Multiplatform automated system for monitoring and sprinkler irrigation control

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***Abstract*—The automation systems together with web and mobile control is a facilitator of the various processes in several areas, among them the agricultural sector. Specifically in the irrigation management, the lowest cost technology is not able to satisfy the farmer's needs, which are the correct water supply to plants and remote monitoring of the irrigation. The objective of this paper is to present a system for controlling and monitoring irrigation with a multiplatform support for both desktop and web/mobile. The system is designed to realize automatic irrigation management in order to provide the exact amount of water needed for culture, avoiding water stress both the culture and the waste of resources such as water and electricity. Additionally, the system allows remote monitoring from anywhere by means of a computer and/or mobile device by internet. This work was developed during the undergraduate mentorship of the authors.**

***Index Terms*—Automation of irrigation, irrigation management, automated system, web, mobile.**

I. Introduction

IRRIGATION can be defined as a water management technique used mainly in agriculture [1]. This paper presents a multiplatform automated system to monitor and control the irrigation of cultures. The main purpose of the system is to control the amount of water received by the culture in a precise way, both in terms of amount of water and in terms of the right irrigation time. This assures the efficiency of the irrigation management and the productivity of the irrigated culture.

The adequate irrigation management can increase agricultural productivity, the availability and stock of produce throughout the year, given that this practice allows for production in periods of drought [2]. Besides, irrigated agriculture decreases uncertainty, insuring the economic agent (irrigating agricultor) against rain irregulaty, both annual and interannual [3]. The precise use of water also preserved this iportant hydric resource that has become increasingly scarcer in some regions of Brazil.

In order to reach its goals, this work automatizes the irrigation management process. Automation consists in a system in which mechanisms control their work with little or none human interference [4]. Process automation can be done to control or instrumentalize steps in the production process.

Productive sectors need automatization and computer use as a way to achieve greater efficiency in their processes. Sectors connected to agriculture are not different and each day their processes are becoming automatized as a way to improve them, both in terms of productivity and in terms of efficiency. Application of automatic monitoring and control in these sectors have been stimulated by the constant and big influence of computer science.

Among the advantages of automation, we can highlight the stricter control of the water usage for irrigation [5], which is done automatically by the system. This means that the moment to turn on and turn off the valves used for the irrigation is calculated automatically according to the crop, the climate conditions and the environment. Hence, we can avoid wasting hydric resources and, consequently, cooperate with the decrease of the impact that might be caused by a management performed erraticaly.

Besides the precision and efficiency of the automated system proposed in this work, it is also important to consider the flexibility added to the monitoring of the irrigation management trough the web/mobile application connected to the system. Web applications allow th euser the freedom to access them wherever and whenever he wants, as long as he has an Internet connection available [6].

Using web and mobile applications, the user is able to monitor the irrigation management from wherever he wants, using a portable computer or mobile devices such as tablets or smartphones. We hope that the success of thsi type of solutions will allow the developed technology to be replicated in crops in a national level, because the automation solution proposed here has low cost and can be implement in whichever property has an irrigation system.

Therefore, the automated system proposed here together with web and mobile applications turn a low efficiency system into a high precisioon one which can be remotely controlled and directly contribute to the productivity of the irrigated crops, besides improving the use of hydric resources and decreasing the environmental impact which is caused by an erractically controlled irrigation management.

II. Related Work

In [7], the authors mention the importance of an automated irrigation system and its elements. In this work, it is proposed a method that uses an electronic controller to turn on the irrigation valves, nowadays very common in some rural areas of Brazil. Nevertheless, this work neither takes into consideration the rain and the evaporation that occurs during the irrigation period, nor used remote access interfaces.

The authors of [8] evaluate the system performance through the soil water tension, that is, by the force the water is retained by the soil. This system uses sensors to verify the pre-established levels for each treatment and to engage the bomb in case the tensions reach those levels. Contrary to what is done by the system developed in our work, the described model does not take into consideration the amount of crops irrigated by a motor bomb, what forece the produces to use an irrigation bomb for each different crop in the property. Besides, the system does not allow for web and mobile remote monitoring.

In [9], the authors propose a remote irrigation automation system that is practical and improves the irrigated crop. The irrigation is remotely controlled by a software with an attractive graphic interface that is simple to use and work on an online platform with the client-server model. The goals behind our work are the same as in Guimaraes2012, but differently from them, the work proposed here allows the user to access the system through a web, mobile and desktop interface. Therefore, the user can monitor the automation both through the internet and through a computer or cell phone, without compromising the cultures because of a lack of Internet connection.

