Hydro-Tech - an integrated decision support system for sustainable irrigation management (II): Software and hardware architecture

Erminio E. Riezzo[1,*], Mario Zippitelli[1], Donato Impedovo[2], Mladen Todorovic[3], Vito Cantore[4], Vito Buono[3]

[1] Sysman Progetti & Servizi srl, Via A. Montagna 2 - zona PIP, 72023 Mesagne (BR), Italy
[2] Dyrecta Lab, Via Vescovo Simplicio 45, 70014 Conversano (BA), Italy
[3] CIHEAM – Mediterranean Agronomic Institute of Bari, Via Ceglie 9, 70010 Valenzano (BA), Italy
[4] CNR – Institute of Science of Food Production, Via Amendola 122/O, 70126 Bari, Italy
[*] Corresponding author E-mail: riezzo@sys-man.it

Abstract: In the framework of the HydroTech project (supported by Apulia region and the EC-ERDF programme), local private ICT companies in collaboration with research institutions are developing and testing at farm scale an integrated Decision Support System (DSS) for irrigation management, through the integration of advanced software and hardware technologies. Hydrotech-DSS provides standard interfaces, which connect on-field devices with client software application through a Data Cloud Network (Hydrotech Data Cloud, HDC). The HDC is composed of: 1) Knowledge Data Base, a DB for large amount of data coming from heterogeneous but strongly correlated sources; 2) a 'gateway' based on web services technology, to connect external (on-field) devices together with an open standard communication protocol; 3) a set of software components constituting the APP Data Chain from source to destination passing by elaboration steps(Data Assimilation, Model Engine, Decision Maker). The Decision Maker module supports two types of decision system: the MSS (Management Support System) enables the end-user to manage the work flow of his farm, whereas the DSS (Decision Support System) supports him during irrigation/fertigation management activities (e.g. timing and amount of irrigation according to weather forecast, crop water stress, irrigation system constraints, etc.). The system allows fast and simply information transfer directly to the field through an easy interface accessible with new smart devices (tablet, smartphone, etc.). The user interface allows: 1) to receive aid for the decision (irrigation and fert-irrigation advice) directly on the field within its validity time window by means of "push-pull" technology; 2) to interact with the HDC to send the feedback (e.g. treatment registration), characterize the individual farm and adjust the system parameters; 3) to use different type of software client application, such as classic client-server for professional use on rugged tablet and computers, or smart/user friendly for mobile device and web based; 4) to work off-line and to synchronize the database when data connection will be available; 5) to enable users for the automation and remote control of irrigation system equipment (e.g. hydrants, electric valves). With respect to the design and development of the hardware infrastructure, the 'field unit' is composed by sensor devices (EAP, end-acquisition-point), actuator devices and the so-called 'coordinator' which is aware of the whole configuration and logics to be respected. Each sensor/actuator must be placed in the most favourable site, and each EAP is equipped with Li-Ion rechargeable battery and a solar panel in order to have the highest installation facility. Acquired data can be transferred to the 'coordinator' by means of different technologies (LAN, 3G, GPRS, ZigBee, WiFI, Bluetooth, etc.). The coordinator is a gateway provided with moderate computation and storage capabilities able to collect data from the EAP, perform basic checks and transmit them to the centralized cloud system, which is able to perform the main computations. Many different technologies can be adopted to transfer data to the cloud system. Once the irrigation decisions have been computed and approved, commands are sent to the 'coordinator' which is responsible to forward these commands to actuators adopting specific field strategies.

Keywords: Irrigation, decision support system, water management, wireless communication, automated control.

1. INTRODUCTION

As it has pointed out in the companion paper (Todorovic *et al.*, 2013; this issue), in southern EU Member States, 'sustainable' water management in agriculture is a major issue and there is an increasing need to develop and test appropriate 'decision support systems' (DSS) to further support the on-farm decision process. Innovative solutions for DSS are based on the integration of the new technologies available in computer science, modelling, electronics, sensor technology and wireless communication.

The application of new technologies to the control and automation of irrigation is becoming a very relevant issue in the last decade, and especially the automatic irrigation scheduling is receiving growing attention.

This is due to a number of factors: i) generalization of real-time digital information on weather data and crop water requirements; ii) increased access to this information from remote sites through wireless connections; iii) improved reliability and effectiveness of sensors used for measurements in the soil-plant system; iv) communication possibilities offered by telemetry/remote control systems, being installed both in collective pressurized systems and in individual farms; v) the cost-effectiveness of these technologies in developed countries when compared to labor costs (McCarthy *et al.*, 2011; Romero *et al.*, 2012; Zapata *et al.*, 2012).

