

Hardware and Software System for Hydric Estimation and Crop Irrigation Scheduling

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Abstract. In hydroponic crops located in underdeveloped countries, the hydric estimation is usually done manually and empirically; however, based on tropical climate, the ideal factors regarding temperature and humidity for each plant can be different. Thus, hydric estimation must be different depending on the plants because it depends on the plants species, type of soil, variety in the diameter of the roots, among others. Therefore, the hydric estimation must be done plant by plant in order to achieve a right development of every plant in a desired crop. In this paper, we present an approach based on software and hardware components integration, which is able to calculate the crops evapotranspiration and to make hydric estimation based on the ideal factors of each plant and the experimental data collected from each species in order to minimize the use of water in irrigation processes and to ensure the right development of plans.

Keywords: Hydric estimation · Crop irrigation · Hardware and software

1 Introduction

Agriculture has a fundamental role in the economic development of underdeveloped countries, where the main function is focused on providing food and the necessary resources for the development of other activities. The study and contributions made in this field are very important for countries in order to have the possibility of excelling in the production and export of agricultural products. Then, the control of the water allows the diversification of crops, stabilizes and increases their performance allowing more seasons of good harvests. Moreover, improved water control enables crop diversification, stabilizes and increases crop yields, and enables more cropping seasons [8].

Most crops do not have intelligent irrigation systems, which decreases the probability of finding a system to measure the hydric need of each plant taking into account their ideal factors such as soil temperature and humidity. This

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causes that the irrigation is done sporadically wasting large amounts of water. Depending on the type of crop or species, the amount of water needed tends to vary; then, sometimes the soil absorbs the greatest amount of liquid, since plants have a certain time to absorb what is necessary for their development.

When irrigation is done manually, water dissipation is high because usually this process is done until the soil has a large quantity of liquid. However, not all chemical processes in plants are the same due to some of them absorb water faster than others. For the case of hydroponic crops, which in most cases are urban crops, normally people do not have the necessary time or knowledge to perform the proper calculation that integrates the necessary factors to validate the water needs for each plant, which would affect the crop by lack or excess of water.

We think it is important to contribute to agricultural development through automation. Then, we intend to reduce water consumption in crops based on automated processes. With this in mind, based on this work, we provide farmers of hydroponic crops a tool for calculating the amount of water and the scheduling irrigation plant by plant. As a result, throughout the development of the harvest, the irrigation becomes an automatic process, which is monitored by farmers. In addition, for each plant, farmers can adjust attributes in the configuration of the system in order to optimize the estimation.

The paper is structured as follows. Section 2 presents the main concepts of crop irrigation. Section 3 presents the related work. In Sect. 4, we illustrate the proposed approach. Section 5 presents the results. Finally, Sect. 6 concludes the paper.

2 Crop Irrigation

Irrigation is the watering of land by artificial methods. Without irrigation, agriculture is limited by the availability and reliability of naturally occurring water from floods or rain. There are different types of irrigation to perform this function. For instance, by drip, by sprinkler, and by microject. Each one has a characteristic that makes it the most effective method according to the crop features. Nevertheless, in most cases, surface drip method required less water [4].

2.1 Hydroponic Crops

A hydroponic crop is the combination of different methods to replace the soil. The technology reduces land requirements for crops by 75% or more, and water use by 90%. Crop nutrients are contained and recycled; then, no residual salts are lost to environment. In addition, herbicides use is non-existent as well as pesticides are natural vegetable sprays and barriers [3].

2.2 Evapotranspiration

Evapotranspiration (ET) is the combination of two separated processes: evaporation and transpiration. The ET is calculated to determine the exact amount

of water that is being lost in the atmosphere. On the one hand, evaporation is the process whereby liquid water is converted to steam and removed from the evaporating surface. The water evaporates from surfaces such as rivers, lakes, vegetation, or even the pavement. On the other hand, the transpiration consists of the vaporization of liquid water contained in plant tissues [2]

ET is expressed in millimeters (mm) per unit of time and indicates the water lost in a cultivated area. Table 1 shows the factors that influence the ET, which are the climatic variables, the types of crops, and the environmental conditions of the land.

