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RESEARCH ARTICLE

An IoT Platform for Data Management in an Industrial-Scale Microalgae Cultivation Plant

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ABSTRACT Microalgae biomass production technology is in continuous progress. One of the challenges deals with scaling up existing medium-scale facilities to industrial-scale production systems. This new expanding infrastructure requires adequate data management and data accessibility tools for all the process variables. In this sense, this work presents a novel solution for microalgae production systems based on Internet of Things (IoT) technology as an important ally in the digitalization of these industrial processes. The paper summarizes the development of an IoT-based platform for data management in a large-scale microalgae cultivation plant with more than 12 industrial photobioreactors. A cloud-based architecture is provided for a solution for data management and a graphical front-end for data access (real-time and historical data). Different profiles can be managed for technicians and researchers depending on their skills and needs.

INDEX TERMS Cloud, data management, IoT, microalgae, photobioreactor.

I. INTRODUCTION

IN last years, the biomass production from microalgae cultivation has been in continuous expansion. Many benefits and products can be obtained from this crop, such as food manufacturing with a high nutritional value for humans [1], [2], or animal feed manufacturing [3], [4]. Microalgae cultivation and biomass generation is opening the doors to researchers and companies to new research and business topics, such as energy generation using biofuels [5], [6], the use of pigments used for cosmetics in pharmaceutical industry and biomedicine [7], [8], or fertilizer manufacturing for agricultural industry [9], [10]. Besides, during the growth of microalgae cultivation, carbon dioxide is absorbed, which contributes to the reduction of the carbon footprint, and also allows the filtration and purification of wastewater [11], [12]. This issue is very interesting and in continuous evolution given the current problems related with climate change and the scarcity of resources around the world.

However, despite these advantages, the sector is not very technologically advanced, which entails a challenge in the improvement of microalgae production. Due to distribution and production complexity, legacy traditional systems are based on Machine to Machine (M2M) wired sensors and spreadsheets, making harder to obtain the optimal monitoring needs of real plants. For optimal microalgae growth, it is necessary to control a set of variables such as temperature, pH, and dissolved oxygen [13], [14], [15], and thus, robust and accurate monitoring and database systems are required for that purpose.

Therefore, the use of emerging technologies such as cloud computing [16], [17], fog computing [18], [19], Mobile-Edge Computing [20], big data [21], [22] and especially the IoT [23] can contribute to improve technology of this sector [24]. In existing proposals, examples about the application of these technologies to other sectors can be found, such as in greenhouse crop production systems [25], [26], water resources management [27], [28], the environmental impact in the production of vehicles [29], [30], monitor the generation of food waste and the use of energy and water in the food sector [31], [32] or intelligent healthcare [33], [34]. Another

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works are focused on monitoring and data management processes, ranging from deep learning-assisted intelligent process planning to real-time production logistics based on the Internet of Things [35], [36], [37]. These works highlight the need for network connectivity for all plant floor devices, how real-time monitoring and process planning facilitate continuous monitoring, how smart sensors aid production planning and scheduling, and how autonomous data collection and integrated patterns can decrease procrastination in decision-making and the implementation of sustainable wireless Industry 4.0. Another example can be found in the security field, with the Trust2Vec [38] system. It is a system which proposes a Transport Management System (TMS) for large-scale IoT systems, which is able to can manage trust relationships in IoT systems and can mitigate trust attacks that are performed by hundreds of malicious devices.

In those works, IoT and cloud computing solutions are developed for data integration and optimization of the industrial sector. However, in this context, only a few works related with microalgae production are available. The study presented by [39] makes a survey describing the state-of-the-art of IoT technologies and their advances in microalgae cultivation. Conclusions of this study are focused on the benefits it brings to the sector, such as: a more ecological, intelligent, automatic and low-cost technical method to achieve the corresponding production purposes. In [40], the construction of a photobioreactor in a simulator and the application of IoT with low-cost Arduino-based sensors are presented. A survey is presented in [41], which aims to evaluate each phase of IoT and machine learning implementation in microalgae smart farming given the limited studies of IoT use in this sector. However, no relevant research has been found on the application of IoT solutions and cloud-based architectures to large-scale microalgae production systems, as it is the case of the solution proposed in this work.

In the problem presented in this paper, a number of challenges arise, such as the interconnection of sensors and actuators, data processing, the development of an IoT platform in the cloud that allows the scalability of sensors and the integration of heterogeneous data from other commercial services, or the use of REST services in an easy way. Moreover, a standard data model is needed to publish the data in open access for researchers and companies, as well as the support for different communication protocols.

Then, the main objective of this work is to contribute to the digitalization of the industrial sector by developing a cloud-based IoT solution for monitoring and data management of a microalgae-based production plant. This solution tries to improve the accessibility to the data generated by the system through the services available in the platform described in this work. The following are the key points of the contribution:

- A cloud architecture has been developed (divided on layers based on the functionality of each service), a standard data model based on FIWARE [42] has been used that allows the integration of new sensors and actuators in a simple way, and a standard communication protocol based on OPC UA integrated. Real-time weather forecasts are also provided. In addition, real-time and historical data is available for each photobioreactor in the system.
- Services are exposed to users through a REST API allowing companies and researchers to get any kind of data generated on the system and develop customized dashboards through different web interfaces. It is important to highlight that the proposed platform offers a default web graphical user interface based on the REST API.
- The IoT platform and cloud architecture developed in this work has been tested in a real biomass production plant located in Almería called SABANA.

