-formatted requests that indicate a specific thesis (subplot). The sensor service responds with the sensor data that are collected in the specified portion of plot.

Other local sensors do not have a dedicated server for data collection and aggregation, and rather have limited control units that do not expose endpoints. In this case, the POSITIVE Server exhibits endpoints to enable the transmission of the collected data from all the control units. In both cases, all data are collected in a georeferenced manner and are checked by the POSITIVE Server, in order to ensure data quality.

IV. Scalable Operating Protocols

The purpose of the Scalable Operating Protocols (POSs) is to define an efficient approach for data exchange between service providers and consumers that belong to the precision irrigation ecosystem. The POSs have been defined by taking into account not only the communication needs of each component, but also the demand for scalable communication mechanisms, to cope with Big Data flows.

All POSs share two common features: support for REST state transfer mechanisms and GeoJSON geometry representation. The REST (Representational State Transfer) paradigm [12] is a lightweight alternative to mechanisms like RPC (Remote Procedure Calls) and XML-based services (SOAP, WSDL, etc.), relying on HTTP, i.e., a stateless, client-server, cacheable communications protocol. GeoJSON [13] is a geospatial data interchange format based on JavaScript Object Notation (JSON) and increasingly used to describe georeferenced data. It defines several types of JSON objects (e.g., geometry objects like position, point, multipoint and polygon) and the manner in which they are combined to represent data about geographic features, their properties, and their spatial extents. The POSs enable the different actors of the system to contribute to the irrigation recipe as illustrated in the Sequence Diagram of Figure 3. The main POSs developed in POSITIVE are described next.

A. Sat Service Interaction

The Sat Service stores and provides the observations acquired by the satellite sensors covering the territory of Regione Emilia-Romagna. Novel data are collected approximately with periodicity of 5 days according to the satellite orbit. The area monitored by the satellite is partitioned into 10×10 m^2 (let $\Delta s = 10$ m be the satellite resolution) square cells $\mathcal{C}_i$ described by UTM32 or WSG84 coordinates. The raw data are processed in order to compute several vegetation indices $I_1, \ldots, I_k$, like NDVI for every cell (call $I_j(\mathcal{C}_i)$ the value of vegetation index j in cell $\mathcal{C}_i$). The number of indices and the portion of monitored cells are carefully selected based on actual farmers' requests, due to the induced large storage requirements.

The POSITIVE Server sends a message to the Sat Service to receive the data related to a polygonal area with contour $\mathcal{F}$ representing the field. The query is in the form of GeoJSON feature with geometry *polygon* and with the coordinate type in the property. The response message adopts the RasterJSON format storing the required indices $I_1, \ldots, I_k$ on the minimum grid containing the polygon $\mathcal{F}$. The choice of raster format allows more compact representation of the dense map.

B. Field Sensors Interaction

In precision agriculture, a wide range of sensors and network protocols are used. In POSITIVE, we put a major effort in defining simple message formats and service APIs, rather than hardcoding sensor stubs into the server. Our design activity has been supported by different sensor providers.

Field sensors acquire local measurements about the irrigation state of fields which supplement large-scale satellite data. For example, gamma-ray spectrometers [14] measure the concentration of sodium iodide in the field and, thus, assess the hydration of plants. Sensors are often collected in a control unit equipped with embedded computers connected to a remote server, e.g., through the 4G cellular network. The acquisition rate is typically quite higher than for satellite data, and significant changes can be observed with hourly monitoring.

A specific POS has been designed to collect these data, when such sensors are available in a field. The POSITIVE Server connects to a registered sensor server to request (by means of a REST API) the data collected by the sensors that lie inside a specific polygon. The request message is in GeoJSON format. The response message is another GeoJSON containing all the most recent measurements, each one characterized by a timestamp and a sensor identifier.