Table 1. Factors that influence ET

Factor	Description
Climate variables	Radiation, air temperature, atmospheric humidity, and wind speed
Crop	The type of crop and the stage of development must be considered when it is about estimating evapotranspiration
Environmental conditions	Low soil fertility, limited use of fertilizers, diseases and soil parasites can limit the development of the crop and reduce ET

Reference crop ET (ETo) is the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m (4.72 in), a fixed surface resistance of 70 s m^{-1} (70 s 3.2 ft^{-1}) and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground [7].

In addition, The relation between ETo and ET with a certain surface allows making the relation with other surfaces by removing the process of defining the ET level for each crop and period. Then, it is important to study the rate of ET in the atmosphere regardless of the type of crop and stage considering that the crop does not have water stress or diseases

The following concepts are required for the calculation of ETo.

- **Average temperature of the environment (T_{hr}).** It is the average between the maximum and the minimum air temperature observed during a period of 24 h.
- **Saturation pressure of steam at air temperature ($e^0(T_{hr})$).** It is the pressure of the gaseous phase for a temperature, in which the liquid water and the steam are in dynamic equilibrium.
- **Saturation pressure of steam (e_s).** It is the average of the vapor saturation pressure at maximum temperature and the vapor saturation pressure at minimum average air temperature

- **Relative Humidity (HR).** It is the division between the amount of water that the air has at certain temperature and the amount of water that it could contain if it is saturated at the same temperature.
- **Actual steam pressure derived from the temperature of the dew point (T_d).** It is the steam saturation pressure at the dew point temperature due the dew point temperature is the temperature that air needs to be cooled in order to be saturated.
- **Slope of steam pressure curve (Δ).** It is the the ratio between the saturation pressure of steam and the temperature.
- **Atmospheric pressure (p):** It is the pressure exerted by the weight of the earth's atmosphere, which is is expressed in kilo pascals (kPa).
- **Latent heat of vaporization (L_v):** It is the energy required to change a mass of liquid water unit to water steam under constant pressure and temperature.
- **Psychometric constant (γ):** It represents the air as the mixture of two gases that do not react with each other and behave almost like two ideal gases: dry air and water steam.
- **Wind speed in relation to height (U_2):** For computing the evapotranspiration and determining how it varies in time, it is necessary to express it as the average over a certain interval of time based on the wind speed.
- **Extraterrestrial radiation (R_a):** It is the daily solar radiation that is received on a horizontal surface located at the upper limit of the atmosphere.
- **Solar radiation (R_s):** It is the energy coming from the sun, which is provided by the reactions of the hydrogen in the nucleus of the sun by nuclear fusion and emitted by the solar surface.
- **Net solar radiation or long wave (Rl_N):** The amount of long wave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. The net energy flow that leaves the earth's surface is less than the calculated and given by the Stefan-Boltzmann law due to the absorption and radiation returned from the sky.
- **Net radiation (R_n):** It represents the sum of all contributions of short and long-wave radiation flows that enter and leave the surface.
- **Density of soil heat flow (G):** It measures the amount of energy transferred through the soil. Since the heat flux of the soil is small compared to the net radiation and for time periods G, it is estimated because when the soil heats, it depends on the net radiation.

ET of the crop under standard conditions (ETc) is the calculation of the ET of any crop when it has optimal soil conditions, abundant fertilizer, and without diseases. It is calculated from climatological data

2.3 Hydric Estimation

It is the process of subtracting the outputs and adding the water inputs. The inputs are: precipitation, amount of water in the previous irrigation, capillary ascent, and superficial inlet drainage. The outputs consist of ET, percolation

losses, and output drainage. The soil water balance is calculated in the Decision Support System for Agrotechnology Transfer (DSSAT) [6] based on crop models in order to evaluate the possible yield reduction caused by soil and plant water deficits [10]

3 Related Work

For the design of crop irrigation systems it is necessary to analyze the context. The peak irrigation requirement for a project or farm will depend on both the pattern of the reference ET rate and the distribution of the crop coefficient curves for the crops of interest during the growing season [10].

Zhang et al., [14] built a hardware and software scheme for the calculation in real time of ET and automatic irrigation based on the period of the crop and climatic data. To obtain them, a hardware component that sends the data to a watering server was installed. The controller in the crop determines the moment of the irrigation and performs the calculations for the water balance according to the time of harvest and the ET obtained. Our approach does not measure the factors by crop, but it does by plant, which is better for the crop.