The 'HydroTech' project is developed at local level in the Apulia Region, with the aim to further develop a decision support system (the HT-DSS) and to bring available modern technologies at the level of farm application, in order to support the 'sustainable' irrigation management. The project is developed by 'AgriTech', a temporary association of local business companies (Sysman Progetti & Servizi, team leader; DyrectaLab) and research institutions (IAM-B; ISPA-CNR). The HT-DSS aims to support the end-users throughout the irrigation management and decision making processes in order to reduce the waste of water and to increase yield as well as water productivity. It makes use of advanced tools to transfer easily the information from/to the field, and provides standard interfaces to connect on-field devices (such as irrigation supply network or weather station) through a Data Cloud Network.

Among the main objectives of the project, the following features of the HT-DSS are currently under implementation: i) to test the applicability of HT-DSS at farm level, in relation to the effectiveness and reliability of the provided support; ii) to test the fast and simply information transfer directly to the field through an easy interface accessible with new smart devices; iii) to design of 'simple and practical', user-friendly computer/mobile-based DSS, by considering also the end-user feedbacks and specific requirements; iv) to test the plug-and-play on-field devices (such as weather station) interconnected through a cloud network; v) to integrate the HT-DSS into possible existing irrigation systems and controllers; vi) to evaluate the most cost-effective solutions, like low budget intelligent devices with sensors and water solenoid that allow remote management and monitoring; vii) to integrate a software module for fert-irrigation management.

In this paper, a general description of the software and hardware architecture of the HydroTech Decision Support System (HT-DSS) is reported, while in a companion paper (Todorovic *et al.*, 2013, this issue) is given a description of the main algorithms and the on-going experimental activity at farm level.

2. HYDROTECH INFORMATION SYSTEM

2.1. Architectural overview

The HT-DSS information system integrates multiple data sources in order to collect all information useful to irrigation and fertilization support, such as information on farm and irrigation units, weather forecast and measured data and crop-soil data. In Fig. 1, the data flow scheme is represented.

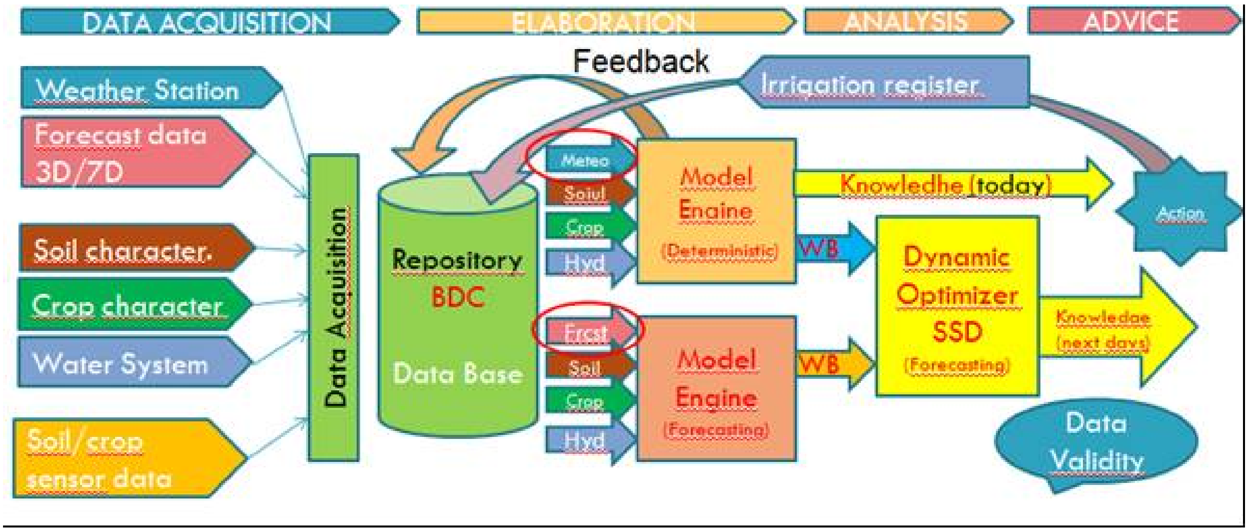

Fig. 1. Data Flow scheme. Multiple data source streams (heterogeneous but strongly related) are stored into DB and aggregated in order to obtain the optimal solution for the irrigation/fertirrigation scenario. The technology transfer permit the interaction with the end user that receive the advice (when and how much) and interact with the system through data entry of knowledge (treatments and field observation).

