AqquaScan: design and implementation of an Internet-based service for the remote monitoring and management of decentralised WWTPs

A. Castro, J. M. Sanz, I. Ayala, E. Ayesa, J. Alferes and I. Irizar

ABSTRACT

This paper describes the design and implementation of AqquaScan, an Internet-based service for remote monitoring and integrated management of decentralised WWTPs. AqquaScan is a multi-user and multi-WWTP service. It has been built according to criteria such as flexibility, scalability and interoperability with the idea of providing an open environment suited to quickly accommodate future scenarios (e.g. incorporation of new plants or upgrading of existing installations). Both, the management of plant information and users interfaces have been implemented in distributed software components that communicate with one another via web services. The implemented web services can be exploited to develop customised user interfaces for visualising the monitored data. By default, a customised web-based client module has been programmed in order for users to be able to exploit the facilities offered within AqquaScan: (1) real-time monitoring of on-line signals; (2) visualisation of historical data; (3) changing operational parameters; (4) notification of time-event information; and (5) storage of measurements from laboratory analysis. At present, AqquaScan is fully operative and is offering supervision services to eleven industrial WWTPs distributed around Northern Spain.

Key words | automation, diagnosis, integrated management, remote supervision, wastewater, web-Services

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INTRODUCTION

Over the last few years, progress in information and communication technologies has promoted the development of new approaches to the operation of wastewater treatment plants (WWTP). Increasingly, the Internet and the Web are being applied to establish frameworks from which to provide users with remote and web-based data monitoring services. Thus, Lardon *et al.* (2002) describe the overall architecture and specifications of a modular Internet-based remote supervision system for WWTPs. Later on, this architecture is used to develop a remote control system for anaerobic digesters (Bernard *et al.* 2005). Likewise, by using WAP and HTML technologies, Alex *et al.* (2003) develop a WWTP on-line information service, accessible from mobile devices. Similarly, Schuchardt *et al.* (2004) and Steinmetz *et al.* (2005) deploy an industrial WLAN network for WWTP that makes mobile devices for supporting the operation available from everywhere within the area of the plant.

With the development of modern technologies for wastewater treatment and reuse, it is expected that the number of decentralised small-scale installations incorporating such technologies will increase significantly in the coming years. In comparison to conventional systems, advanced on-site technologies are more complex and include additional equipment (pumps, air supply, online sensors, etc.) which require periodic monitoring and maintenance. In this context, the deployment of remote monitoring solutions appears in the forefront, mainly when integrated management of all these plants is in demand. Thus, the exploitation of these tools is

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mandatory to deal effectively with issues such as plant diagnosis, the prompt detection of faults or the estimation of manpower for the overall maintenance of plants (Teichgräber *et al.* 2002). Nevertheless, such a scenario involves new models for supervision to be developed since, rather than dedicated solutions using, the whole supervision of decentralised systems needs to be tackled on the basis of an integrated approach.

It is important to point out that the number and kind of on-site installations might be subject to changes throughout time. Therefore, the remote supervision system should be designed with enough flexibility to give appropriate solutions for all these situations. In addition, the integrated management of multiple plants will generate large volume of stored data in the database of the remote supervision system. Taking advantage of powerful data analysis tools (data mining, case-based reasoning tools) the stored data could be automatically processed to obtain valuable and accurate information about the state of every plant (Comas *et al.* 2006). In this respect, two factors are crucial for the success of the supervision system: (1) design of well-formed data structures for the storage of plant information; and (2) implementation of standard network interfaces for providing external applications with remote access to the stored data. Taking into consideration all of these questions, this paper describes the design and implementation of AqquaScan, an Internet-based service for the remote monitoring and integrated management of decentralised WWTPs.