Notice that most of the current agro-industrial production systems do not have smart sensors capable of sending data to the cloud. Typically, traditional wired sensors are used, introducing a cost of plant transformation to use IoT. For this reason, this proposal allows the integration of both IoT smart sensors and traditional wired sensors, making easier any plant can be integrated to the proposed system architecture. It is important to remark that the current proposal of this work is focused on the integration of heterogeneous data from different sources, not on the comparison and production performance with traditional microalgae cultivation systems.

This paper is organized as follows. Section 2 details the relevance of FIWARE and the SABANA plant used for the development of the work. The proposed architecture is introduced in Section 3. Section 4 describes the services available within the cloud-based architecture. Section 5 shows examples of how services work either in graphical or in JSON format. Finally, section 6 discusses the conclusions.

II. MATERIALS AND METHODS

This section presents the FIWARE platform and the facilities where this work has been developed.

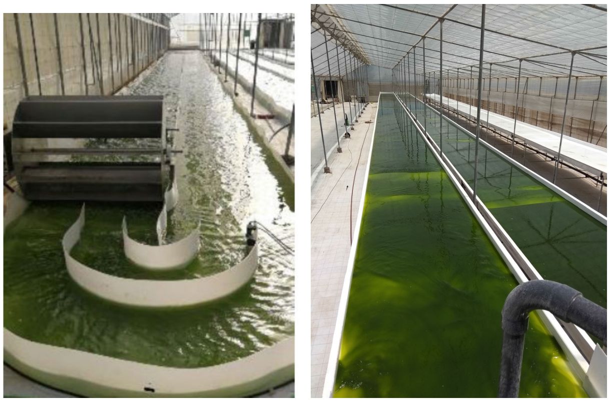
A. FIWARE

The European Union is promoting the use of IoT platforms that can help to improve efficiency and sustainability. In this context, FIWARE [42] is an open source framework funded through a European PPP (Public Private Partnership) project in which the public and private sectors collaborate to create the Internet of the future. FIWARE is based on a modular architecture, which is supported by a set of GEs (Generic Enablers) that provide a series of functionalities and standards that make easier the development of smart applications. FIWARE components may be integrated with other components developed by third parties, thus allowing to accelerate the use of smart solutions. These GEs makes easier to interface with IoT systems, context data, API management, as well as information processing and analysis. The core of FIWARE is the GE known as Orion Context Broker (OCB), which deals with managing all the context information produced by the system. In FIWARE, the term context is the name given to all the information about an ecosystem. Context is about entities and their attributes and can be found in sensor networks, third party applications, public data sources, actuators, and so on. Below, the most relevant GEs in the FIWARE ecosystem are introduced:

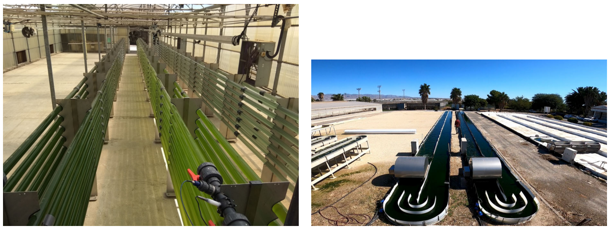
- OCB (Orion Context Broker): It is the core and a required component to be used on any FIWARE based solution. It deals with the management of context information generated by the system in a decentralized and scalable way. A special feature of OCB to be considered is that historical data is not stored. Such a functionality is carried out by other enablers.
- Cygnus: This component deals with the storage of historic data.
- STH Comet: This GE stores historic data in short periods of time, usually in months.
- IoT Agents: This component plays a key role translating the context information into the FIWARE NGSI standard [43]. It is an element that lies between the information generator layer and OCB. It allows the following protocols: LWM2M over CoaP, JSON or UltraLight over HTTP / MQTT or OPC UA. In addition, it offers the possibility of designing your own agent, thus adapting it to the needs of each user.
- Cosmos: This GE allows to process a large volume of data by integrating with current Big data platforms.
- Wilma: It acts as a security layer offering proxy functionality based on OAuth2 schemes.
- Perseus: This GE allows to generate a series of alarms, making subscriptions to the OCB entities notifying changes using SMS, Email, or HTTP notifications.

B. SABANA FACILITIES

This subsection describes the facilities related to the "Sustainable Algae Biorefinery for Agriculture and Aquaculture" (SABANA) project and the processes carried out in the plant, as well as the main elements involved in these processes. The SABANA project has been developed within the framework of the research and innovation program of the European Union "Horizon 2020" and under the "Blue Growth" call, which aims to recognize the importance of the seas and oceans to boost the European economy for its great potential for innovation and growth [44]. This project is led by the University of Almeria (UAL) within the Marine Microalgae Biotechnology Group (BIO-173). The Automation, Robotics and Mechatronics Group (TEP-197) is collaborating in the automation and data integration tasks. This project aims to produce biostimulants, biopesticides, feed additives and biofertilizers, mainly using seawater and nutrients from wastewater in a microalgae biorefinery plant. Another objective is to create an online data center available to different research groups to get access to the data generated on the plant for research purposes (such as validation of techniques, modelling and simulation, and so on). Thus, after the development of this project, current facilities are known under the name of SABANA, and this is also the name used through this manuscript to make reference to the platform and data services presented in this work.



(a) Raceway Photobioreactor (b) Thin-layer Photobioreactor



(c) Tubular Photobioreactor (d) External Raceway Photobioreactors

FIGURE 1. **SABANA Facilities.**

The facility used in this project is located in the agricultural research and training center IFAPA (Instituto de Investigación y Formación Agraria y Pesquera Andaluz) located in La Cañada, Almería, Spain. It has approximately 5000 m^2 where the microalgae cultivation, nutrient storage and water supply services are located.

