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EXEHDA-SF: a IoT Based Proposal for the Irrigation Management

Rogério Albandes, Roger Machado, João Lopes, Jorge Barbosa and Adenauer Yamin

***Abstract*— According to the National Water Agency (ANA), approximately 46.2% of all clean water used in Brazil is destined for irrigation, which has been motivating the evaluation of alternatives for water supply agricultural crops. Considering this scenario, this article presents the EXEHDA-SF proposal, which aims to explore Situation Awareness in the decision making process, with the perspective of minimizing socioenvironmental impacts. For evaluation of EXEHDA-SF a prototype was developed that integrates open-source IoT technologies to the EXEHDA middleware and explores a weather prediction service. The results achieved were promising, reaching a success rate of approximately 94% regarding the irrigation decision.**

***Keywords*— Internet of Things, Situation Awareness, Watering Automatic Control, EXEHDA Middleware.**

I. Introduction

Water is considered the most important resource for maintaining life on Earth. Of the amount of fresh water existing on the planet, the use for irrigation corresponds to about 70% of all water consumed in the world. With the need to produce food and knowing the limitation of agriculture, producers seek measures that will allow them to produce more, being irrigation one of them [1].

The design of an irrigation system can be evaluated through several performance indicators, considering the scope of this article, it is possible to highlight its operational efficiency and the costs associated with the water consumed. Inadequate water management creates a number of problems, such as lower productivity, lower quality fruits, environmental damage, soil erosion and reduced soil air, which translates into a high socio-environmental impact. In this sense, the literature has pointed out that the use of irrigation systems has been harmed by inadequate decisions regarding the moment of irrigation [2].

In 2016, the total water demand for irrigation in Brazil was 969 thousand liters per second throughout the year, amount that according to the National Water Agency (ANA[1]), corresponded to 46.2% of all clean water used in Brazil in the period [3].

Being motivated mostly by this high percentage of water consumption related to irrigation, this article discusses a system of Smart Farming (SF), that has as main objective to decide the need for irrigation, using a mechanism for Situation Awareness. As a data source for this mechanism, the information provided by a weather forecasting service is used as a logical sensor, without the use of physical sensors, thus minimizing installation, calibration and maintenance efforts.

The proposal called EXEHDA-SF (EXEHDA Smart Farming), integrates the research efforts of the EXEHDA middleware under development in the G3PD/UCPEL (Parallel and Distributed Processing Research Group), particularly those related to the evaluation of its use in real situations.

The evaluation of the proposal was done through a case study, which explored a prototyping of the proposal considering the software architecture of the EXEHDA middleware. In this case study, the EXEHDA-SF is used for monitoring the climatic conditions of the region of Pelotas city, obtained from a public service of forecast, and based on these data it evaluates the need for irrigation. The obtained results were very promising, reaching high levels of correctness, when deciding to irrigate or not.

This article is organized in six sections. This second Section presents the characteristics of the EXEHDA middleware in providing Situation Awareness. In the third Section some related papers are discussed. The fourth Section exhibits the idea of the proposal EXEHDA-SF, showing its main functions. In the fifth Section the prototyping of the proposal is discussed, being addressed the hardware and software used and the evaluation that was done. Finally, the sixth Section presents the final considerations and future work.

II. Middleware EXEHDA

The EXEHDA consists of a situation-aware middleware which aims to create and manage a widely distributed computing system environment, as well as to promote implementation of applications on it. The middleware has been explored by the G3PD on research fronts that consider the challenges of the Internet of Things (IoT) [4].

The EXEHDA has an organization formed by a set of execution cells, as it can be observed in Figure 1. Each cell, related to the provision of Situation Awareness, is formed by a server Context Server, and by various Edge Servers and/or Gateways.

The gateways collect contextual information from physical or logical sensors, and have the purpose of treating the heterogeneity of the various types of sensors, in aspects of both hardware and protocol; transfer the collected information in a standard way to the Edge Servers.