The authors in [10] present SisCI (Irrigation Control System using Cell Phones, in its Portuguese acronym), which is a real time system that monitors irrigation remotely getting from sensors information that is fed to the agricultor. These data can be humidity, temperature, wind speed, and atmospheric pressure in the field. Additionaly, it has a web system that together with a DBMS (Database Management System) stores all the data in the culture. Nevertheless, SisCI does not have a functionality to effectively control and start the irrigation, which is exactly the difference between that work and the one we present here. In our work, besides gathering information from the field, we also allow to start the solenoid valves using a single mouse click or allowing the software to automatically determine the irrigation time base on the calculations made by the system itself based on the local climate data (transpiration and precipitation).

In [11] the authors present a project which is divided into two systems: the first is IGmanejo, which sends SMS (*Short Message Service*) to previously stores cell phones with information on the irrigated area. This information includes identification, applied water and the time it was applied. The second piece of software is IGmanejo mobile, which intends to guide agricultors with information on the pluviometer and evaporimeter tanks. Both softwares help with decision making on management, informing the agricultor, for instance, on how much he should irrigate each field, the information on water spent and others. In spite of the softwares positive characteristics, there is no automation integrated in IGmanejo. Therefore, even if the agricultor knows how much he should irrigate, it would still be necessary to manually start and stop the system.

Table I presents a brief comparison of all the related work presented in this section.

TABLE I
Characteristics of the presented systems

Characteristic:	[7]	[8]	[9]	[10]	[11]	Este
Considers the soil water level	No	Yes	Yes	Yes	Yes	Yes
Interface for local computer access.	No	No	Yes	No	Yes	Yes
Interface for mobile device access.	No	No	Yes	Yes	Yes	Yes
Controls the irrigation of different cultures simultaneously.	Yes	No	Yes	No	No	Yes
Needs sensors to work.	Yes	No	Yes	Yes	No	Yes

III. System structure

The system has two independent but mutually related parts.The first part is a automation control desktop software that is kept in a local server connected to the personal computer responsible for sending wireless signals to the irrigation valves through the *xbee* modules. The second part supports the web and mobile systems, that is, contains a website and an app for execution in mobile devices and, therefore is stored in an online server. Both parts communicate through a database that is resoponsible for storing data from these systems. The Figure 1 gives an overview of the project structure.

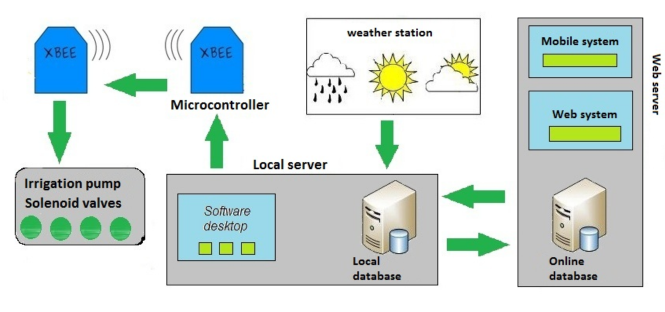

Fig. 1. General system structure.

A. Meteorological Station

The system needs an automated meteorological station that informs the amount of water received by the soil (precipitation) and the amount the soil lost (evaporation). This equipment is a data registry console, Wheaterlink software, air temperature sensor ()-40ºc to 65ºc), relative humidity sensor (0 to 100%), which stores non condesed relative humidity, wind speed sensor (0 to 67 m/s), wind direction sensor (0º to 360º), atmospheric pressure senso (880 to 1080 mb), prepitation sensor (0 to 9999mm) and a global solar radiation sensor (0 to 1800 w/m^2).

The meteorological station used in this project was the *Davis Vantage Pro 2 Wireless* model, which costs approximately R$10.000,00 in the Brazilian market and around US$600,00 plus import costs in the international market. This is an important investment whose cost may be divided by other persons interested in having the captured data, given that it covers an area of several kilometers in radius.

The data are capture in the station console through a script that executes automatic actions in the operating system, such as opening, closing and executing files. This script is programmed to execute once every hour in the computer in order to capture the necessary data that were generated by the station. Its execution interval can be changed depending on the scenario, but we used this interval because the station equipment is pre-programmed to get the meteorological data every sixty minutes.