A SCADA (Supervisory Control And Data Acquisition) system is available to monitor and control the plant. The plant consists of 13 photobioreactors distributed in two greenhouses and a plot. Photobioreactors are the place where the cultivation of microalgae process is carried out. They allow the control of parameters related with the microalgae growth. Depending on the cultivation stage, different kinds of photobioreactors are used (see Figures 1(a), 1(b), 1(c), and 1(d)). For the cultivation of microalgae a control process manages the pH, dissolved oxygen and temperature levels of the medium. So, sensors are required to measure them in each photobioreactor [13], [45]. The control of the above parameters is performed by injecting air and carbon dioxide through all-or-none valves. In addition, a forced flow during cultivation by means of pumps and agitators with impellers is carried out, whose movements are controlled by frequency converters. The control loops of the sprinkler system and forced flow system will take into account the atmospheric conditions that have a significant effect on the growth of the crop. So, there is also a weather station available to obtain data on solar radiation, outside temperature, outside humidity, wind direction and wind speed [46].

The SCADA software includes an OPC UA client [47]. The system communicates with the data acquisition cards installed in the plant via Modbus TCP/IP protocol. In addition, this system is remotely supervised by a group of technicians through a customizable dashboard.

III. CLOUD ARCHITECTURE

This section describes the architecture proposed in the work. This architecture tries to solve the problems of interoperability between devices, services for data extraction, and to provide a correct management of the life cycle of a plant for microalgae cultivation. Figure 2 shows the different layers of the proposed architecture: Perception layer, Storage and Data Processing layer, and Services and Applications layer. In addition to the different functionalities available to the user, layered architecture makes easier integration issues and system scalability when new photobioreactors and sensors are added.

The proposed architecture consists of a set of services and microservices depending on their functionality. Each of them is deployed as an independent Docker container. This allows to have an extra layer of security, since each service is isolated and segregated in an independent container. The advantage of having the services divided into containers is to have modularity in each of them, what allows the development of new functionalities reducing complexity, providing scalability, and without affecting the global functionality of the whole application. In addition, this solution contributes to the increase and distribution of replicas in case of an increasing demand of services. In this work, it was decided to have horizontal scalability based on Docker microservices. Therefore, each component can be scaled according to the bottleneck that arises, being this the key to scaling SABANA Data Services up. In the subsequent sections, the different architecture layers are described.

A. PERCEPTION LAYER

Located at the bottom of Figure 2, it is the sensory layer of the IoT where "things" identify their environment, collect data from the physical world and interact with it. In this layer, the context information corresponding to FIWARE is generated. This term refers to all the data generated by the sensors and actuators in the environment and surrounding the IoT system ecosystem.

Sensors and actuators are scattered throughout the plant. Some of these sensors are located inside the photobioreactors allowing a correct supervision and control of the plant. There are approximately 60 variables between sensors and actuators to monitor in the plant and an external weather station. In Figure 2, the different elements in this layer can be observed: photobioreactors, sensors, actuators, PLCs and data acquisition cards, and local SCADA systems:

- Sensors and actuators: Photobioreactors are equipped with sensors and actuators to allow monitoring the state of the crop. Sensor data such as temperature, dissolved oxygen and pH are controlled for each of the photobioreactors. In addition, other sensors and actuators, such as paddle wheel, medium pumps, injection pumps, harvesting pumps, solenoid valves, CO_2 injected flow rate, air flow rate, medium inlet flow rate, medium outlet flow rate and frequency variators are also present. Moreover, there is a weather station located outside the plant that allows monitoring parameters such as temperature, global radiation, PAR radiation, relative humidity, rain detector, wind speed and direction. These sensors and actuators are connected to LabJack UE9 data acquisition cards. Labjack UE9 devices are remote units that allow communication between the different devices installed in the plant. It is a device designed to work in industrial environments due to its robust construction. It also allows communication based on the open Modbus TCP/IP protocol. These sensors and actuators are connected through this protocol to a computer located in the facilities. Finally, the plant also includes smart sensors, which communicate directly with the upper layer without using acquisition cards.
- SCADA System: The plant is controlled by an Azeotech DAQFactory industrial SCADA system. This SCADA acts as an OPC UA client, which allows a wide connection with a large amount of devices that support this standard. This system may provide to the technical user with real time information, alarm systems when variables are out of range, and control operations on the photobioreactors.

The Perception layer allows to scale up the number of photobioreactors and systems horizontally. That is, it allows to add as many photobioreactors or sensors as needed. Another advantage of using this architecture is the proximity to the devices where data is generated, access to local devices, reduced latency, improved speed when acquiring information from other devices and bandwidth savings.

B. STORAGE AND DATA PROCESSING LAYER

Layer 1, located in the middle area of the architecture (see Figure 2) deals with processing data generated in Layer 0 (Perception layer). In this layer, the tasks are related with the processes of Data extraction, Transformation/filtering and Load (ETL) processes, FIWARE components, protocol language translators, OPC UA server and the different databases:

- Orion Context Broker: This FIWARE GE is the core of the architecture. It is in charge of managing data generated by sensors in Layer 0 or Perception Layer. OCB uses the OMA NGSI standard [48]. The NGSI data model consists of entities, attributes and metadata. In our project, entities are photobioreactors, the weather station and some actuator assemblies such as injection pumps, medium pumps, irrigation headwater or wheel blades among others. Table 1 shows entities created in OCB. In addition, OCB also manages sensor and actuator attributes as data type, its value and metadata.