In EXEHDA the processing of contextual information is distributed, remaining a part with the Edge Server, and another

Rogério Albandes and Adenauer Yamin. Catholic University of Pelotas - Emails: rogerio.albandes@sou.ucpel.edu.br, adenauer.yamin@ucpel.edu.br; João Lopes. Federal Institute Sul-Rio-Grandense - Email: joaolopes@cavf.ifsul.edu.br; Roger Machado. Federal University of Pelotas - Emails: rdsmachado@inf.ufpel.edu.br; Jorge Barbosa. Universidade do Vale do Rio dos Sinos - Email: jbarbosa@unisinos.br

[1]http://www3.ana.gov.br/

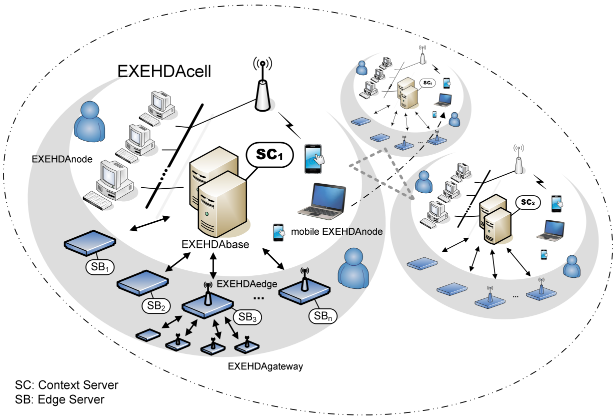

Fig. 1. Environment for the IoT provided by EXEHDA

with the Context Server (see Figure 2). The data received by the several Edge Servers are transmitted to the Context Server that manages them, and performs the storage and contextual processing steps. The Context Server can combine the data from the Edge Servers with historical information, which are recorded in the Context-based Information Repository. A broader discussion about the different functionalities of both the Gateway and the Edge Servers is available in [4]. On the other hand, an approach of the different capabilities of the Context Server can be found in [5].

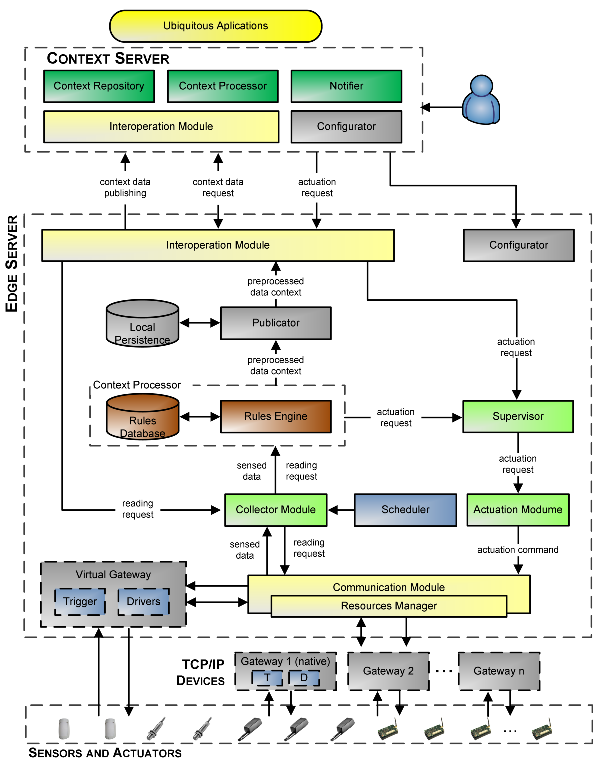

Fig. 2. Software architecture of EXEHDA to provide Situation Awareness

III. RELATED WORK

This section discusses papers related to the proposal EXEHDA-SF. A review of the literature was carried out, with the criteria for selection of the papers being its modernity and the use of methodologies associated with SF and IoT.

In paper [6] an intelligent irrigation architecture based on IoT is proposed, along with a hybrid approach based on machine learning to predict soil moisture. The proposed algorithm uses sensor data from the recent past and predicted meteorological data for soil moisture forecast for the following days.

The work [7] shows an automatic water supply system for agriculture using data from 2 sensors (soil moisture and light intensity). In addition, notifications are sent to the farm manager if there is a lack of water, and the interaction between the system and the manager is possible through the exchange of short message service (SMS) messages.

In the paper [8] a cloud-based framework and IoT are proposed to implement an intelligent irrigation system that preserves harvest during unforeseen rains, increases groundwater levels with a competent mechanism and reuses the excessive water generated during the rain for the irrigation of crops.

In the article [9] the linear regression algorithm is used, which helps in the prediction of the amount of water required for daily irrigation based on data provided by sensors scattered around the environment. The proposed system also reduces human and energy efforts. People can gain instant access to data through a mobile application.

The paper [10] uses field-scattered moisture sensors that are connected to a microprocessor (Arduino UNO). Whenever the humidity decreases below the plant wilting point, the sensors report to the system, which in turn triggers the irrigation pump, and when there is sufficient humidity, the shutdown command is sent.