In general terms, the system consists of the following main components (Fig. 2):

- Field Unit
- HydroTech Information System (HDC, HydroTech Data Cloud) with DSS Dynamic Optimizer
- Software and user devices for the technology transfer

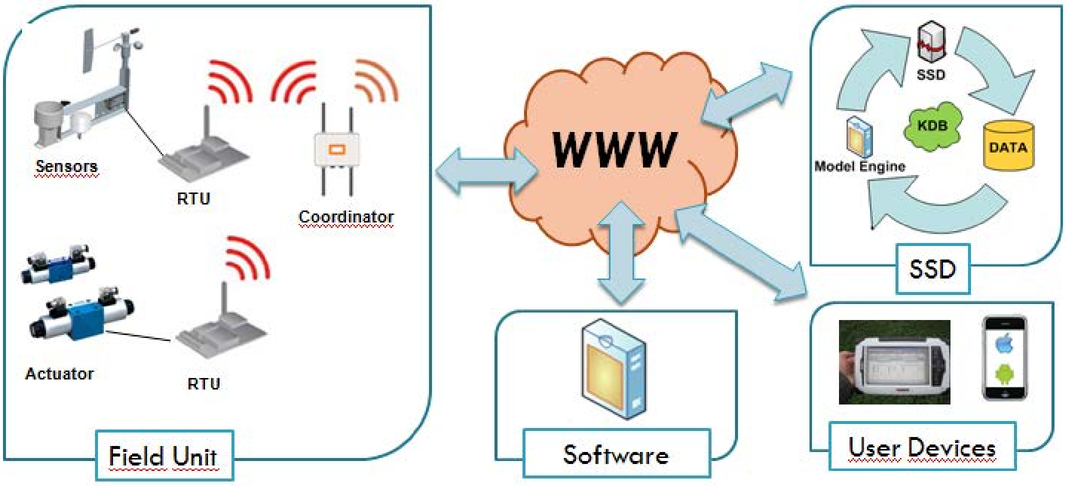

Fig. 2. General scheme and main components of the HydroTech architecture.

2.2. Field Unit

The field unit, from a logical point of view, is composed by:

- ‘sensor’ devices, connected to a microcontroller (SENS);
- ‘actuator’ devices, connected to a microcontroller (ACT);
- a ‘coordinator’, which is aware of the whole configuration and logics to be respected.

Each sensor/actuator station (depending on the specific configuration, sensors and actuators can be connected to the same microcontroller) can be placed in the most profitable area, in fact each SENS/ACT station is equipped with Li-Ion rechargeable battery and a solar panel in order to have the highest installation facility. The Fig. 3 shows the logic structure of the field unit.

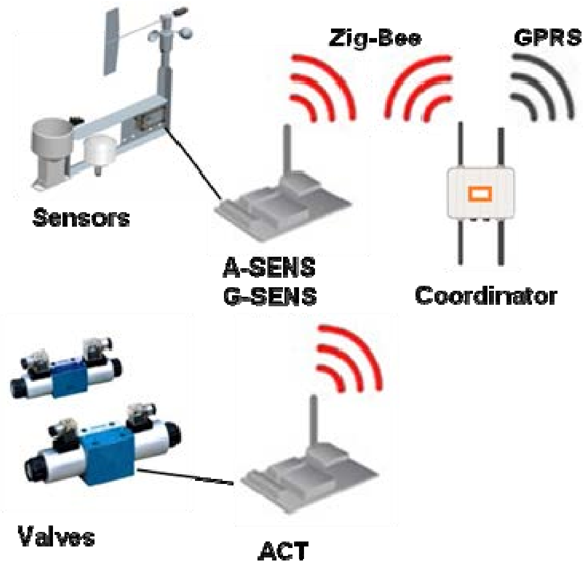

Fig. 3. Field unit: logic structure.

2.2.1 SENS and ACT stations

Data acquired by the SENS station are: 1) weather measurements: atmospheric temperature, atmospheric humidity, atmospheric pressure, solar radiation, wind direction and speed, rainfall amount. 2) soil measurements: apparent dielectric permittivity, soil volumetric water content (VWC), electrical conductivity (EC) and temperature; digital as well as analog sensors are used.