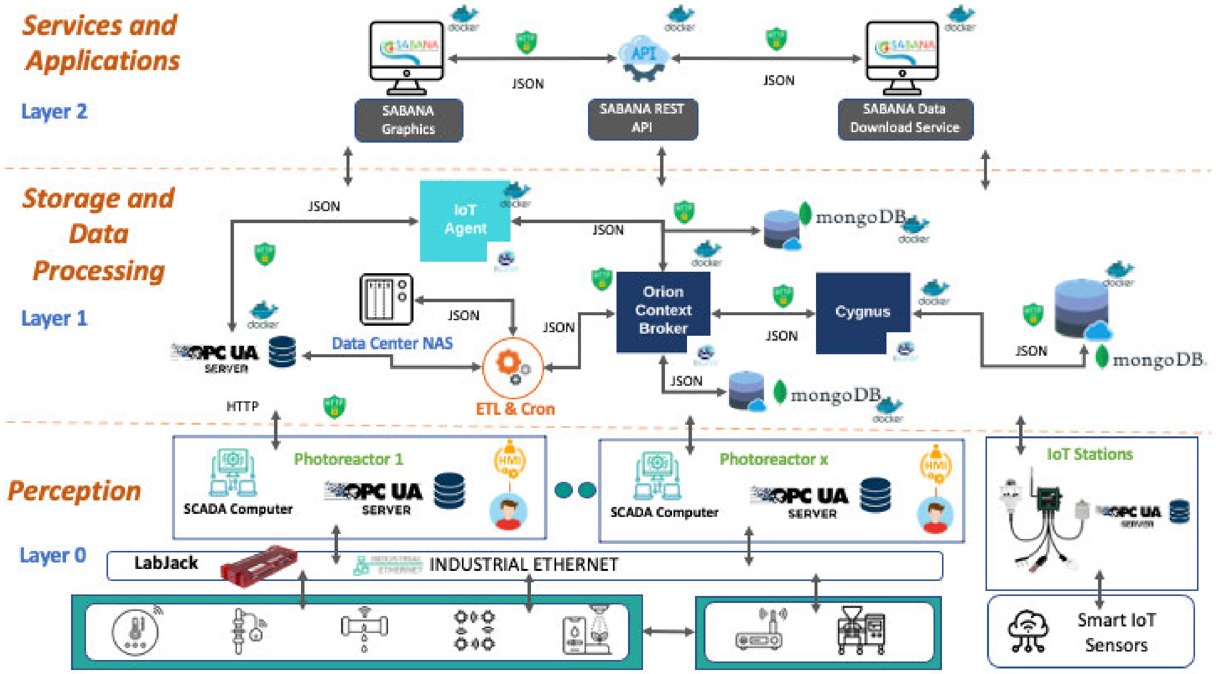


FIGURE 2. SABANA IoT cloud architecture. Division of system layers, workflow, communication protocols and services.

Entities and attributes are not generated from OCB because the OPC UA agent does this work. A special feature of OCB is that it does not store historical data. OCB only stores the last sensor status. Therefore, when a new value is sent, new value overwrites the old one. if historical data must be stored, another GE (Cygnus) must be used. OCB allows subscriptions to a REST API service. Notifications will be sent to subscribers when values are modified. Besides, subscription address must be provided to OCB. Once the subscribed attribute is modified, data will be sent to Cygnus endpoint automatically. OCB provides many sorts of subscriptions for each entity, making a complete mapping of all the data, which allows to add sensors later, and these will be automatically stored in the system. OCB has its own MongoDB database to store entities and their values.

- Cygnus: This GE of FIWARE is in charge of storing historical data of the plant. For storage, Cygnus allows different databases such as PostgreSQL, MongoDB [49], Hadoop [50], among others. In our proposal, Cygnus stores data in a MongoDB database. Cygnus uses the Orion subscription/notification functions. On behalf of Cygnus, a subscription is made to Orion with a detailed description of the attributes for which a notification is desired when any of the entity properties are updated. Cygnus allows to configure different parameters related to the storage format such as the data type or the data model. If row configuration is used, data is stored in the native OCB format. Regarding the data model, Cygnus allows to choose between creating tables by entity, by service-path and by entity type. It was decided to store it by service-path in a single table of the database, where sensor data is stored since in OCB they share the root service-path called SABANA.
- OPC UA: It is one of the main elements of this architecture. OPC UA is the evolution of the classic OPC, but supporting new technologies, such as IoT. In our proposal, OPC UA acts as a data server, where data generated by devices are stored. Each photobioreactor are attached to an OPC UA server and provides photobioreactor sensor data. The SCADA system acts as a client of OPC UA server to display information to users.

TABLE 1. Entities used in OCB.

Entities	Attributes	Metadata
RW1	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
RW2	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
RW3	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
RW4	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TL1	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TL2	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TL3	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
COL1	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
COL2	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
COL3	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TUB1	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TUB1	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TUB2	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
TUB2	pH, CO_2, temp, dissox, solvalves,...	id, timestamp
MediumPumps	pump1, pump2	id, timestamp
InjectionPumps	pump1, pump2,...pump8	id, timestamp
HarvestingPumps	pump1, pump2	id, timestamp
PaddleWheels	paddle1, paddle2, paddle3, paddle4	id, timestamp
IrrigationHeader	water, nutrients,...	id, timestamp
WeatgerStation	hum, temp, rad-par/global, CO_2, wind	id, timestamp

Having each photobioreactor in an independent node allows a better management when sensors have to be added. This server allows to have a standard data model for a bidirectional communication to perform control and query data by other external services.