Analyzing the five selected papers, among the several articles identified, it can be highlighted that EXEHDA-SF has two main differentials: (i) it does not use physical sensors, reducing installation, calibration and maintenance costs; and (ii) it explores Situation Awareness in the decision of irrigation, considering as contextual variables the volume of recent previous precipitation, as well as the forecast of occurrence of precipitation in the following hours.

IV. EXEHDA-SF: ORGANIZATION AND FUNCTIONALITIES

The organization of the software platform designed for EXEHDA-SF is presented in Figure 3. After in this section, the functionalities of the different modules will be touched, and their operational profiles discussed.

A. *Environment Interoperation Block*

The Environment Interoperation Block consists of the Forecast API Module, Communication Module and Actuator Module. This block operates on a Native Gateway of middleware EXEHDA

The Forecast API Module from the geographical coordinates of the city obtains the weather forecast data provided by the Dark Sky Service [11]. Its execution happens every hour, capturing the climatic data of the last 24 hours, and in case it has rained, the volume of precipitated water is also captured.

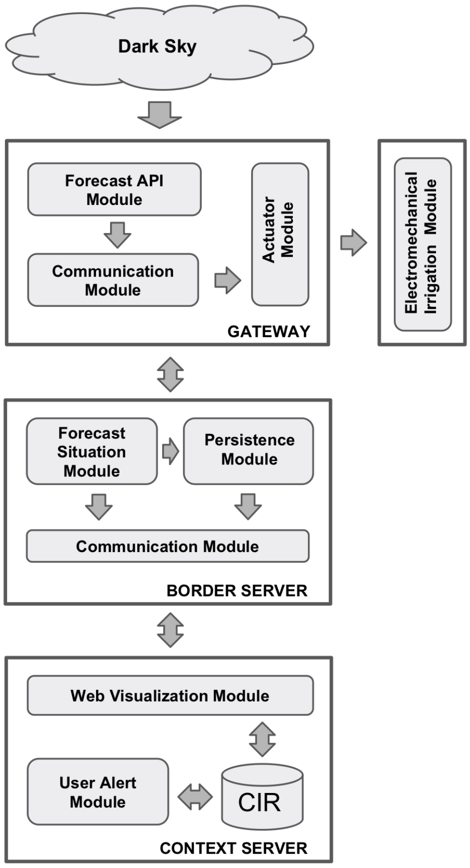

Fig. 3. EXEHDA-SF prototipation

In addition, the climatological forecast is collected for the following 24 hours, recording both the probability of occurrence of precipitation and the expected rainfall intensity. The Communication Module is responsible for transferring/receiving information and commands from the Edge Server. Finally, the Actuation Module manages the electromechanical device used to control the irrigation procedure.

B. Irrigation Control Block

Three modules form the Irrigation Control Block, which is instantiated on the EXEHDA Edge Server:

- Communication Module, which is responsible for interoperating with the User Interface Block, this functionality is instantiated in the Server Interoperation of the Edge Server;
- Persistence Module, which is intended to perform a temporary persistence if the Internet connection with the User Interface Block is lost. This functionality is instantiated on the Local Persistence module of the Edge Server;
- Forecast Situation Module, which is central to the EXEHDA-SF proposal, and is based on the Edge Server Rule Engine (see Figure 2), and it has two main responsibilities that are detailed below.

Calculation of Probability of Precipitation (PoP) It quantifies the possibility of precipitation occurrence in a given area over a specified period of time. The probability of precipitation (PoP) is defined by the product between two percentages:

- **C**: the confidence that precipitation will occur somewhere in the forecast area;
- **A**: the percentage of the area that will receive precipitation if it actually occurs.

Considering that there is 50% confidence (C) that a precipitation will occur and the expectation that measurable rain will occur around 80% of the area considered (A), the PoP will be 40%, that is, PoP = C x A (0.5 x 0.8) [12].

Algorithm for Irrigation Decision

In EXEHDA-SF the Irrigation Decision Algorithm is based on the moment of irrigation defined by the user and considers the rain data and its intensity, both from the previous 12 hours and from the following 12 hours. Based on the average values in the literature [13], the decision to irrigate at EXEHDA-SF will be considered as a 25mm rainfall reference and as a 60% PoP.

The 25mm reference for rainfall intensity is an international standard that consider the amount of rainwater that has accumulated in a given location over a period of time. In the International System of Units, the millimeter (mm) is used as the unit. A rainfall intensity of 1 millimeter equals the accumulation of the volume of 1 liter (L) of rainwater over a surface area equal to 1 square meter [14]. An internationally accepted distribution is shown in Table I.