B. Web server

Web servers receive requests though a HTTP protocol (*Hypertext Transfer Protocol*) [12]. These requests are made by clients when using a web browser. This server is the one who makes available all online context using HTML (*HyperText Markup Language*).

The web server offers the infrastructure to allocate the web system that was developed to offer more flexibility for the control of the automatized irrigation system. Besides, it also receives the data from the meteorological station every hour through FTP (*File Transfer Protocol*) file transfer.

1) Web system: The web system is an application that is hosted in the web server and accessed thorugh the Internet using a browser [13]. It does not require its own server, but it is important that it is an isolated instance from all the other applications that may also be hosted in the server. This system was developed using the programming languages PHP (*Hypertext Preprocessor*) and JavaScript, the markup language HTML and the style language CSS (*Cascading Style Sheets*).

With the web system it is possible to follow up and control the whole irrigation system without being physically present at the irrigation place. The user may turn on or off all the irrigation valves from anywhere, as long as he has Internet access and has access granted to the system. Figure 2 presentes the interface developed for this system.

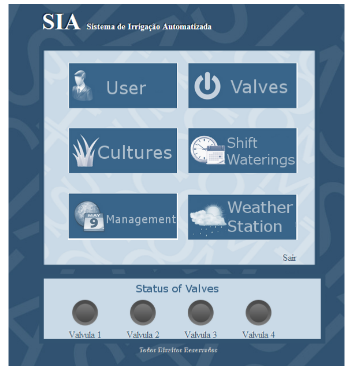

Fig. 2. Main screen of the web system.

The web system also communicates with the mobile system through a data structure called JSON (*JavaScript Object Notation*).

2) Mobile System: The mobile system is an interface of the web application to the Android operational system. This version for mobile devices was developed using the Java programming language and the XML (*eXtensible Markup Language*) markup language.

As mentioned, this application communicates with th web server, as seen in Figure 3, that is, the moile system does not communicate directly to the irrigation system - it sends requests for the web server and the latter is in charge of communicating with the desktop application.

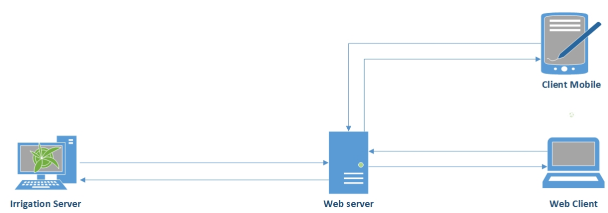

Fig. 3. Communication between the web and mobile systems.

The mobile system does not have the same functionalities as the web and desktop systems for safety reasons and also because we did not want to make the applicate so big as to hinder its execution. This version for mobile devices presented in Figure 4 focuses only on the visualization of the irrigation system, and in it the user can see which irrigation valves are turned on and which are turned of but he cannot control them. This software also has the warning resource, where the user receives a message from the application informing him if an irrigation valve was turned on or off.

C. Database

In order to manage and control the database operations, we used the SQL language (*Structured Query Language*) and in order to make it easier to manipulate the data, we also used the MySQL SGBD with the PHPMyAdmin and MySQL *Workbench* interfaces.

Besides storing the data, another function of the database in this project is the communication between

Fig. 4. Interface principal sistema *mobile* com a limitação dos menus para permitir apenas o acompanhamento das ações.

the web and desktop systems. This communication is made in a way that when the database is changed, the web and desktop interfaces are updated through data replication. This way, the applications are always updated with the same state of the irrigation system and are able to calculate precisely the necessary amount of water to irrigate.

D. Local Server

The local server is responsible for the hosting the desktop software we developed. The server used is a desktop computer with 8Gb RAM, 80 Gb HD and Windows 7 operational System. This server currently resides in the research lab of the Information Systems graduation course at the Federal University of Viçosa - Rio Parnaíba Campus.

1) Desktop Software: The desktop software is responsible for controlling and monitoring the irrigation and was developed in the Java programming language. This languagen can be interpreted on several different platforms and communicates easily with the microcontroller. This software performs all the necessary calculations and shares the results with the other applications through the database.

The software is divided into three main modules, and each module performs a specific function. Figure 5 depicts the division of these modules.