Shah et al., [11] created a network of wireless sensors (WSN) for the harvesting grapes. The main reason for this study is to relate the requirements of optimal irrigation in terms of water savings. Sensors were deployed at a grid of 30 m by 30 m. Each node was able to transmit/receive packets to other nodes inside a well-defined transmission range of 30 m. The network collects data on humidity and PH of the soil, environment temperature, and humidity. Based on the information of said variables, decision making is made at a central node. However, in hydroponic crops there is no natural soil to optimally install a sensor mesh; then, our approach uses sensors that can go to each plant in the crop.

In Umair et al., [13], authors describe an approach for irrigation based on an artificial neural network as a control unit. Inputs of sensors located in the crop feed the network. The main function of this is to maintain the ideal moisture in front of to the real humidity of the soil. They conclude that the project fails due to limitations in the controller.

Zheng et al., [15] performed a hardware and software architecture, where installed subnodes operate through a web platform. The cloud server makes connections with the controlling subnode every minute and inquires the latest unexecuted controlling instructions, which are sent by the cloud server to the subnode. Daily, the system recompile the data stored for the calculation of ET and water balance. The hydric estimation is done by harvest and not by plant as we are considering in this project.

Shamshirband et al., [12] calculated evapotranspiration using the cuckoo search algorithm (CSA) using climate data against four ANN computer models: ANN, ANN CSA, ANFIS, and ANFIS CSA. They successfully established that the optimized version of ANFIS using CSA has better results than the ANFIS model in the training and testing phases for calculating the ETo.

4 Proposed Approach

In this project, we proposed an approach based on the integration of hardware and software components through a communications flow. A prototype was created in order to access to each plant of the crop through a coordinate system allowing accessing to every plant in real time. It performs the process for water estimation taking into account the temperature, plant humidity, crop ET, ideal factors of the plant, and the floor space for each plant.

4.1 System Architecture

Our solution consists in an environment made up of several hardware and software artifacts. Each artifact has a main function and a direct communication with another artifact. The architecture is presented in Fig. 1. It includes four artifacts: central system, client application, master component, and slave component.

– **Central system.** It has the process for sending requests to the master component. It consists in searching the plants with programmed irrigation during the day. Based on this, it sends a request to the slave component to measure temperatures and humidity to calculate the ET.

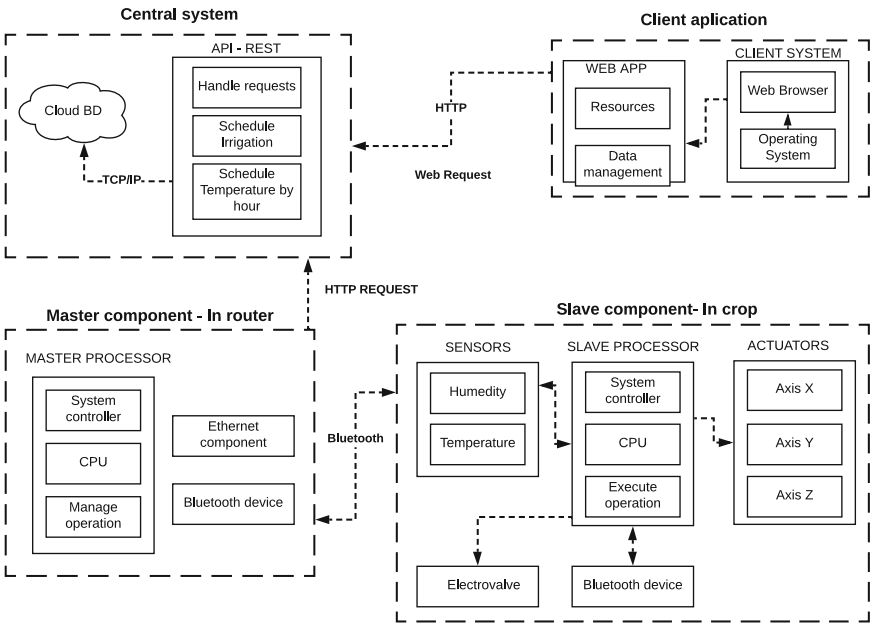

Fig. 1. System architecture

This environment consists of two components, the API-REST developed with the loopback framework for Node.js[1], which has communication through TCP/IP protocol to the second components that is a non-relational database created in MongoDB[2] that stores the information from sensors, irrigation, data of the plants, and data of farmers.
In addition, the API-REST manages three modules: (a) *handle request*, which is a listener that responds the requests of the clients, (b) *schedule irrigation*, which is a process that obtains the necessary data to sort the humidity measures and generates the corresponding irrigation to the plants of the crop, and (c) *schedule temperature by hour*, where the request is sent to the master component to take the room temperature every hour throughout the day.