The sampling frequency can be set as preferred, successively the microcontroller is responsible for post-processing (mean, min, max, etc.). In the testing phase, given a specific farm, there is typically a single Air SENS (A-SENS) station and multiple Ground SENS (G-SENS) stations. More soil moisture sensors, placed in different points and at different depths, are connected to the same G-SENS..

The ACT station is placed in the nearby of valves to be controlled (open/close). In this case the microcontroller is responsible for commands actuation taking into account the irrigation time scheduled by the system.

2.2.2 Coordinator and connectivity

The coordinator (typically one per site) is a Linux mesh router provided with moderate computation and storage capabilities which integrates 2 different communication interfaces: ZigBee and 3G/GPRS. The first one is used to transfer data from/to SENS and ACT stations, the second one from/to the cloud system able to perform the Decision Support computations.

2.3. Hydrotech Information System: core components

In Fig. 4, a general overview of the ‘HydroTech Information System’ is given, to represent the main communication and elaboration flows of data and information.

The ‘Grib Data Manager’, ‘WS Data Manager’ and ‘Ground Data Manager’ packages process all input data and store it into a central remote database. The ‘Model Engine’ is the system core and has two different execution modes: 1) ‘on-demand’ or ‘stand-alone’: user interacts with the system and can execute the Model Engine to update field data and observations; 2) ‘services’ or ‘auto-run’: each day the model engine automatically calculates specific irrigation and fertilization plan.

The Model Engine consists of four software modules:

- FIELD WATER BALANCE: this module calculates crop water balance using measured and forecast meteorological data.
- FERTILIZATION: the module supports fertilization activities calculating the correct amount of different fertilizers to provide for each crop;
- DATA QUALITY CONTROL: this module checks data quality in order to identify wrong data and substitute them with calculated ones;
- DYNAMIC OPTIMIZER: this software module supports the user, designing a specific irrigation strategy according to specific objectives;
- ANDROID & WEB PAGE: these modules are responsible of interaction between users and the system using internet devices (mobile, web) through Web Service functionality;
- JAVA: this module is the desktop interface of HT-DSS, interacting through TCP/IP protocol.

2.3.1 Dynamic Optimizer (DSS)

Models for optimal irrigation scheduling have been developed by several researchers based on mathematical formulations within the framework of dynamic programming. Such models are, however, generally suited for long-term decision-making and solve essentially the problem of water allocation during the growing season. Few attempts have been made at developing real-time irrigation scheduling models that consider short-term weather forecasts for optimal irrigation decisions (Bergez *et al*., 2002; Gowing and Ejieji, 2001).

The HT-DSS uses the so-called ‘Dynamic Optimizer’ to calculate the optimal irrigation scheduling (‘when’ and ‘how much’ water to apply) with the goal to maximize irrigation efficiency reaching an optimal trade-off between crop water needs and water availability (Todorovic *et al.*, 2013; this issue). To achieve this, the Dynamic Optimizer takes account of the progress in crop-soil water balance (as simulated by both measured and forecast data), the information about the irrigation system and the irrigation strategy as selected by the user (Fig. 5). The forecast data are provided by the Italian Air Force Weather Service (for 3-days forecast) and by the American National Oceanic and Atmospheric Administration ((for 7-days forecast). The main key features of the Dynamic Optimizer are:

- ‘scalability’: the Dynamic Optimizer can manage multiple irrigation units supplied by the same water source; there is not a pre-defined irrigation units configuration, and the specific configuration can be set by the user;
- ‘real time execution’: optimal irrigation scheduling is calculated in real-time whatever the farm complexity;
- ‘priority management’: if water availability is less than water needs, the Dynamic Optimizer takes account of this problem managing a priority scale among the crops based on multiple criteria;
- ‘adaptation to user behaviour’: the irrigation strategy is the way to control and adapt Dynamic Optimizer to user behaviour; e.g., the user can set the minimum or maximum quantity of water applied, the specific crop water stress sensitivity and the priority management criteria.