PREREQUISITES FOR THE DESIGN OF AQQUASCAN

Unlike dedicated solutions, the AqquaScan tool (AqS) is intended for supporting the remote supervision of WWTPs in general. In this respect, its design has considered all those specifications that can generally be found in WWTP automation systems. AqS has been built according criteria such as flexibility, scalability and interoperability with the idea of providing an open environment suited to accommodate quickly future scenarios (e.g. incorporation of new plants or upgrading of existing installations). Next, the major features considered for the design of AqS are enumerated:

1. *Multi-WWTP*. The underlying idea of AqS is the implementation of an integrated service from which multiple WWTPs can be monitored remotely and concurrently. The supervision of a wide range of WWTPs (different sizes, treatment technologies, process variables, etc) has been considered to occur in the AqS service. Therefore, the AqS architecture should be able to support: (1) the incorporation of new plants (registration of WWTPs); and (2) updating and modifying the registered plants.
2. *Multi-User*. AqS will include an effective administration of users so as to unequivocally identify them within the platform (user registration). This feature is important since AqS should always guarantee the integrity and privacy of data collected from the WWTPs. Moreover, by establishing this authentication mechanism, AqS would be able to recognise those users with permissions to modify the state of the plant (usually, plant operators).
3. *Multi-platform*. Users should be able to take advantage of the AqS remote service from any local computer platform independently of its operating system (Windows, Linux, Unix …). The only requirement for registered users is to have an Internet connection.
4. *Integrated Management of WWTP information*. Laboratory measurements are important indicators of the state of the plant. Thus, the diagnosis of the plant involves the analysis of on-line signals but also lab-measurements. The AqS environment will make the diagnosis of WWTPs easier, since it will integrate all this information within its data management system.
5. *Independence of WWTP automation hardware*. In order for the AqS service to be easily integrated within automation systems, it should provide connectivity with the most common hardware used in WWTP installations for control and communication. Thus, the AqS software will support compatibility with: (1) common PLC vendors (Siemens, Allen-Bradley, Omron, Telemecanique …); and (2) common technologies for WAN communications (DSL, GPRS …).

DESIGN AND IMPLEMENTATION

Two years ago, the Spanish water company ATM, in collaboration with the research organisation CEIT, developed a Web-based platform for the remote supervision of WWTPs (Irizar *et al.* 2006). This application was built based on similar specifications as described in the previous section.

In fact, this tool is currently offering successfully remote monitoring services to eleven small WWTPs. However, some implementation drawbacks have been detected which might deteriorate its performance if the number of registered plants increases. The AqS has an enhanced design and implementation where such problems have been corrected. Moreover, important features like robustness and scalability have been improved in the AqS approach.

The software architecture of AqS consists of two main distributed components: the engineering module and the controller module (Figure 1). In addition, a third distributed component, the client module, is needed to provide users with interfaces for accessing the AqS architecture. However, as it will be shown below, the engineering and controller modules have been designed using the standard Web Services technology (http://www.w3.org/2002/ws/) so that the client module has enough flexibility to be implemented in multiple ways. In fact, advanced users could develop customised client interfaces to exploit all the functionality offered within the AqS service.

The controller module is the software component that communicates locally with the WWTPs. Every time a new plant is registered, AqS assigns it a new instance of the controller module (controller instances). The controller instances are previously configured to connect with the specific automation hardware present in their corresponding WWTP (PLC model, field buses, Internet connections, etc). Once the controller instances have been configured, they are ready to monitor the process variables of their respective plants. Controller instances collect real-time information from the WWTPs, and then transmit them to the engineering module via the Internet. The controller component has been developed in C programming language due to the fact that its performance is better for real-time operations. In addition, a Web Service (WS) has been implemented within this module for processing the requests from the engineering module.

The communication between users and WWTPs is centralised by means of the engineering module which, in this way, represents the core of AqS. A database has been introduced within this module to organise all the information concerning users and plants. To preserve the integrity of the stored data, the engineering module manages any attempt to remotely access to the database (either from users or WWTPs). In regards to the implementation of this module, it has been programmed in Java so as to ensure a full compatibility with any computer platform and operating system. Moreover, the remote communication between this module and the other software components (controller instances and clients) has also been implemented using WS technology. The engineering module has been designed by dividing the development into three software layers (Figure 2, left): (1) the *web service layer* contains the web services that provide the communication with the controller and the clients instances of AqS; (2) the *business logic layer* implements the logic which is needed to perform the actions demanded from clients and WWTPs efficiently; and (3) the *data access layer*, the only layer with permissions to access the database. Similarly, the design of the controller module has also been separated into three layers: (1) the *web service layer* which implements the web services for communicating with the engineering module; (2) the *business logic layer* which manages any exchange of information between the upper and lower layers; and (3) the *automation layer* (which is WWTP-specific) which monitors the process signals by establishing permanent communication with the automation hardware (Figure 2, middle).