2) Capture Module: The meteorological station software generates a file in ASCCI format (*American Standard Code for Information Interchange*) with all the data captured by the station. Among the data gathered, the potential evapotranspiration (ETP) and the precipitation (P) are selected and used by the system to calculate the time and amount of necessary irrigation. Besides this information, the user must also inform some data to the system, because each region has its own climatic particularities and soils with distinct characteristics. Table II lists the data that must be inserted by the user into the system. These data are explained in detail in [14].

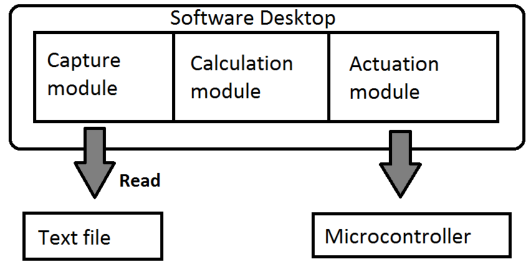

Fig. 5. Desktop software modules developed to calculate the irrigation time and to control the valves.

TABLE II
DATA THAT MUST BE INFORMED BY THE USER

Acronym	Description	Measurement Unit
CC	Field capacity	(%)
PMP	Permanent whithering point	(%)
D	Soil density	(g/cm^3)
Z	Radicular system depth	(mm)
KC	Culture coefficient	-
F	Soil Water Availability Factor	(%)
TR	Intervals in days of the watering shift	(days)

3) Calculation Module: Once the data was gathered by the capture module, the calculation module operates automatically. When the system has enough information on the irrigated crops and the watering shifts for each crop, calculations are made daily to determine the amount of water each plant must receive.

The amount of water applied to each culture is calculated based on the potential evapotranspiration (ETP) estimated by the Penman-Monteith equation with the adoption of a variable water shift. This method consists in an adaptation of the original model proposed by Penmam, in which were introduced the concepts of dossel resistance (rc) and areodynamic resistance (ra) [15]. The Penman-Monteith method is considered a standard for evapotranspiration estimatives by the ICID (International Comission on Irrigation and Drainage) and also by FAO (United Nations Organization for Food and Agriculture) [16].

In order to estimativa the potential evapotranspiration, we used the data gathered by the automated meteorological stration. The values of the water shift, crop evapotranspiration (ETC), soli available water capacity (CAD), initial easily available water (AFDi), final easily available water (AFDf) and hydric deficit (DF) are calculated according to [17]. Table III presents the necessary calculations to come to the values aforementioned.

Hence, the irrigation time is calculated exactly based on the plant DF, a very important factor to avoid the plant to suffer hydric stress caused either by the lack or the excess of water. In order to define the work time of the irrigation valves, the system uses only the DF already calculated and divides it by the volume of water thrown by the sprinkers (LA). For instance, given DF=15mm and LA = 4,8 mm/h,

TABLE III
CALCULATIONS USED TO DEFINE IRRIGATION

Calculation	Equation	Measurement Unit
ETC	CC * KC	(mm)
CAD	0,01 * (CC - PMP) * D * Z	(-)
AFDi	CAD * F	(mm)
AFDf	(AFDi + P) - ETP	(mm)
DF	(F * CAD) - AFDf	(mm)

the the irrigation time is equal to 15 divided by 4,8, which is approximately 03h07.

4) Actuation Module: Given the results found by the calculation module, the system has the precise time each irrigation valve must remain open to supply the exact water needed by each crop. The actuattion model is responsible for the communication with the microcontroller (see Section III-E), through the USB (*Universal Serial Bus*) communication port. This module sends the signals to activate and deactivate each irrigation valve. The signal sent is binary, that is 0 (zero) means that the valve needs to be turned off and 1 (one) indicates that the valve must be turned on. Figure 6 illustrates how the actuation is done.

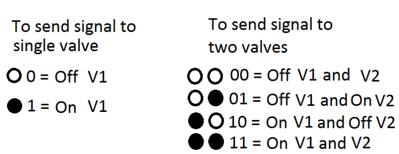

Fig. 6. Signals sent to the microcontroller to turn on the valves.

E. The Arduino Platform

Arduino is an I/O (*Input/Output*) control board based on the microcontroller Atmega (Atmel) that can control several other systems [18]. The differential of this board is that it is developed and improved by a community that opens its boards and application codes, because the board conception is *open-source*, which means that any person can make the changes it considers necessary in the board configuration.