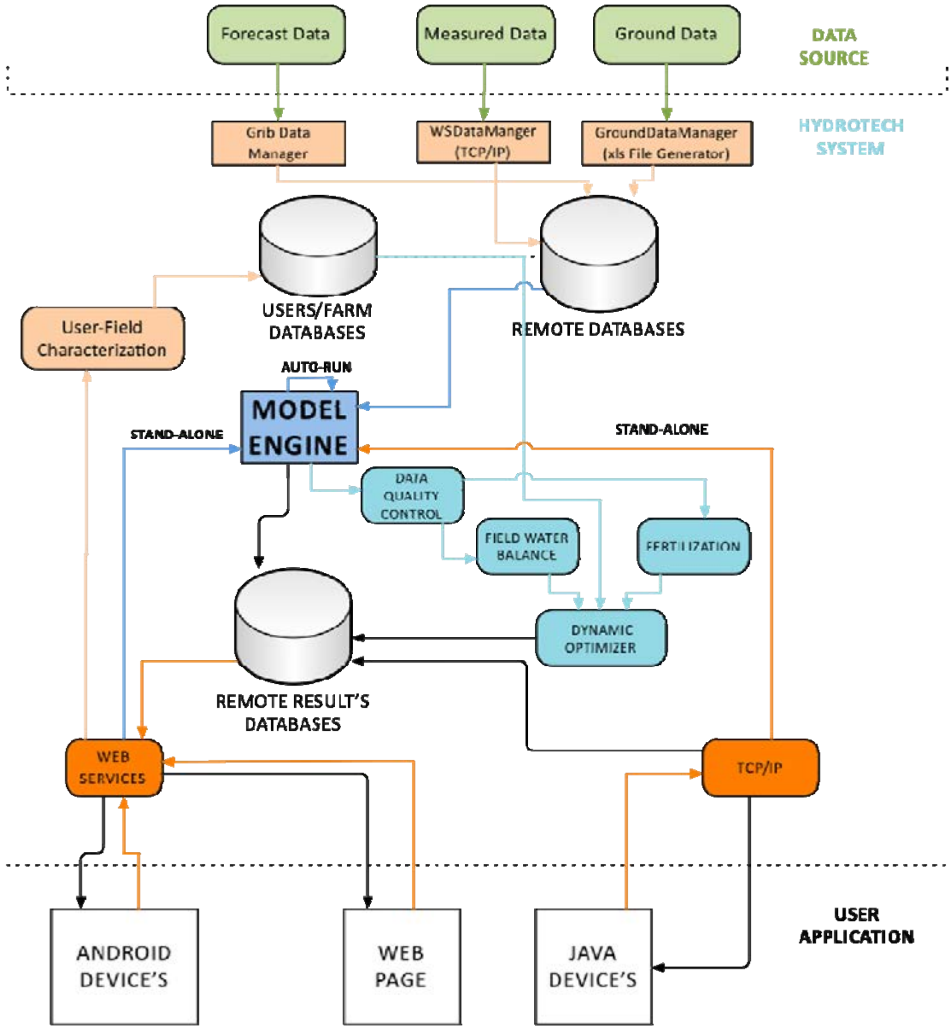

Fig. 4. Data communication and elaboration: general scheme of the HydroTech Information System.