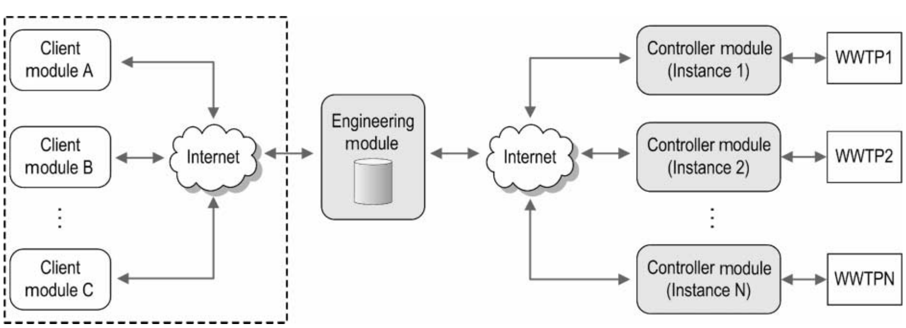

Figure 1 | General schema of the AqS software architecture.

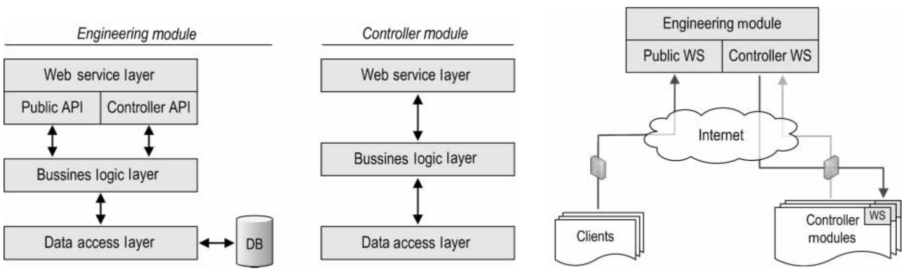

Figure 2 | Design of the AqS architecture: (left) the engineering module; (middle) the controller module; (right) WS communication between software components.

Three major reasons have determined the implementation of WS for communicating between the AqS modules: (1) they provide a communication interface independently of the operating system; (2) As WS work over HTTP, they can go through firewalls regardless of the client location; and (3) the integration of external tools within the AqS environment can be made straightforward. The AqS architecture exposes three different WS (Figure 2 right). Thus, the engineering module implements two WS: (1) the *Public API* which enables client applications to make use of the AqS functionalities; and (2) the *Controller API* which provides controller instances with an interface for access to the engineering module. In regards the controller module, it exposes another WS that can only be used by the engineering module. The engineering module employs this WS to set-up controller instances with the appropriate parameters in order to monitor the state of each registered plant. Though the Public WS is accessible from the Internet, it incorporates a previous authentication of users (username and password) that ensures only registered users can interact with the AqS architecture. In a similar way, the Controller WS implements an authentication mechanism that prevents any software other than the engineering module for accessing the plants. Moreover, additional security measures such as firewalls and IP tunnels between the engineering and controller modules have been taken so as to increase the protection of AqS against network attacks.

Hardware of AqS

As mentioned above, every supervised plant within AqS has its respective instance of the controller module. Controller instances monitor online signals by communicating locally with the automation hardware in the WWTPs. The AqS service provides its own controller hardware for the installation of controller instances. After testing different low-cost hardware alternatives, a small i386 PC compatible hardware was chosen to fulfil this task. The selection of this device was based on the following considerations: (1) Several hardware interfaces (serial, USB, LAN) are available to communicate the controller modules with the automation equipment in the WWTPs; (2) Both the operating system and the controller instance can be launched from a compact flash storage card. It gives the controller hardware enough robustness to operate in industrial environments where mechanical hard disks become considerably more unstable and sensitive to vibrations, humidity, electromagnetic noise, etc.; and (3) the selected device offers a good balance between CPU performance and price. In fact, the computational power of the controller devices is being exploited by AqS with the implementation of advanced algorithms for the online estimation of OUR and K_La. OUR and K_La algorithms require an extra processing of the dissolved oxygen measurements which involves noise filtering, calculating time-derivatives and performing linear regressions (Suescun *et al.* 1998).