TABLE I
INTENSITY OF RAIN

Intensity (mm)	Description
<5 mm	Light rain
between 5.1mm and 25mm	Moderate rain
between 25.1mm and 50mm	Heavy rain
>50mm	Violent rain

As indicated in Figure 4, if in the previous 12h there was higher volume of precipitation than 25mm, no irrigation will be triggered. Otherwise, the PoP will be considered for the next 12 hours, if less than 60% it will be irrigated. If the PoP of the following 12h is greater than 60% should be evaluated by the precipitation value; if less than 25mm the irrigation must happen.

C. User Interface Block

The User Interface Block was designed by exploring the functionality of the EXEHDA Context Server (see Figure2). This EXEHDA-SF block, besides providing information to users through the Internet, also includes persistence and notification functions.

- The CIR Module is implemented in the Context Information Repository. Particularly on the relational database functionalities. All information regarding irrigation decision making is stored;
- The Web Visualization Module provides the user with information on weather forecasts and irrigation decisions. The user is allowed to have the history records, with

the possibility of indicating the occurrence and totals considering a certain period of time;

- The User Alert Module scans the functions of the Notifier, and sends alerts to users using a public message sending platform, in this case Telegram.

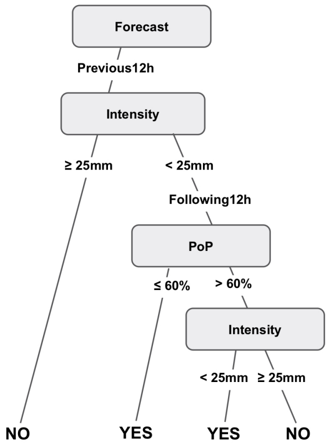

Fig. 4. Hierarchical decision structure

V. EXEHDA-SF: PROTOTYPING AND RESULTS

This section presents the decisions regarding the choice of hardware/software technologies for the EXEHDA-SF prototyping. The fact that the technology is open-source was the basic criterion for its selection.

A. Hardware Adopted

The Gateway in the EXEHDA-SF architecture explores the ESP32 NodeMCU module (5a). This module consists of an IoT-oriented System-on-a-chip (SOC), formed by a 32-bit Tensilica Xtensa dual core microprocessor with built-in support for the Wi-Fi network (802.11) and bluetooth version 4.2, and with a 16 Mb integrated flash memory [15]. Its choice is because it supports multithreading programming in Python, and because it is an open source hardware with excellent cost-benefit relation.

The Edge Server in EXEHDA-SF explores Raspberry PI III b (see Figure 5b). The used model offers network connection and for its operation an operating system called Raspbian was installed, which is a variant of the Linux's Debian distribution. The different functionalities of the Edge Server were designed through the Python Programming Language [16].

As an electromechanical actuator to control the water flow, the Hunter PGV-101G valve was used, which is supplied at 24V and offers a flow rate ranging from 0.7 to 150 l/min (see Figure 5c). This valve is triggered by a solenoid, and its choice was a consequence of both its large use in irrigation projects and its ease of interfacing with different microcontroller platforms.

B. Software Frameworks Adopted

Besides the software platforms used in the other modules of the EXEHDA middleware that are discussed in [5], [4], the following software artifacts stand out for the design of EXEHDA-SF:

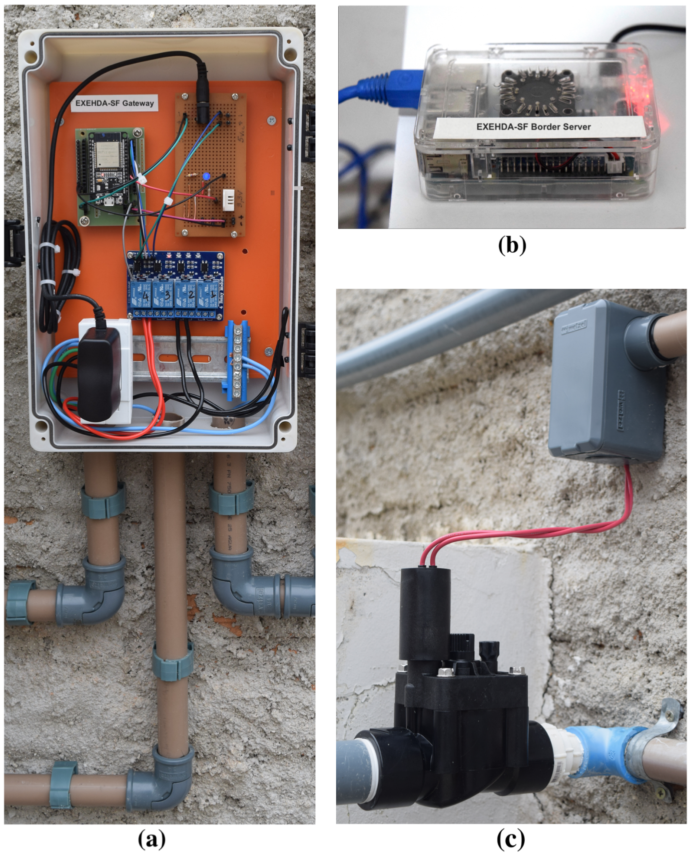

Fig. 5. Prototype developed for EXEHDA-SF evaluation

- **MicroPython:** besides implementing a selection of the main Python language libraries, MicroPython includes specific features for use with microcontrollers. In the case of the EXEHDA-SF Gateway, the "machine" library stands out, which is used to access different hardware features such as input and output ports [17].
- **Picoweb:** also in the Gateway of EXEHDA-SF a web-server, named Picoweb [18], was installed, under which algorithms were developed to interpret REST commands sent via the GET command by the Edge Server, using the JSON notation. Based on these functionalities, the Communication Module has been designed, through which it is possible to implement performance commands, particularly the activation of the Hunter PGV-101G valve, which activates the irrigation.
- **Dark Sky API:** it is an API that provides hourly weather conditions for a given region [11]. In EXEHDA-SF the Dark Sky API behaves as the source of the contextual data used to infer a possible irrigation situation.

C. Evaluation

In order to evaluate the EXEHDA-SF, information about its operation were collected over a period of 90 days, with a total of 180 decision making procedures, performed twice a day. The tests were carried out in the neighborhood Las Acacias in Pelotas, RS, which is part of the forecasting task offered by Dark Sky. Its API has coverage for areas with a radius of approximately 50 km. In Table II are the total errors that were observed. Precipitation volumes were estimated with the aid of a rain gauge.

TABLE II
DECISION ERRORS BY EXEHDA-SF

Period of Measurement	$\geq$ 25 mm	<25 mm
Previous 12h	2	1
Following 12h (PoP $\geq$ 60%)	4	2
Following 12h (PoP $<$ 60%)	1	1

In the universe of 180 decision making situations made by EXEHDA-SF, a total of 11 non confirmed cases by the observation of what actually occurred, which translates into a correctness rate of approximately 94%. These non confirmed cases happened due to errors in the forecast API. For example, inconsistent values regarding rain intensity of the previous 12h, or incorrect predictions of probability of precipitation (PoP) and/or rain intensity of the following 12h.

VI. FINAL CONSIDERATIONS

The study and research effort related to the conception and development of EXEHDA-SF pointed out that the combined exploration of Situation Awareness and the Internet of Things is a promising way for computational systems to adjust their behavior regarding modifications in their contexts of interest.

On the other hand, it can be observed that the middleware-based approach can reduce the complexity of the development of situation-aware applications by providing support for the acquisition, modeling, storage and processing of the context, among other aspects. Thus, the use of middleware may release developers of context-related concerns, allowing them to focus on defining the operational rules and developing the application-specific functionality.

The high percentage of clean water used in irrigation, in the case of Brazil, 46.2% in 2016, highlights the importance of optimizing irrigation procedures for world agriculture, with the aim of improving their efficiency, contributing to the farmers who seek for alternatives that provide better use of water to meet their water requirements.

From this perspective, this paper presented the EXEHDA-SF proposal, which aims to explore the Situation Awareness in decision making for irrigation, seeking to minimize socio-environmental impacts. EXEHDA-SF aims to explore the Situation Awareness in decision making for irrigation, seeking to minimize socio-environmental impacts. In addition, the proposal does not employ physical sensors, thus reducing installation, calibration and maintenance costs. In EXEHDA-SF the decision to perform irrigation is based on rainfall data and its intensity, both from the previous 12 hours and from the following 12 hours.

The proposal EXEHDA-SF was evaluated based on data collected and information regarding its operation over a period of 90 days. In this evaluation, a success rate of 94% was obtained in the decision making, achieving promising results pointing to the continuity of the research. Among the expected future work is the expectation of observing the behavior of EXEHDA-SF throughout the 4 seasons of the year, as well as to use a machine learning algorithm to optimize the parameters used for the irrigation decision, including the difference in water consumption with the use of EXEHDA-SF.

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