According to [19], Arduino can be used to develop interactive objects, receiving inputs from several switches and sensors and controlling a variety of lights, motos, mechanisms and other outputs. The Arduino projects can be either autonomous or comunicate with softwares.

Arduino works as a bridge between the software and the irrigation valves on which we actuacte through the solenoid relays. Figure 7 and Figure 8 represent the solenoid relays and the irrigation valves, respectively. Once the signals are sent by the software through the USB connector, its function is to interpret those signals and turn on or off the irrigation valve through a solenoid relay.

The Arduino platform can be connected to several relay modules dimultaneously and hence, the system can control several valves in parallel. If every valvle is responsible for irrigating a different culture, it is possible to monitor the irrigation time of each one of those crops separately. Hence, the system is adapted to work in properties that need to irrigate more than one type of crop.

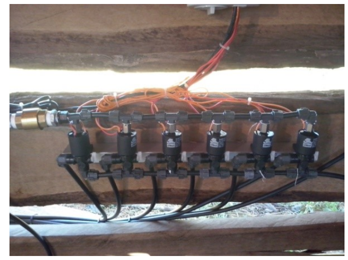

Fig. 7. Solenoid relays installed in the rural property. The relays are responsible for the opening and closing of the irrigation valves and are controlled by the system.

Fig. 8. Automatic irrigation valves installed in the rural property. The valves receive the opening and closing instructions from the system through the solenoid relays.

1) Wireless communication: The solenoid relays are connected to the irrigation valves that are in the field, that is, they are not at close quarters with the computer. Hence, it is not feasible to take electric wirtes from the valvles and motorbomb to the local serv. Hence, we use the xbee wireless kit, which is responible to take the signal the Arduino board received from the software to the solenoid relays. Since Arduino is not able to transmit a wireless signal, xbee is a module that can be added to the platform and perform this task.

This equipment must be in an cool environment and must neither be exposed directly to the sun rays nor be wet, under risk of damage or reduction of its life expectancy. Figure 9 represents the scheme of how this equipment works.

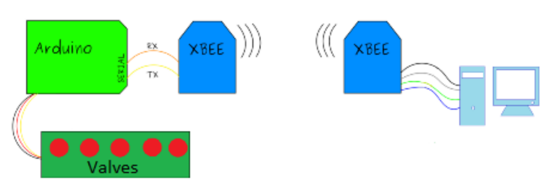

Fig. 9. Wireless communication system between the Arduino platform and the desktop system.

IV. EXPERIMENTS

THE proposed system was implemented by a team made of students and professors of the Federal University of Voçosa - Campus Rios Parnaíba. Nevertheless, its field implementation is recent and the data gathered since its implemenetation is not enough to demonstrate its efficiency, given that we need a long period of time for a reliable analysis. Hence, we used the proposed system to simulate irrigation periods based on real data gathered from the irrigation system used in the Cascudo Farm located in the Rio Parnaíba county in the state of Minas Gerais, Brazil and which is geographically located in the coordinates 19º09'48,41" South and 46º34'63" West, with altitude of 877 m. The data was gathered from 06/01/2009 to 05/21/2014, that is, for a period of five years. The farm is run by a couple, which also run it, and its income is based exclusively on milk. In order to guarantee a good milk production throughout the year, it is very important that the animal pasture is irrigated and in good condition.

This property has a semi-automated irrigation system to control water management that is applied to pasture. This system uses a controlable device that turns the irrigiation valve on and off always at the same time and for the same period of time.

The rural property in which we tested the application has nowadays twenty three pasture pickets, all irrigiated, where each picket has an area of 3300 m^2 and has twelve sprinklers whose flow rate is 1,49 m^3/h. Figure 10 presetns the division of those pickets. It is necessary to inform that five of those pickets have highly heterogeneous cultures. Hence, in onrder to assure higher precision in the calculations, we used only the eighteen pasture pickets in the simulation performed in this work. In those pickets the main species is the Braquiarão grass (*Brachiaria Brizantha cv. Manduru*) and, for this reason, the simulation performed here is based on this crop.