C. In Vivo Sensors Interaction

An in vivo biosensor [15], [16] monitors the water need of a plant by means of transducers in contact to or inserted into the plant itself. Such devices are more invasive, but allow continuous and accurate monitoring of the irrigation needs, as well as of other biophysical parameters, via one or few sample plants representative of the whole crop. These sensors are suitable to check the correlation between the hydration status and other indirect parameters like the vegetation indices or spectral measurements. In POSITIVE, the data provided by in vivo sensors are delivered according to a specific POS. The in vivo sensors are connected to a control unit that periodically delivers to the POSITIVE Server a measurement notification message in GeoJSON format, where the geometry field refers to the respective thesis. Further measurements provided by the same control unit, using conventional sensors, are related to the temperature, humidity and luminosity of environment.

D. Irrinet+ Interaction

The goal of the communication between POSITIVE Server and Irrinet+ is to produce the irrigation prescription for a given field in a specific time. Each field $\mathcal{F}$ has been previously registered in Irrinet+ with its geographic description and information about the cultivation. Each field is associated to an Irrinet+ user and account (*userIF*). In order to compute a new irrigation prescription, Irrinet+ requires the data retrieved from Sat Service as previously illustrated. In particular, the POSITIVE Server retrieves the vegetation indices $I_1, \ldots, I_k$ for every grid cell intersecting the field, i.e., the $\mathcal{C}_i$ s.t. $\mathcal{C}_i \cap \mathcal{F} \neq \emptyset$.

POSITIVE Server sends to Irrinet+ the vegetation indices map in GeoJSON format, where the contour of each cell $\mathcal{C}_i$ is defined by a polygon type and the corresponding indices are the attributes. This operation is performed every time new satellite data are available.

POSITIVE Server requests an irrigation prescription to Irrinet+ based on the loaded map, on demand from the end user or according to the irrigation calendar set by Irrinet+. The response of Irrinet+ is the irrigation prescription defined as a map associating each $\mathcal{C}_i$ to the suggested water setpoint $W(\mathcal{C}_i)$. The response message also adopts the GeoJSON format.

The third message exchange between POSITIVE Server and Irrinet+ occurs after the irrigation. The POSITIVE Server receives from the irrigation machine the water level actually supplied to each portion of the field and delivers such data to Irrinet+. Even though Irrinet+ only requires the total amount of water supplied to the field for modeling purposes, a trace of the actual variable rate delivered irrigation is useful for detailed crop productivity analysis.

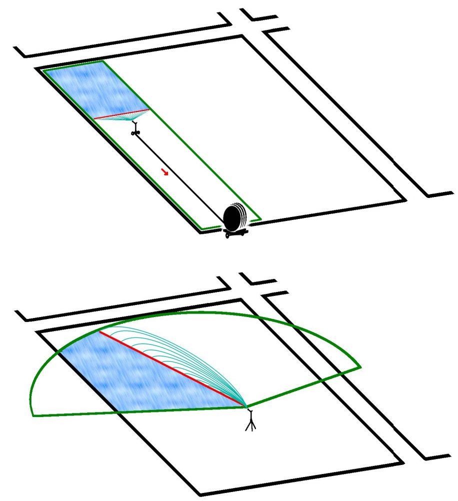

Fig. 4. Schema illustrating the linear (top) and central pivot (bottom) irrigation machines and the respective partition of the fields into strips and angular sectors.

E. Agricultural Machinery Interaction

The POS for agricultural machinery provides the irrigation prescription that a specific machine should apply on a specific field. The POS supports variable-rate irrigation, at the resolution of the satellite service, even though available moving irrigation machines support a coarser resolution or must be programmed with a fixed water amount. This POS therefore takes care of adapting the irrigation map to the actual capabilities of the available machine, whose characteristics have been previously registered in Irrinet+ alongside with the type of crop they are associated with.

The actors of this communication are the Irrigation Machine, who is the initiator of the communication, and the POSITIVE Server. The POSITIVE Server interacts with the other actors of the system, namely the previously described Sat Service and Irrinet+. The Irrigation Machine initial message provides the information about the machine type, the partition of the field to be irrigated and other irrigation parameters. This initial partition is generated based on the requirements of the final user and the way the machine operates in the field, but it can be refined up to the best supported resolution.