- IoTAgent: This FIWARE GE translates the communication protocols of the different data sources to the OCB NGSI standard. In our proposal, the OPC UA agent is being used. Specifically, a complete mapping of all OPC UA server nodes and their variables is performed. This Enabler allows 3 types of monitoring: active, lazy and command sending. In our proposal, two of them are being used: active and lazy monitoring. Active monitoring of variables allows working in real time with values. In lazy monitoring, the agent sends the data to OCB when clients send a query. Given that the IoT agent acts as an intermediary translator between the OPC UA server and OCB, several tasks must be carried out. First, IoT agent must be configured with each node of the OPC UA server and the variables to be monitored. In this step, active or lazy monitoring for attributes is configured. Besides, OPC server, service and subservice IP addresses, the agent that communicates with OCB, and monitored variables must be configured. The agent has its own MongoDB database to save the configuration to avoid service reconfiguration. Finally, once all the configuration is completed, the agent can generate all the entities with their attributes already translated to the OCB NSGIv2 standard. This is an advantage because it is not necessary to configure OCB manually. So, when new photobioreactors or sensors must be added, simply modify the OPC UA agent and then, entities and attributes will be generated automatically. Using these IoT agents is an advantage since smart sensors using other communication protocols such as MQTT or LoRaWaN can be easily added to the system by generating a new intermediate IoT agent.
- Databases: In this layer, different databases are used to store the data generated in the plant. First, the OPC UA Agent uses a MongoDB database to store data related to the OPC UA communication standard that contains the measurement data of the sensors with the attributes of the OCB entities. Another MongoDB database is used by OCB to store the last sensor measurement in the NGSI standard, making it compatible with the remainder of FIWARE Enablers. On the other hand, data stored by Cygnus and further processed data are stored in another MongoDB database, where data is ready to be queried from the layer 2 or services and applications. These databases are independent and deployed as Docker containers in different volumes. MongoDB does not force a fixed data structure. By contrast, a flexible data model is used and unstructured data can be stored, so that photobioreactor sensors and actuators with different attributes can be added without modifying stored data. Besides, MongoDB allows horizontal scaling by means of sharding and replicating techniques, distributing and replicating data to different nodes of the MongoDB cluster. This architecture is transparent to Layer 2 services and solves scaling limitations of relational databases, that provide a better performance on a single server.
- ETL and Cron Processes: ETL is responsible for obtaining the values from sensors connected to LabJack acquisition cards. Resulting data are sent to the OPC UA server. Cron processes preaggregate data by hour, day and month to speed up queries. Data is aggregated as unstructured data and it is stored on a MongoDB database. Furthermore, other cron processes make backup jobs on NAS periodically.

C. SERVICES AND APPLICATIONS

Located at the top of the Figure 2, this layer exposes applications, interfaces and services to end users. It contains a REST API, data services and smart applications. The components are named as SABANA REST API, SABANA Data Download and SABANA Graphics:

- SABANA REST API: It offers a REST API to query data and to provide data to SABANA Graphics and SABANA Data Download.
- SABANA Data Download: It provides a service to download photobioreactor data in different formats, such as JSON or CSV.
- SABANA Graphics: It consists of a set of web applications that offer two frontend solutions. These services are SABANA Graphics for Researchers and SABANA Graphics for Technicians, respectively, depending on the end user role. The latter can also be consumed by means of SABANA Dashboard, a set of Grafana dashboards that allow users design and customize their own dashboards to visualize data.

SABANA Graphics and SABANA Data Download are based on SABANA REST API using HTTP requests and displaying the requested information to the user. Each service in packed in a Docker container and can be scaled up horizontally depending on demand. In addition, the other layers have not to be modified due to increasing requests on this layer, resulting in a scalable and dynamic architecture.

IV. SABANA DATA COMPONENTS

This section describes the services available in SABANA Data Services (Figure 3). Figure represents an overview of platform options, showing the data sources, interfaces and services available. The system provides a set of services listed from 1 to 8 (see Figure 3) starting with the SABANA FIWARE sensor registering and query group, followed by the SABANA SCADA monitoring system, and ending with SABANA Graphics and SABANA REST API services. Services are based on SABANA REST API. End users can access to services using the graphical interfaces depending on their role (SABANA Graphics for Researchers, SABANA Graphics for Technicians) or using the SABANA REST API