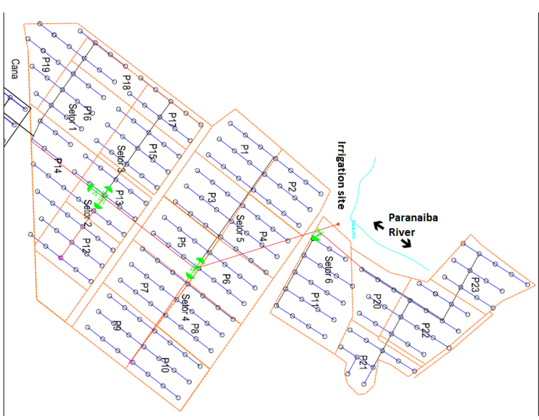

Fig. 10. Division of the pasture pickets in Cascudo Farm.

The experiment described here consists in a simulation of the application of the developed system. The simulation results are compared with thte irrigation data performed in the Cascudo farm during the same period of time. As authors, we understand that the data gathered in the real use of the application would be more appealing. Nevertheless, in order to find significant data of water economy using the platform, we would require data from long periods of time, because they can be influecned by the climate (too dry or too rainy). Additionaly, it is possible to calculate the exact water consumption by the system, because it was developed with this feature and real results should be identical to those calculated, or the system would be deffective. Nevertheless, it is not possible to estimated the consumption without the system in the same place, at the same time, for it is totally arbitrary, operated by the property workers during an arbitrary time defined by the worker himself based on his experience. Therefore, since it is possible to estimate the system consumption during a lenghty period, it is impossible to do the same without it, we foudn real data from the property prior to the system installation and made a simulation of the system application during the same analyzed period. Hence, we were able to compare data from the same place and the same period of time with and without the system.

We insist that the calculations performed in this work show the exact amount of water estimated for the periods presented in the system and that those are exactly equal to the real consumption, if the system works properly. The results are presented in Tables IV and V. In the next years, based on the application/use of the developed work, we hope to have the real/practical significative data, that is, data over a lengthy period of time.

The simulation to compare the efficiency of the proposed system and the system previously installed at the Cascudo farm was performed in the research lab of the authors alma mater. We used a computer with the characteristics described in Section III-D to execute the desktop software. The data from the meteorological station from the period of June/2009 to May/2014 were imported to the database. This way, the desktop software loaded the climate data directly from the database to perform the calculations. Within the above mentioned perior, the system calculated the irrigation necessary for every watering shifts. In order to validate the working of the valves in each shift, we connected the Arduino to a module with relays, where each relay represent an irrigation valve. Hence, we observed whether the LED (*Light Emitting Diode*) connected to the relay was automaticaly turned on by the system and also if it stayed on for the exact time the system was suposed to irrigate according to the calculations.

A. Results Found

Given the scenario we present, the values of water consumption (in liters) by the conventional method and by the calculation of the proposed system are presented in Table IV in two ways: the value to the left (outside the parenthesis) correspond to the absolute sum of the anual consumption in the 12 month period and the value to the right (inside the parenthesis) corresponds to the average consumption per irrigation during this period. It is important to point out that the conventional method used by the property consists in irrigating the property though equal length intervals and fixed times.

TABLE IV
DIFFERENCES IN WATER CONSUMPTION

Period	Conventional (l)	System (l)
01/06/2009 31/05/2010	59,218 $\times 10^6$ (1,287 $\times 10^6$)	55,962 $\times 10^6$ (1,216 $\times 10^6$)
01/06/2010 31/05/2011	61,793 $\times 10^6$ (1,287 $\times 10^6$)	58,971 $\times 10^6$ (1,228 $\times 10^6$)
01/06/2011 31/05/2012	55,356 $\times 10^6$ (1,287 $\times 10^6$)	52,878 $\times 10^6$ (1,229 $\times 10^6$)
01/06/2012 31/05/2013	60,505 $\times 10^6$ (1,287 $\times 10^6$)	58,129 $\times 10^6$ (1,236 $\times 10^6$)
01/06/2013 31/05/2014	61,793 $\times 10^6$ (1,287 $\times 10^6$)	57,995 $\times 10^6$ (1,208 $\times 10^6$)

Given the results presented in Table IV, it is possible to see that there was water economy in all studied periods. In order to verify if the difference between the results of the compared methods is significant, we applied two statistic tests. The first is the Student t-test, with 95% confidence [20]. Given that the Student t-test assumes that the variance of the samples is similar, we decide to use all the non-parametric Wilcoxon/Mann-Whitnet test for two samples with 95% confidence. The efficiency of the Wilcoxon/Mann-Whitnet test is close to 95% in comparison to parametric tests such as the t-test or the z-test, even when the data follows a normal distribution [20].