Currently, two machine types are defined by the proposed protocol: the linear irrigation machine and the center pivot, both shown in Figure 4. The machine type establishes the geometry of the field partition. Linear irrigation machines (moving sprinkling bars) distribute water by moving forward or backward a nozzle cart or water ranger, which are pulled and fed by a pump through a rolling pipe. The field is split into approximately rectangular strips, whose width depends on the maximum range of the nozzle or the ranger size. Center pivot machines provide water on circular areas by rotating a ranger around a fixed pivot.

The Irrigation Machine requests the POSITIVE Server to receive an irrigation prescription by providing the machine type, the data to access the Irrinet+ account of the user, the time and date and the geometry of the field partition in GeoJSON format. The geometry is *multipolygon* for linear irrigation machine and *point* with radius attribute for central pivot. The raw partition of field $\mathcal{F}$ into functional subfields $\mathcal{F}_1, \ldots, \mathcal{F}_f$ given by the user is due only to functional features of the machine. A linear irrigation machine covers rectangular strips $\mathcal{F}_i$ while pulling the nozzle. The width of the strip depends on the watering range of the nozzle whereas the length depends on the field. The central pivot machine divides the field into circular sectors $\mathcal{F}_i$. To achieve variable-rate irrigation (an enhanced form of precision irrigation), the irrigation prescription is provided for smaller sectors than the functional sectors described before. However, each machine has an achievable *minimum resolution*, a length Δl for linear machines or angular $\Delta\alpha$ for central pivot ones. Realistic values (in current advanced irrigation equipment) are $\Delta l = 50\ m$ and $\Delta\alpha \simeq 10°$. Thus, the Irrigation Machine provides this value (Δl or $\Delta\alpha$) in the request message.

The POSITIVE Server forwards the request of a new irrigation prescription to Irrinet+. Irrinet+ returns a prescription map $I_1(\mathcal{C}_i), \ldots, I_k(\mathcal{C}_i)$ at satellite map resolution Δs, which is usually less than the minimum resolution Δl. Moreover, the grid $\{\mathcal{C}_i\}$ has arbitrary orientation w.r.t. to the polygonal edges of each subfields. Thus, the POSITIVE Server splits each subfield $\mathcal{F}_j$ into smaller cells $\mathcal{F}_j^{(1)}, \ldots, \mathcal{F}_j^{(g)}$ each of minimum length Δl. Then, it computes the prescribed water $W(\mathcal{F}_j^{(u)})$ by interpolating the water prescriptions $W(\mathcal{C}_m)$ of intersecting cells $\mathcal{C}_m$ s.t. $\mathcal{C}_m \cap \mathcal{F}_j^{(u)} \neq \emptyset$. The prescription map on the adapted partition is sent to the Irrigation Machine.

Once the irrigation has been performed, the Irrigation Machine sends a message with the effective water level distributed in the field. Such information is forwarded to Irrinet+ as illustrated in section IV-D.

V. Conclusion

As irrigation in agriculture accounts for more than 50% of actual water usage, a more savvy use of this resource in agriculture is due in view of the Sustainable Development Goals. Indeed, in the last decade Emilia-Romagna has experienced multiple water shortages affecting its valuable agrifood produces. Optimizing water use in agriculture is no longer an option but a necessity.

In this paper, we have presented a distributed information system, developed in the frame of project POSITIVE, leveraging upon a number of available best practices and tools to enable precision irrigation: a satellite data processing service for region-scale computation of vegetation indices and biophysical parameters, an advanced irrigation advisory service reaching a large number of farmers, providers of sensor systems for agriculture, irrigation equipment manufacturers ready to innovate their products as soon as the market will be ready to buy them. Based on state-of-the-art distributed systems engineering practices, POSITIVE provides scalable operational protocols to reach each component of the irrigation eco-system. All defined protocols are public and open, thereby enabling additional data producers and consumers to contribute and improve precision irrigation practice. Ongoing work is concerned with expanding the range of irrigation equipment supported by POSITIVE protocols and conducting extensive experimentation in several farms of the region.