- **Client application.** It is the interface for the farmer to consult the quantity of water irrigated to each plant, to create plants, and to sort irrigation. This interface has been developed with the framework Vue.js[3], which provides a web application deployed in a web browser and manages the data. Finally, it provides the necessary resources for the services of the system such as (a) management of ideal factors of each plant, (b) validation of positions for irrigation and humidity, (c) search of plants to order irrigation at any moment, (d) configuration of crop data, and (e) irrigation control for each plant per month and per day.
- **Master component.** It constantly queries the API-REST for the not performed operations and sends this data to the slave component. It is supported by the master processor, which is an arduino located in the router. It is composed of a Bluetooth module and arduino Ethernet. The Bluetooth module allows communication between the master and the slave components. For this communications the Bluetooth module was selected for two main reasons. The former is because the slave component must move along the crop; thus, a wired connection would limit its movement. The latter is because based on the arduino architecture, the Bluetooth connection is easy to configure. The Ethernet allows communication with the API-REST in order to find new tasks.
- **Slave component.** It is in the crop waiting for tasks sent by the master component. Based on the received data, its functions are: go to the plant, perform moisture-temperature measurement, and irrigate plants. This component is supported by an arduino for the execution of operations. The software core is designed to execute an incoming operation and send a response to the master component. The actuator component consists of three axes (x, y, z) for the movement towards each plant. The control system converts the analog signals of the humidity and temperature sensors into digital signals. The electrovalve is operated by time, when the operation is to irrigate a plant.

[1] https://nodejs.org/en/.
[2] https://www.mongodb.com/.
[3] https://vuejs.org/.

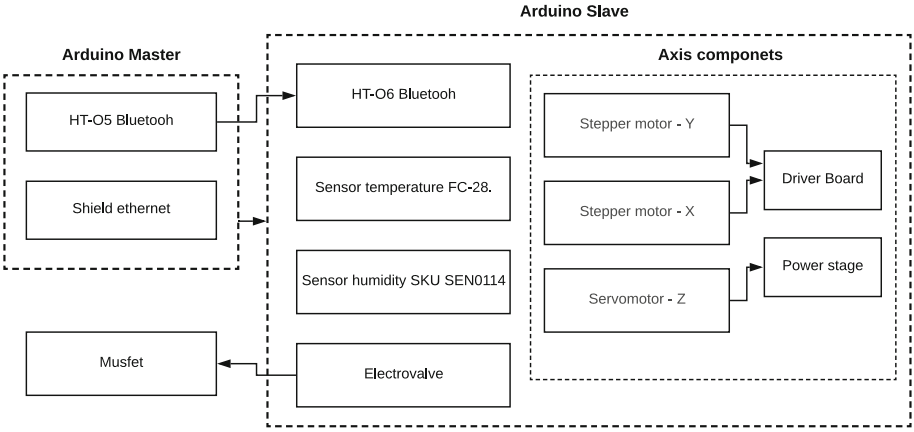

Fig. 2. Hardware subsystem architecture

Electronic Prototype. The electronic prototype is a hardware system that integrates several electronic devices. Mainly, it includes the arduino in the slave component, which operates at 5 V, in which two sensors are implemented: humidity *FC-28* and temperature *DHT11*. In addition, a Bluetooth device *HC-06*, which will sends information and receives requests. The prototype also includes two steeper motors that work at 12 V for x-axis and y-axis. They move the device to the desired position. Moreover, it includes a servomotor for the z-axis. Finally, there is an electrovalve that works at 12 V. On the other side, we have the arduino in the master component, which works at 5 V, in which an Ethernet is implemented for connecting to internet and receiving API-REST requests that will be sent through the Bluetooth device *HC-05*. Figure 2 presents the described hardware architecture.