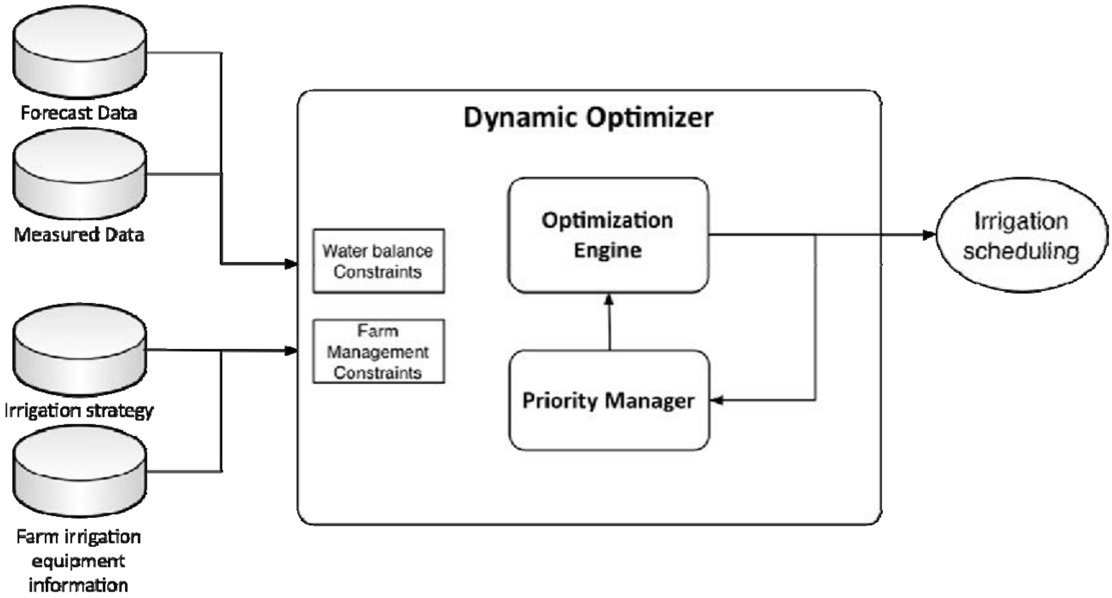

Fig. 5. Irrigation is scheduled by considering meteorological data (forecast and measured), the specific farm irrigation equipment and the irrigation strategy selected by the user. All this data are used to calculate optimal scheduling or to manage priorities in order to get sub-optimal solution.

2.4. On-field technology transfer

The expected interaction between the end-user and the information system is related to three main actions, to be undertaken under an ergonomic graphical interface: ‘data entry’, ‘consultation of results’ and ‘start of remote procedures’. According to this requirements, the system is designed according to a ‘three-tier’ architecture characterized by a user interface layer, a web-service, an application layer and a data-storage layer. The approach is compatible with the development of software components separated into independent elements, which communicate with each other according to a client-server architecture making use of well-defined interfaces, giving the whole system an high degree of scalability and maintainability.

The ‘user interface’ layer allows the fruition of the system through personal computers and smartphones/tablets from the latest generation, and is implemented as a web-application(PHP, HTML/Javascript, AJAX) for web browsers and as a mobile-application (Java) for Android devices. The web-application is supported by the most common web browsers (or W3C compliant web browsers) such as Google Chrome, Internet Explorer 8+ and Mozilla Firefox. The mobile-application is supported by Android version 2.3 Gingerbread (or newer) and correctly shown on different screen sizes such as 3.5" (Sony Xperia GO), 4.3" (Samsung Galaxy Nexus) and 10.1" (Samsung Galaxy Tab 2).

After the authentication procedure, a list of macro-areas and a list of irrigation zones is proposed to the end-user, to proceed to the detailed information on the current status of the each zone, on future weather conditions, on projections and on the irrigation advice processed by the expert system. The most significant trends are also conveniently represented graphically, such as for datasets collected from weather and ground stations. The rendering of the graphical interface is suitably decoupled from the remote content processing through asynchronous HTTP requests to the web-service, allowing user interactions while waiting for responses. The web-application implements asynchronous data exchange with AJAX technologies, showing pleasing animations and status messages during data transmission, minimizing the waiting time in the transitions between pages. The mobile-application implements asynchronous data exchange using a third-party HTTP class, managing the communication with the web-service in a separate process from the graphical interface, avoiding misleading and improper deadlock conditions during the execution of the app. The mobile-application is predisposed to the distribution of push notifications that may, for example, alert the user on the update in weather data.

The ‘web-service’ layer exposes the remote methods required for each interaction with the application-layer and the data-storage layer, and is implemented in PHP according to an RPC-style paradigm. The web-service responds with JSON objects to remote calls, if eligible. The web-application and the mobile-application takes advantage of the web-service as an interface to information and commands inside the information system, for which it constitutes an universal level of abstraction, open to the implementation of new user interfaces (such as a mobile-application for IOs and future data mining tools).