Figure 3 shows the overall hardware architecture of the AqS service. It is seen that a controller device has to be incorporated in each monitored WWTP. The controller devices connect locally with the automation hardware. In addition, these devices work as gateways to communicate the engineering module with the WWTPs through the Internet. The engineering module runs on a hardware dedicated to web hosting. This server has been hosted in a professional data centre, located in London, in a special building with very stringent security features like dedicated diesel generators, climate controls, pre-action fire suppression systems, redundant internet connexions, etc. Consequently, the occurrence of power supply and internet

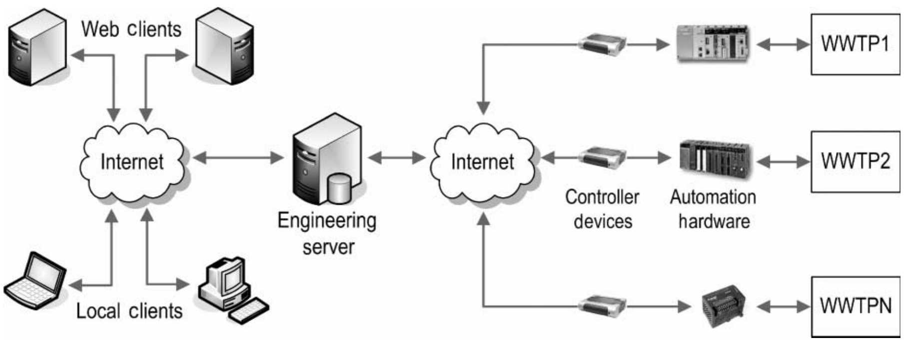

Figure 3 | Hardware architecture of AqS.

shut-downs is minimised and the availability of the AqS service is ensured most the time.

For connecting users and plants, the AqS environment supports multiple implementations of the client module. Thus, this module can be implemented as a web-based client application located in a server and accessible from any standard browser. Such an approach has the advantage that the AqS service can be operated from any local computer connected to the Internet. In contrast, typical limitations of web user interfaces make the implementation of advanced graphical user interfaces difficult. A further implementation approach for the client module is as a local and customised application. In this case, powerful user-friendly interfaces can be programmed with the objective of facilitating the visualisation of the monitored data. Moreover, enriched information for WWTP diagnosis and control could be obtained from the data stored in the AqS database by developing "virtual expert users" with advanced capabilities for data analysis (data mining, case-based reasoning tools, etc). Unlike web clients, local client applications run on local hardware, consequently, they have to be installed in every client machine.

SYSTEM PERFORMANCE

All the WWTPs registered in the old Web-based platform have been successfully migrated to the AqS service. These small plants are distributed geographically around northern Spain. The connectivity of the controller devices with the automation systems of the different plants was straightforward in all cases. At present, local communications of the controller module have been satisfactorily tested with two PLC manufacturers (Omron and Siemens). Moreover, depending on the telecommunication infrastructures available in every plant, controller devices connect to the Internet via either DSL or GPRS. Table 1 lists the number of signals (digital and analog) per plant that are being supervised. Within AqS, signals have been classified in four categories: (1) *on-line*: read-only signals that require continuous supervision, but transitory storage; (2) *alarm*: read-only signals whose values must be notified and stored (but only when changing); (3) *operating*: read-write signals that can be modified and whose values must be notified and stored only when changing, (4) *historical*: read-only signals that require continuous supervision and permanent storage (usually named historical data).

Due to the slow dynamics of biological treatment processes, signals are monitored at regular intervals that range from a few seconds to several minutes and, therefore,

Table 1 | WWTPs registered in AqS. Number of signals monitored per plant

WWTP's name	On-line	Alarm	Operating	Historical	Total
Alcaliber	40	14	46	30	130
Alcorta	12	4	36	14	66
Bodegas Olarra	18	11	32	4	65
Bonduelle	58	9	43	6	116
Coop San Esteban	45	14	54	12	125
Distiller	72	19	77	39	207
Gutarra	23	8	26	4	61
Marie Brizard	8	1	17	3	29
Papelera Ebro	17	9	42	16	84
Papelera Oria	21	7	45	7	80
Papertech	60	2	18	11	91