4.2 Hydric Balance Process

In order to irrigate every plant of the crop, the system must obtain the necessary parameters for the hydraulic need, presented in Fig. 3, which has three elements: data required of measurements DB sensors, data required DB, and process in central system.

Data Required DB. This element is a database that stores all parameters of the crop, plant, and irrigation in order to provide all required information for calculating the amount of water needed by each plant in the irrigation process.

Data Required Measurements Sensors DB. These element is used to store the information obtained by the readings based on the sensors installed in the hardware. Sensors are able to read temperature and humidity for each plant in the crop.

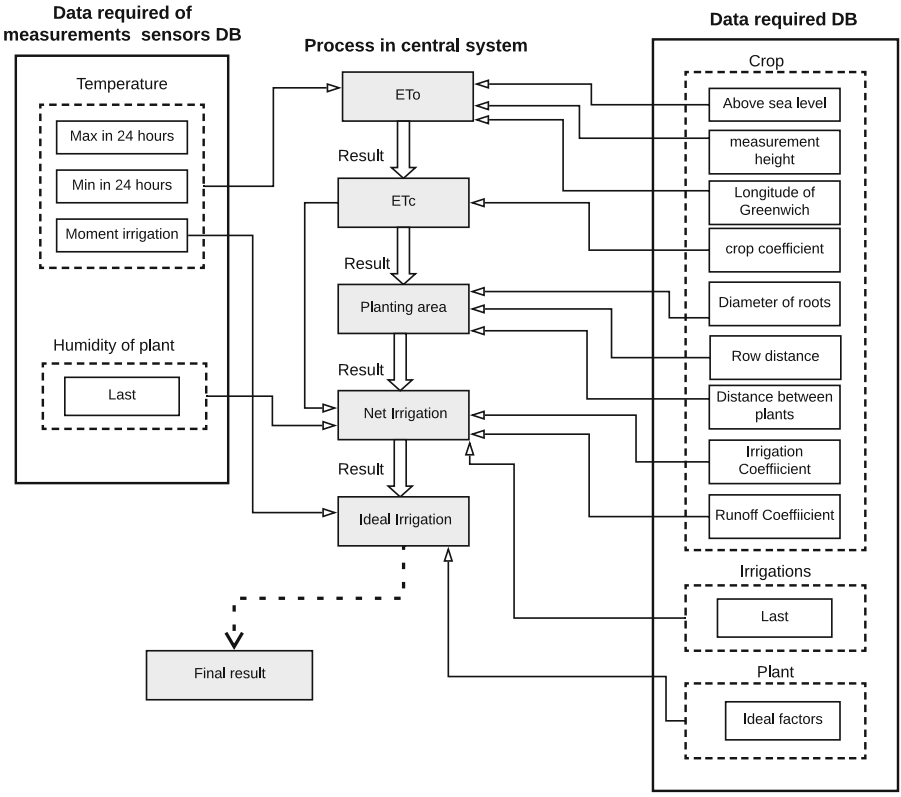

Fig. 3. Data required in hydric balance process

Process in Central System. This element consists of a flow of sub-processes for making calculations based on some input variables in order to obtain an output. These sub-processes are:

– **Evapotranspiration reference ETo**: It is the first sub-process to be carried out. It consists of four inputs and one output, which is the ETo. Equation 1, which is FAO Penman-Monteith [16], was implemented for time periods.

$$ET_0 = \frac{0,48\Delta(R_n - G) + \gamma \frac{37}{Thr+273} u_2 (e^0(T_{hr}) - e_a)}{\Delta + \gamma(1 + 0,34u_2)} \quad (1)$$

where:

ET_o	Reference evapotranspiration (mm hour^{-1})
T_{hr}	Air temperature in one hour (°C)
G	Density of heat flow in the soil (MJ m^{-2} hour^{-1})
R_n	Net radiation of the crop surface (MJ m^{-2} hour^{-1})
γ	Psychometric constant (kPa °C^{-1})
Δ	Slope of the steam precision curve (kPa °C^{-1})

U_2 Wind speed at a height (ms^{-1})
$e^0(T_{hr})$ Pressure of vapor saturation at air temperature (kPa)
e_a Real steam pressure (kPa)

The temperatures *Max - Min* are used to calculate Thr. Based on that, we can calculate $e^0(T_{hr})$, the *saturation pressure (e_s)*, and also the *steam pressure ($e_s - e_a$)*. From this, the average temperature is used to calculate the slope of the steam precision curve (Δ). In order to calculate whether data that depend on the location of the crop, the information in the database regarding sea level and longitude-latitude coordinates are used. Based on this information, we can also calculate the *extraterrestrial radiation (R_a)*. Finally the ETo is calculated.