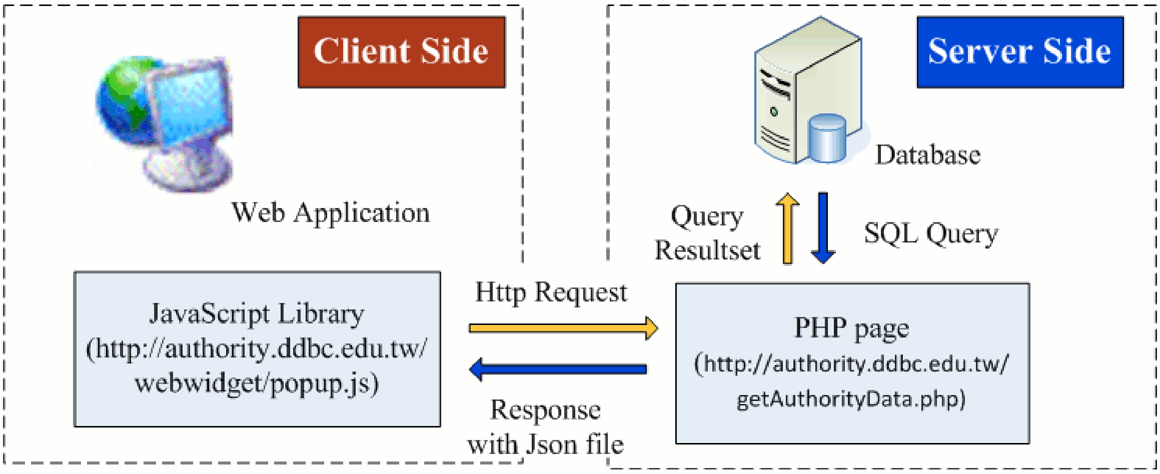

Fig. 6. Communication scheme between client and server through web services.

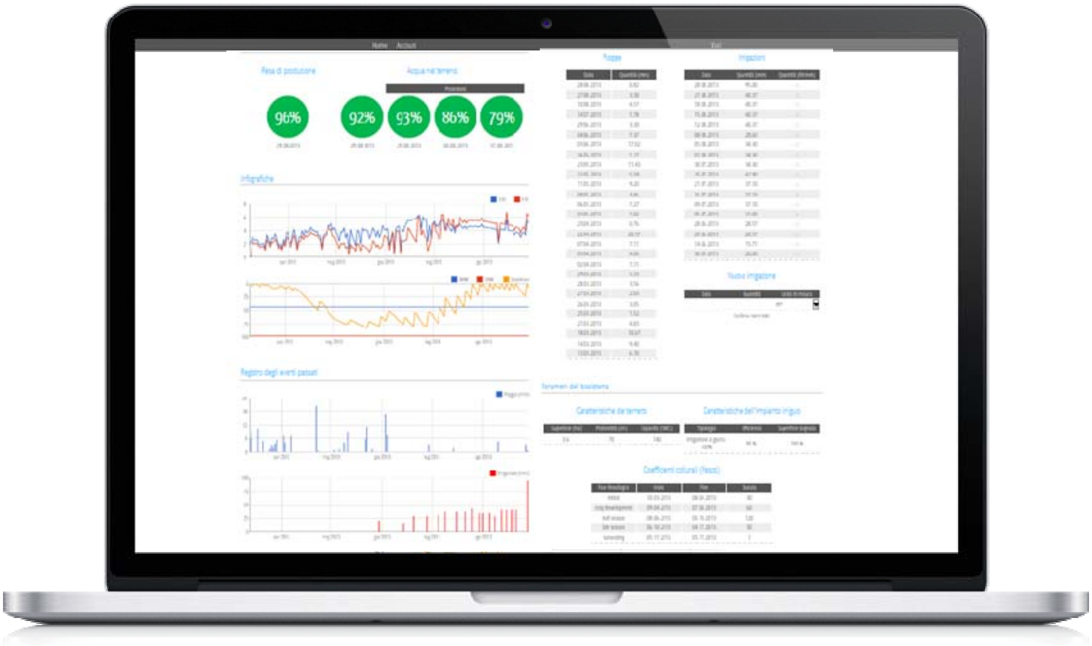

Fig. 7. Example of DESK WEB application. On the left, the following variables are displayed: current status and projected 3-days changes in the percentage of soil water content (the 'green' colour means that non stress is expected); the seasonal trend of ETo versus ETc; the seasonal trend of soil water depletion; the graph of recorded rainfall and irrigation. On the right: the complete table list of recorded rainfall and irrigation events (with the possibility for the user to add new irrigations); the table with the basic soil-crop parameters.

The 'application-layer' is the expert system responsible of the whole data processing required to find an optimal solution to the water balance equation, and is implemented in Java. The execution of the solver is launched invoking a remote method exposed by the web-service. The insertion of new inputs performed by the end-user (such as the insertion of a new irrigation) or performed at system level (such as an update in weather data) results in the loss of validity for the latest solution found: every time this condition occurs during the consultation phase, the calculation of a new solution is automatically launched without user interaction. Finally, the 'data-storage layers' is the database-server on which is recorded the whole dataset of collected and processed information, and is implemented as a relational database.