Acknowledgment

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References

[1] Directorate-General for Internal Policies, "Precision Agriculture: an Opportunity for EU Farmers," European Commission, Tech. Rep., 2014.

[2] European Union, "Copernicus: European Union's Earth Observation Programme." [Online]. Available: https://www.copernicus.eu/en

[3] POSITIVE Consortium, "POSITIVE: Scalable Operating Protocols for Precision Agriculture." [Online]. Available: https://www.progettopositive.it

[4] P. Mannini, R. Genovesi, and T. Letterio, "IRRINET: Large Scale DSS Application for On-farm Irrigation Scheduling," *Procedia Environmental Sciences*, vol. 19, pp. 823–829, 2013.

[5] Y. Kim, R. G. Evans, and W. M. Iversen, "Remote sensing and control of an irrigation system using a distributed wireless sensor network," *IEEE Trans. Instr. Measurement*, vol. 57, no. 7, pp. 1379–1387, 2008.

[6] J. Aleotti, M. Amoretti, A. Nicoli, and S. Caselli, "A smart precision-agriculture platform for linear irrigation systems," in *2018 26th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, 2018, pp. 1–6.

[7] C. Kamienski, J.-P. Soininen, M. Taumberger, R. Dantas, A. Toscano, T. Salmon Cinotti, R. Filev Maia, and A. Torre Neto, "Smart water management platform: Iot-based precision irrigation for agriculture," *Sensors*, vol. 19, no. 2, pp. 276–296, 2019.

[8] K. Perakis, F. Lampathaki, K. Nikas, Y. Georgiou, O. Marko, and J. Maselyne, "CYBELE – Fostering precision agriculture & livestock farming through secure access to large-scale HPC enabled virtual industrial experimentation environments fostering scalable big data analytics," *Computer Networks*, vol. 168, no. 107035, 2020.

[9] Open Geospatial Consortium, "The GIS Standards," Web Site. [Online]. Available: https://www.gistandards.eu/gis-standards/

[10] Google, "The Go Programming Language," Web Site. [Online]. Available: https://golang.org/

[11] F. J. Kriegler, W. A. Malila, R. F. Nalepka, and W. Richardson, "Preprocessing Transformations and Their Effects on Multispectral Recognition," in *Remote Sensing of Environment, VI*, Jan. 1969, p. 97.

[12] R. T. Fielding and R. N. Taylor, "Principled design of the modern web architecture," *ACM Trans. Internet Technol.*, vol. 2, no. 2, pp. 115–150, 2002.

[13] H. Butler and M. Daly and A. Doyle and S. Gillies and S. Hagen and T. Schaub, "The GeoJSON Format," RFC 7946. [Online]. Available: https://tools.ietf.org/html/rfc7946

[14] B. Fabbri, M. Valt, C. Parretta, S. Gherardi, A. Gaiardo, C. Malagù, F. Mantovani, V. Strati, and V. Guidi, "Correlation of gaseous emissions to water stress in tomato and maize crops: From field to laboratory and back," *Sensors and Actuators B: Chemical*, vol. 303, p. 127227, 2020.

[15] N. Coppedè, M. Janni, B. M., C. Maida, F. Gentile, M. Villani, R. Ruotolo, S. Iannotta, N. Marmiroli, M. Marmiroli, and A. Zappettini, "An in vivo biosensing, biomimetic electrochemical transistor with applications in plant science and precision farming," *Scientific Reports*, vol. 7, 2017.

[16] F. Vurro, M. Janni, N. Coppedè, F. Gentile, R. Manfredi, B. M., and A. Zappettini, "Development of an In Vivo Sensor to Monitor the Effects of Vapour Pressure Deficit (VPD) Changes to Improve Water Productivity in Agriculture," *Sensors*, vol. 19, pp. 46–67, 2019.