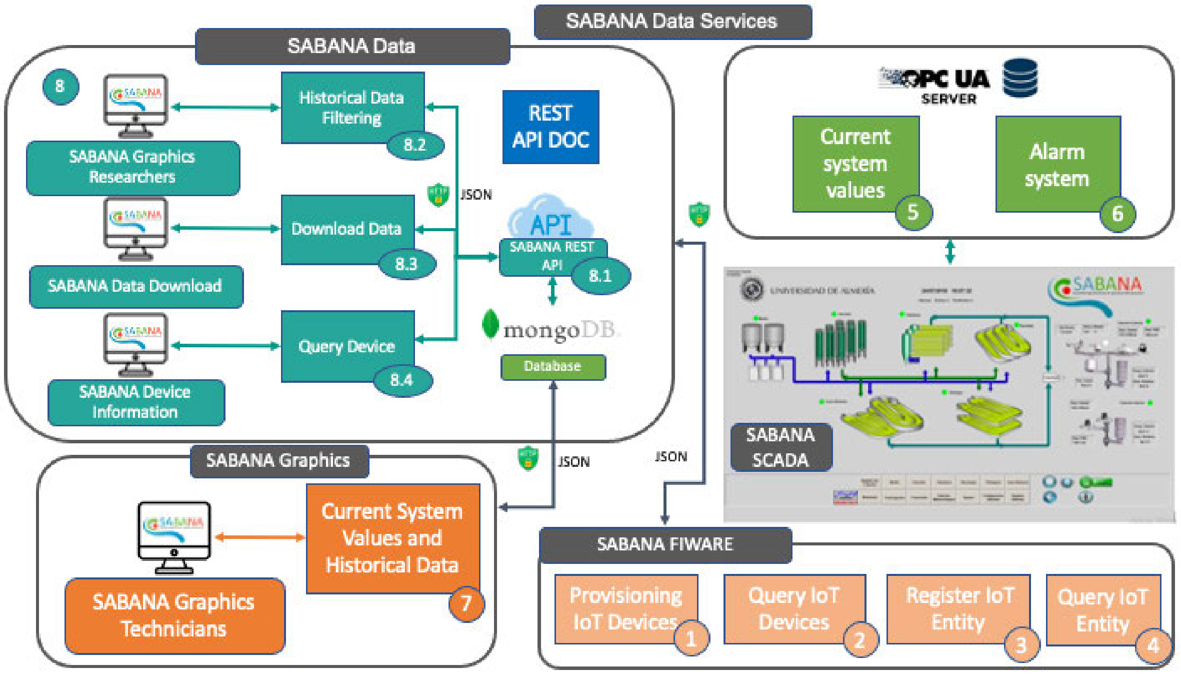


FIGURE 3. SABANA Data Services. Registering of IoT sensors, functionalities and services.

TABLE 2. SABANA Data Services.

Service	Method	End Point
Provisioning IoT Devices	POST	/iot/devices/
Query IoT Devices	GET	/iot/devices/
Register Entity IoT	POST	/v2/entities/
Query IoT Entity	GET	/v2/entities/
Historical Data/Query Device	GET	/api/v1/sensor/

TABLE 3. Provisioning IoT Devices.

HTTP request	
POST	/iot/devices/
Parameters	
Headers	
Content-Type	application/json
fiware-service	First level of the hierarchy
fiware-servicepath	Second level of the hierarchy
Required parameters	
device_id	String Device identifier
entity_name	String Entity name OCB
entity_type	String Type of entity Photobioreactors
Interlude	Active attributes: real-time mapping Lazy atributos: At the request of the IoT agent Command: methods on the OPC UA server Array of objects from the fields below
object_id	String The node and device name in OPC UA
name	String The name to be displayed in OCB
type	String Acceptable values are: Text, Number, Boolean, StructuredValue

directly. Table 2 shows the services available through http within SABANA Data Services.

The main services that make up SABANA Data Services are the following:

- *Provisioning IoT Devices* (1) allows provisioning new devices such as sensors, actuators or photoreactors in the system. This service is in the FIWARE provisioning group and translates data from the OPC UA standard to the NGSI OMA standard of OCB. New photobioreactor sensors must be registered in the service. Once sensors are registered, entities are generated by this service, and sensor data from OPC UA server are sent to OCB. Table 3 shows the endpoint, HTTP headers and request parameters to perform sensor provisioning. Headers allow to generate hierarchies between the first and second level entities respectively with fiware-service and fiware-servicepath.
- *Query IoT Devices* (2) get data from devices registered in Service 1. Table 4 shows the endpoint, HTTP headers and request parameters to get device IoT devices registered with the agent. Headers allow to generate hierarchies between the first and second level entities respectively with fiware-service and fiware-servicepath.
- *Register Entity IoT* (3) of the FIWARE group registers new entities and IoT smart devices in OCB. This service is used only for IoT stations or smarts sensors compliant with FIWARE NGSI standard for communications.

TABLE 4. Query IoT Devices.

HTTP request	
GET	/iot/devices/
Parameters	
Headers	
Content-Type	application/json
fiware-service	First level of the hierarchy
fiware-servicepath	Second level of the hierarchy
Required parameters	
device_id	String Device identifier

TABLE 5. Register Entity IoT.

HTTP request	
POST	/v2/entities/
Parameters	
Headers	
Content-Type	application/json
fiware-service	First level of the hierarchy
fiware-servicepath	Second level of the hierarchy
Request arguments	
id	String Id or name of the entity
type	String Type of entity Photobioreactors
Attributes	String Device name
value	Number, String Measure
type	String The data type
Optional	
metadata	Object: name, value, type

TABLE 6. Query Entity IoT.

HTTP request	
GET	/v2/entities/
Parameters	
Headers	
Content-Type	application/json
fiware-service	First level of the hierarchy
fiware-servicepath	Second level of the hierarchy
Required parameters	
id	String Device identifier
Filters	
attrs	String Entity name attributes
value	String Retrieves the measure

Table 5 shows the endpoint, HTTP headers and request parameters to perform IoT entity registration. Headers allow to generate hierarchies between the first and second level entities respectively with fiware-service and fiware-servicepath.

- *Query Entity IoT* (4) of the FIWARE group is the core of the architecture. This service gets real time data of plant sensors and actuators using the NGSI standard of OMA. Filters can also be used (e.g. time, entity ID, attribute name of the attributes, range of values). Headers allow to generate hierarchies between the first and second level entities respectively with fiware-service and fiware-servicepath. Details about the use of this service are available in Table 6.
- *Current System values* and *Alarm system* (5-6) belongs to SABANA SCADA services. The former gets sensor data in real time. An OPC UA client to establish the communication with the server must be created to access sensor data. A SCADA system is used to perform plant monitoring and control tasks. The latter provides a subscription mechanism to system variables so technicians can be noticed when subscribed variables are out of range.
- *Current System Values and Historical Data* (7) allows technical users to view real time and historical data on a web interface. This is connected to the real-time database generated by Cygnus. This service is linked to SABANA Graphics for Technicians using Grafana and new customized dashboards may be created.
- *SABANA Data* (8) consists of four subservices, named as SABANA REST API (8.1), Historical Data Filtering (8.2), Download Data (8.3) and Query Device (8.4). SABANA Rest API is a core component and it is used by the rest of the subservices and provide a query mechanism to historic data generated by the plant sensors in different formats. Table 7 shows the endpoint, HTTP headers and request parameters to use the service. Filters can also be used (e.g. time attributes, mode, output, and so on). This service provides information from the beginning of the campaign until the last 24 hours. It has a set of processes that are executed nightly accessing to the database and performing data cleaning and aggregation operations. Historical Data Filtering (8.2) is used to visualize historical data of the plant through a graphical interface named as SABANA Graphics for Researchers. Download Data Service (8.3) allows downloading historical data of the plant in JSON or CSV format through a graphical interface named as SABANA Data Download. Query Device subservice (8.4) provides a query mechanism to get technical information about devices installed in the plant, such as manufacturer, sensor errors, revisions, maintenance, among others through a graphical interface named as SABANA Device Information.