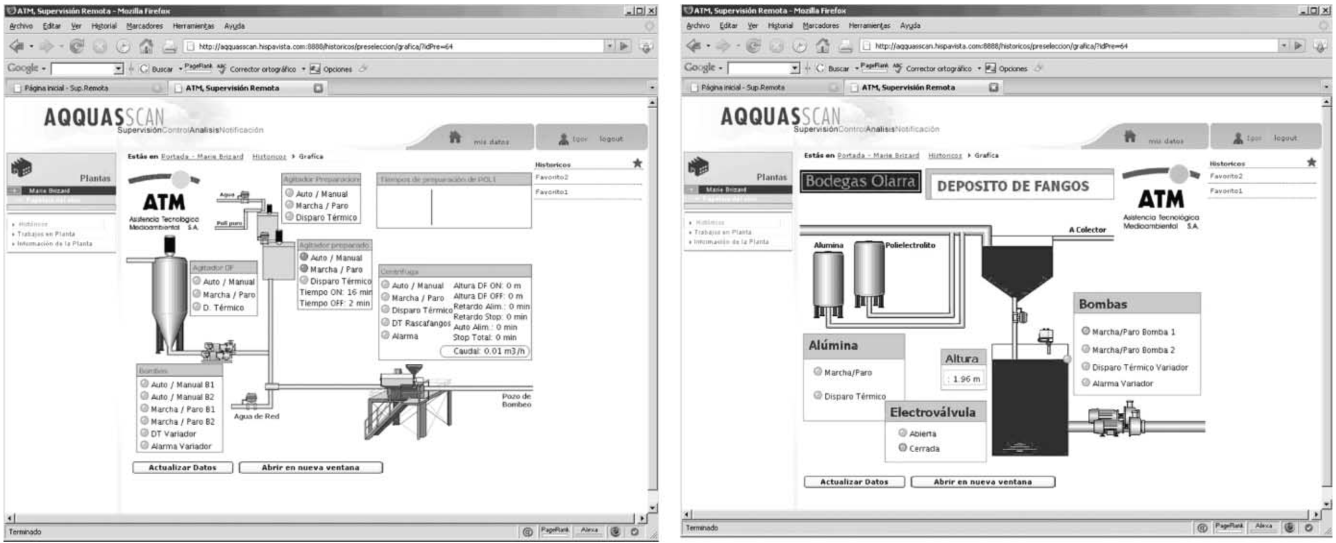

Figure 4 | Web user interfaces for on-line monitoring.

the CPU time for monitoring and processing every signal is not significant. Moreover, the AqS architecture supports the duplication of the engineering module in different machines so as to overcome an unforeseen increase in the number of supervised plants. Likewise, the capabilities of the controller devices to perform real-time extra calculations on the monitored data have been also verified. In this respect, three industrial WWTPs (Papelera Ebro, Distiller and Alcaliber) have implemented signal processing algorithms for the online estimation of OUR and K_La. The excellent results show that the selected hardware for the controller devices is adequate not only for monitoring data, but also when additional real-time operations are required (state observers, automatic control algorithms, etc).

By default, a customised web-based client module has been programmed to exploit the facilities offered within AqS. Currently, the web client runs on the same server as the engineering module, although it is optional. In fact, the AqS architecture has been designed to make the distribution of modules in different machines possible. Web-user interfaces have been developed by employing a unified pattern for every WWTP registered into the system. This pattern has used classical interfaces for SCADA applications as reference, aiming to provide clients with a user-friendly environment. In a similar way, Kawada *et al.* (2006) proposes the implementation of SCADA-like interfaces on cell-phones to assist maintenance workers in industrial plants. So far, the developed web client application fulfils the following five functionalities:

1. *Real-time monitoring of on-line signals into synoptic diagrams*. Users can supervise the status of WWTPs by selecting this option. Thus, instantaneous values of on-line variables are visualised in the respective synoptic diagrams configured for each individual WWTP. Figure 4 shows a screenshot of this interface for two different WWTPs (Alcaliber and Bodegas Olarra).
2. *Visualising historical data*. AqS users analyse the WWTP performance by querying historical data information stored in the database. The output interface supports two different representations: graphical mode and table-form mode. In Figure 5 the appearance of the graphical mode interface is displayed.
3. *Modifying operational parameters*. While any user can read the current values of operational parameters, only authorised users have permission to access this interface for changing their values.
4. *Notifications*. In contrast to interfaces for visualisation of time-continuous information, this facility concentrates on time-event information. Thus, user can be informed about changes in values of alarm signals that have occurred in the WWTPs and changes in values of operational variables.
5. *Entering daily measurements from laboratory analysis*. Finally, with the aim of integrating all the information related to the operation of the supervised WWTPs into