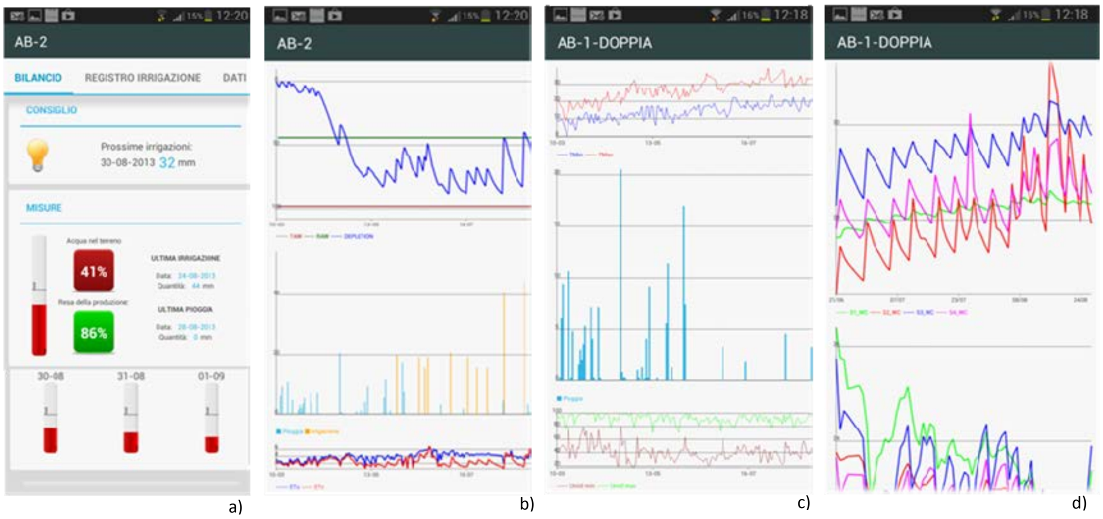

Fig. 8. Example of MOBILE Android application. The following screen display are here shown: a) suggestion of the next irrigation (day, amount), with the level of current and projected 3-days changes in the percentage of soil water content (the 'red' colour means 'under stress'); b) the seasonal trend of soil water depletion, with respect to the RAW threshold, together with the graph of rainfall and irrigations; c) meteorological variables: temperatures, daily rainfall and relative humidity; d) daily trend of soil water content at different depths as recorded by soil moisture sensors.

3. ACKNOWLEDGEMENTS

This work has been realized within the ‘HydroTech’ project, supported by the Apulia Region in the framework of the Operative Programmes O.P. Puglia 2007-2013 - European Regional Development Found (ERDF) (Axes I – Line 1.2 Action 1.2.4 – “Grants to support regional partnerships for innovation”).

4. REFERENCES

Bergez J.E., Deumier J.M., lacroix B., Leroy P., Wallach D., 2002. Improving irrigation schedules by using a biophysical and a decisional model. Eur. J. Agr. 16, 123-135.

Coates R.W., Delwiche M.J., Broad A., Holler M., 2013. Wireless sensor network with irrigation valve control. Computer Electr. Agr. 96, 13-22.

Gowing J.W. and Ejieji C.J., 2001. Real-time scheduling of supplemental irrigation for potatoes using a decision model and short-term weather forecast. Agr. Water Man. 47, 137-153.

Kim Y., R.G. Evans, 2009. Software design for wireless sensor-based site-specific irrigation. Computer Electr. Agr. 66, 159-165.

McCarthy A.C., Hancock N.H., Raine S.R., 2011. Advanced process control of irrigation: the current state and an analysis to aid future development. Irrig. Sci. 31(3), 183-192.

Romero R., Muriel J.L., Garcia, I., Munoz del La Pena D., 2012. Research on automatic irrigation control: state of the art and recent results. Agr. Wat. Man. 114, 59-66.

Todorovic M., Cantore V., Riezzo E.E., Zippitelli M., Gagliano A.M., Buono V., 2013. Hydrotech – An integrated decision support system for sustainable irrigation management (I): Main algorithms and field testing. Proc. 1st CIGR Inter-Regional Conference on Environment-Water, Bari, Italy, Sept. 10-14, 2013. (this issue)

Zapata N., Salvador R., Cavero J., Lecina S., Lopez C., Mantero N., Anadon R., Playan E., 2012. Field test o fan automatic controller for solid-set sprinkler irrigation. Irrig. Sci. 31(5), 1237-1249.