V. USE OF THE PROPOSED SERVICES

This section shows some examples of the IoT services developed in this article. In addition, these services will be visualized through the different components available in SABANA Data Services and SABANA Graphics.

A. SABANA FIWARE

This section makes use of SABANA Data Services through HTTP requests. This is formed by the Provisioning IoT Devices and Register Entity IoT services.

1) PROVISIONING IoT DEVICES

This section shows an example of how to use the provisioning service to create a photobioreactor using the OPC UA agent. The following code shows the body of the request in JSON

TABLE 7. Historical Data.

HTTP request	
GET	/api/v1/sensor/
Required parameters	
id_sensor	String id_sensor comma separated list
Filters	Detail of parameters
day	Integer The day parameter with format YYYYMMDD
time	Integer The time parameter with format YYYYMMDDHHMM
fromtime	Integer The fromtime parameter with format YYYYMMDDHHMM
totime	Integer The totime parameter with format YYYYMMDDHHMM
month	Integer Time in YYYYMM
mode	String Use aggregation type by default aggregations per day
by	String Use hour type to aggregate by hours
output	String Use CSV for this format

to create a raceway photobioreactor. Details about the use of this service are available in Table 3.

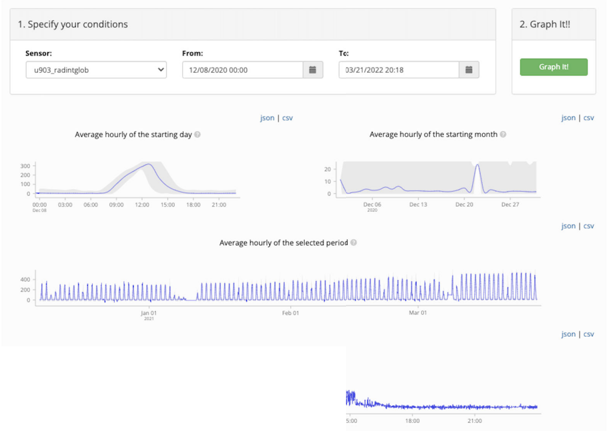
```
{
   "devices":[
      {
         "device_id":"RW1",
         "entity_name":"RW1",
         "entity_type":"device",
         "attributes":[
            {
               "object_id":"ns*1:s*temp_rw1",
               "name":"temp_rw1",
               "type":"Number"
            },
            ......
         ],
         "lazy":[],
         "commands":[]
      }
   ]
}
```

2) REGISTER IoT ENTITY

Next, the request body to register a smart sensor that uses NGSI standard to communicate with FIWARE is listed. Details about the use of this service are available in Table 6.

```
{
   "id":"RW2",
   "type":"device1",
   "CO2_rw2":{
      "type":"Number",
      "value":"8.440798112015251",
      "metadata":{}
   },
   ......
}
```

FIGURE 4. SABANA Graphics for Technicians. Visualization of two photobioreactors RW1 and TL1.


1. Specify your conditions

Sensor: u903_radintglob

From: 12/08/2020 00:00

To: 03/21/2022 20:18

2. Graph It!!

FIGURE 5. SABANA Graphics for Researchers.

B. SABANA GRAPHICS

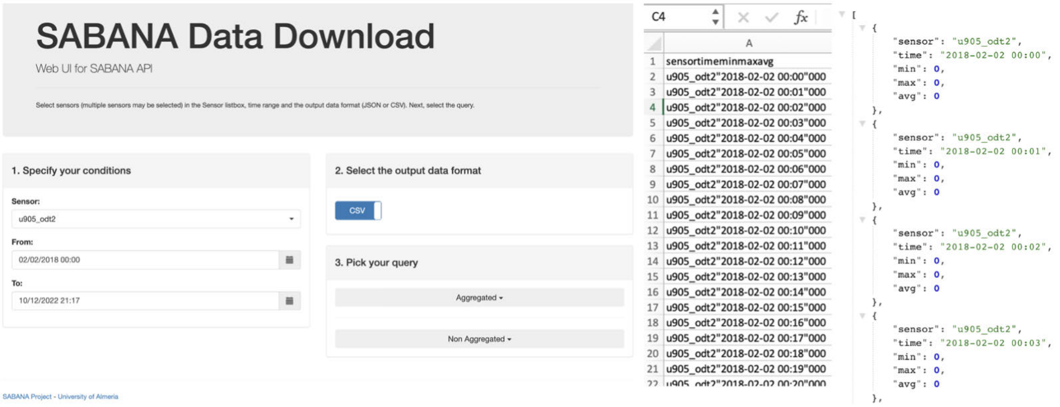
In this section, the use of SABANA Data Services through the available graphic tools is illustrated.

1) SABANA GRAPHICS TECHNICIANS

This service is used by technical users of the plant. It consists of a set of Grafana dashboards showing real time and historical photobioreactor sensor data by using a graphical format. These dashboards may be modified to customize depicted data. Figure 4 shows the data for two photobioreactors of the raceway and tubular type and their different variables.