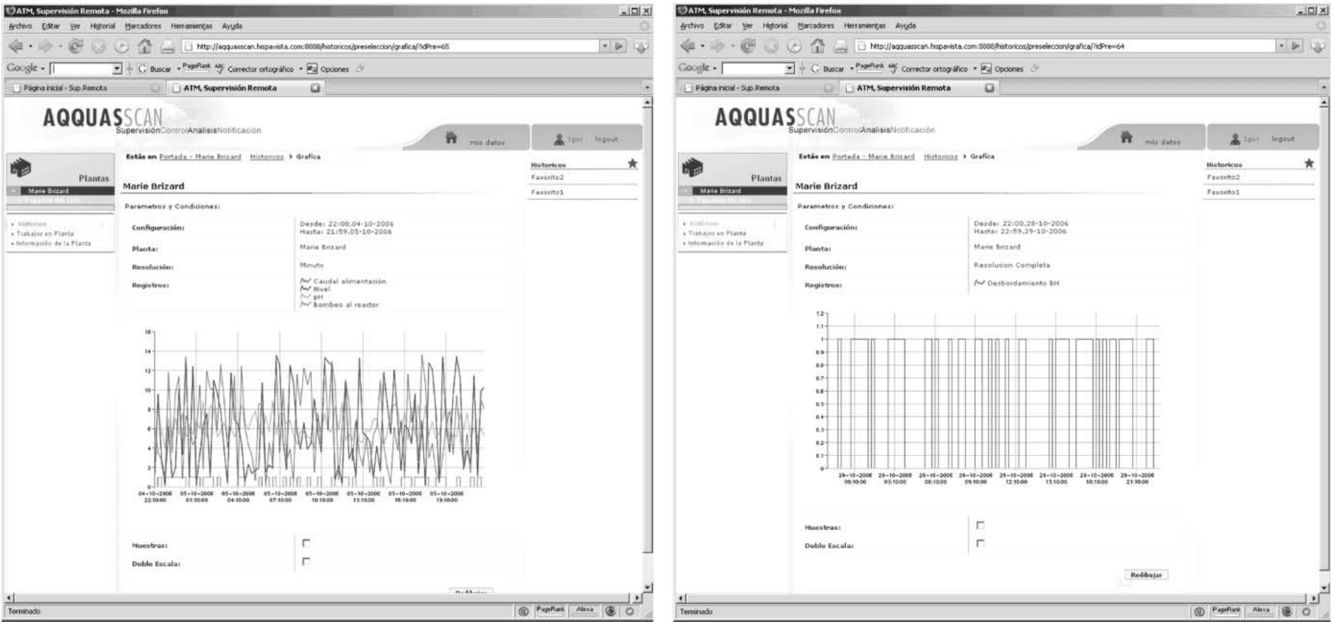

Figure 5 | Web user interfaces for representation of historical data.

the AqS database, the web-based client includes a customised user interface for entering readings from laboratory analysis. Obviously, only authorised users have permission to introduce such information.

CONCLUSIONS

The AqquaScan Internet-based service (AqS) has been developed aiming to assist the supervision and maintenance of hugely decentralised wastewater treatment systems. AqS has been built according criteria of flexibility, scalability and interoperability with the idea of providing an open environment able to manage the remote supervision of multiple WWTPs effectively. AqS is a dynamic service in the sense that it allows new plants to be incorporated within the platform at any instant with no extra code added. In addition, AqS offers full-connectivity with the most typical automation systems found in WWTP facilities. In order to achieve full-connectivity a specific controller device has been installed locally in every supervised plant.

AqS exposes a web service interface to enable remote clients the access to the monitored data. Through this standard interface, customised client applications can be easily integrated within AqS. By default, a web-based client application has been integrated with AqS. The software architecture of AqS has also considered the future interaction of AqS with data analysis tools for diagnosis and control of WWTPs. Currently, eleven industrial WWTPs are being supervised within the AqS platform. The product is fully operative and offers the following functionalities: (1) real-time monitoring of on-line signals; (2) visualisation of historical data; (3) changing operational parameters; (4) notification of time-event information; and (5) storage of measurements from laboratory analysis. AqS is being exploited and commercialised by the Spanish water company ATM S.A.

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