Using those statistic tests, it was possible to verify that the water economy through the system is significative for all the compared results, withing the confidence interval of the tests. Besides, the water economy, the system also allows for the economy of electricity. Table V shows a comparative of electricity expenditure using the same scenarions aforementioned. The values withing the parenthesis is the average consumption per irrigation and the value outside the parenthesis is the total consumption in the period.

TABLE V
DIFFERENCES IN ENERGY CONSUMPTION

Period	Irrigation Farm (kW)	Irrigation System (kW)
01/06/2009 31/05/2010	3128 (68)	2975 (64)
01/06/2010 31/05/2011	3264 (68)	3135 (65)
01/06/2011 31/05/2012	2924 (68)	2814 (65)
01/06/2012 31/05/2013	3196 (68)	3089 (65)
01/06/2013 31/05/2014	3264 (68)	3086 (64)

The data presented in Table V allow us to conclude that the proposed system also results in a reduction in energy consumption. In spite of this reduction is small for each irrigation performed, the system allows for a significative reduction if the whole period is considered. The statistical tests **t** and Wilcoxon/Mann-Whitney were also applied with the samples of energy consumption and they were deemed as significatively different, with 95% confidence.

In order to allow a better visualization of this economy in the long term, charts with the total consumption in both periods are presented in Figure 11 and in Figure 12.

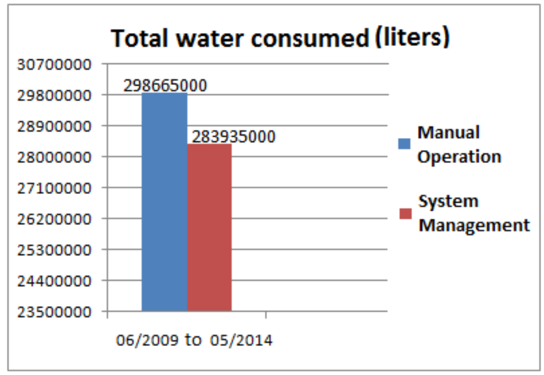

Fig. 11. Chart with the total result of water consumption

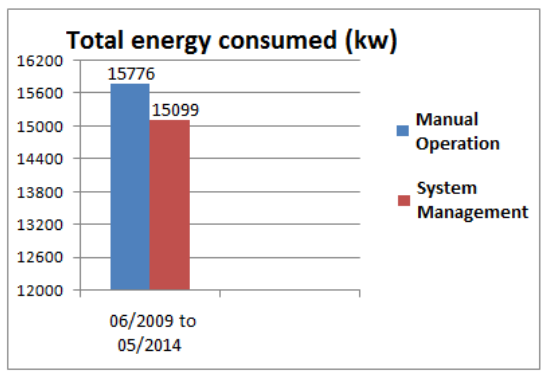

Fig. 12. Chart with the total result of energy consumption

In spite of the fact that the water and energy economy is only applciable to each irrigation period presented in Tables IV and V, the accumulated impact during the analyzed periods can be deemed as significative, because there is an economy of hundreds of millions of liters of water and thousands watts of energy, as shown in the charts above.

V. CONCLUSION

BASED on the results found in our simulated experiment, it was possible to come to the conclusion that this system can cause a considerable ecomonomy of hydric and energetic resources. It is important to point out that the results of the irrigation control system developed in this work were compared to the results of a semi-automated manual control system which is widely used to manage irrigation in rural properties all around Brazil.

The system has a relatively low maintenance cost, because the only expenses are the hosting of the web/mobile software in a web server and the electicity used by a computer (local server) turned on twenty four hours a day. Nevertheless, it is an investment that pays off with the access and safety offered by a web platform that allows for the remote management of the whole irrigation system and a mobile application that allows for visualiztion of the irrigation process in real time.

This paper does not evaluate the functional development of the system when exposed to adverse conditions of wheater, temperature, etc. As future work, the full implementation, production and replication of the system is warranted. Besides, it would also be interesting to analyze its performance in scenarios of climate adversities and day to day problems, such as power failures and Internet connection problems.

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