2) SABANA GRAPHICS RESEARCHERS

In SABANA Graphics for Researchers, users select sensors from a list and choose a date range. Then, the component



SABANA Data Download

Web UI for SABANA API

Select sensors (multiple sensors may be selected) in the Sensor listbox, time range and the output data format (JSON or CSV). Next, select the query.

1. Specify your conditions

Sensor: u905_odt2

From: 02/02/2018 00:00

To: 10/12/2022 21:17

2. Select the output data format

3. Pick your query

```
1  sensortimeminmaxavg
2  u905_odt2"2018-02-02 00:00"000
3  u905_odt2"2018-02-02 00:01"000
4  u905_odt2"2018-02-02 00:02"000
5  u905_odt2"2018-02-02 00:03"000
6  u905_odt2"2018-02-02 00:04"000
7  u905_odt2"2018-02-02 00:05"000
8  u905_odt2"2018-02-02 00:06"000
9  u905_odt2"2018-02-02 00:07"000
10 u905_odt2"2018-02-02 00:08"000
11 u905_odt2"2018-02-02 00:09"000
12 u905_odt2"2018-02-02 00:10"000
13 u905_odt2"2018-02-02 00:11"000
14 u905_odt2"2018-02-02 00:12"000
15 u905_odt2"2018-02-02 00:13"000
16 u905_odt2"2018-02-02 00:14"000
17 u905_odt2"2018-02-02 00:15"000
18 u905_odt2"2018-02-02 00:16"000
19 u905_odt2"2018-02-02 00:17"000
20 u905_odt2"2018-02-02 00:18"000
21 u905_odt2"2018-02-02 00:19"000
22 u905_odt2"2018-02-02 00:20"000
```

```
[
  {
     "sensor": "u905_odt2",
     "time": "2018-02-02 00:00",
     "min": 0,
     "max": 0,
     "avg": 0
  },
  {
     "sensor": "u905_odt2",
     "time": "2018-02-02 00:01",
     "min": 0,
     "max": 0,
     "avg": 0
  },
  {
     "sensor": "u905_odt2",
     "time": "2018-02-02 00:02",
     "min": 0,
     "max": 0,
     "avg": 0
  },
  {
     "sensor": "u905_odt2",
     "time": "2018-02-02 00:03",
     "min": 0,
     "max": 0,
     "avg": 0
  },
```

FIGURE 6. SABANA Data Download. Graphic interface for data download in CSV and JSON format.

displays data in form of four graphs (see Figure 5). Hourly average of selected date, hourly average of selected month, hourly average of the selected period, and raw data of selected date. This service is based on the SABANA REST API (see service 8 Section IV), which allows retrieving historical data in different formats using the filters of the Table 7. In addition, graphics data can be downloaded in JSON or CSV format. This feature is very useful for researchers and companies as they can analyze data offline.

3) SABANA DEVICE INFORMATION

This service gets technical information of plant IoT devices. Users select from a list of available sensors in the plant, and data is retrieved from the database. Data is returned in JSON with information about calibration, installation location, PDF with the manufacturer's datasheet, and so on.

C. SABANA DATA DOWNLOAD

This service offers users the possibility to download the data generated by the sensors in different formats and modes graphically through a set of drop-downs. The Figure 6 shows the use of the graphical interface for data download and an example of the file in CSV and JSON format. The user can select multiple sensors, a start and end date, the format in which he wants the data (JSON or CSV), and then several possibilities within the aggregate menu (The starting date as a whole, The starting date hourly, The month of the starting date hourly) and in the non-aggregate menu (Data of the starting instant, Data of a period, Raw data of the starting date). This interface facilitates data access for all types of expert and inexperienced users.

VI. CONCLUSION

This work is developed and tested in the real SABANA plant specialized in biomass production located in Almería, covering the complete production cycle of the system, from obtaining measurements from the sensors and sending data, registration of new devices, data processing, data query services and plant monitoring. The IoT platform developed is a proprietary solution and relies on the use of the NGSI standard of the FIWARE platform for data integration, making easier information exchange between different type of sensors. In addition, other enablers are used for the integration of different communication protocols.

This paper proposes a cloud-based IoT solution for large-scale data management of a biomass production system through microalgae cultivation as a solution for this sector to the lack of digitization and the issues to data access. SABANA Data Services are focused on monitoring, access, and extraction of the data generated by the photobioreactors associated to the SABANA plant. Services available to users are: real-time data, historical data, sensor information, additional sensor integration, IoT entity creation, and system monitoring. These services are exposed to users through a set of REST APIs, called SABANA Data Center, which allow the user to make use of them in two ways: through a set of web interfaces, or through HTTP requests. The former allows less advanced users to make use of SABANA graphical services. The latter allows advanced users or researchers to make use of the REST API to perform queries or extract data for simulation purposes and develop their own dashboard in their systems or companies. The results presented in the work allow us to reach the following conclusions:

1) The use of technologies, such as IoT, is presented as an effective tool to manage existing heterogeneous data in a large-scale microalgae production system. Moreover, cloud-based solutions and REST APIs are introduced as key elements to manage the large amount of data generated in these industrial systems.
2) The developed IoT platform allows the integration of ordinary sensors and new smart sensors in an easy and scalable way.
3) The set of REST APIs services developed allow the user to make use of them according to their

background, by using a graphical format or through HTTP requests. This makes the accessibility, management, and visualization of the plant data easier for all types of profiles.

In relation to future work, the services developed could be used to remotely perform control operations in the plant, allowing bidirectional communication from one of the graphic clients of SABANA Data Services. It would also be interesting to present a proposal for an economic feasibility analysis to determine the cost of migrating a traditional plant to the acquisition of IoT sensors, infrastructure and communication networks. This would allow to know the profitability of traditional systems versus IoT systems.

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