- **Evapotranspiration of the crop under standard conditions ETc:** It refers to the crop with the following conditions: no environmental factors, good fertilization, and good conditions for crop development. Then, the input *crop coefficient (K_c)* is used to relate the ETo with the ETc, which generates an output that corresponds to ETc.
- **Planting area:** It is the third process of water balance, which consists of three inputs and one output. The first input is *Diameter of roots (r)* used to determine the floor area used by each plant. The second input is *Row distance (dh)*, which is the distance covered by each row. The third input is *Distance between plants (dpl)*, which defines the distance between plants in the row. Based on these, the result of the planting area is generated.
- **Net irrigation:** The fourth process consists of five inputs. The first input comes from *ETc*, which in the water balance is the main loss of water. The second input is last of humidity, which is obtained from the prototype before calculating the irrigation. Based on this, the calculation of the *Eto* is validated. The third input is *irrigation coefficient (K_r)*, which determines the performance, transportation, and failures in the irrigation. The fourth input is *Runoff coefficient (K_e)*, which is related to the *precipitation (P)* of rain that the crop has had as an additional water gain. The last input is last irrigation, which is the last amount of water applied.
- **Ideal irrigation:** It is the fifth process to perform. It consists of two inputs: the first input is the temperature at the time of irrigation and the second input is ideal factors stored by plant (humidity, temperature and amount of water). Based on them, we know wheather or not the plant is in condition to receive irrigation.
- **Final result:** If it is necessary to water the plant, the final result is the calculation of time in which the device will irrigate. It is determined with the volume of the hose and according to the flow or quantity of water calculated in the previous steps.

4.3 System Coordinates

The device makes two displacements for calculating the water balance. The first displacement is made to read the humidity of the plant, while the second displacement is made at the time of irrigation. In the crop, each plant has a dropper,

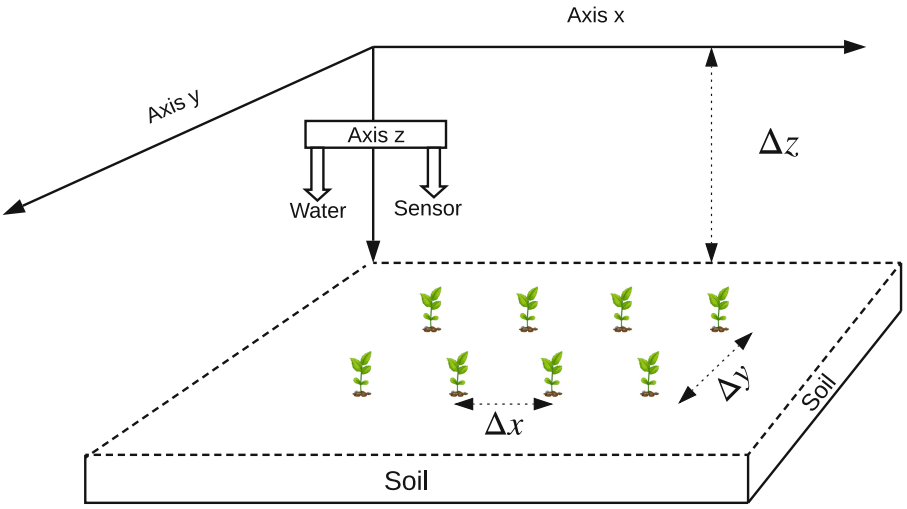

Fig. 4. Coordinate system in the crop.

where the water is deposited to perform the drip irrigation. There are three axes *(x, y, z)*, where Axes *x, y* are used for the displacement Δx and Δy respectively. The axis z is used to irrigate. Figure 4 presents the Cartesian plane implemented in the crop. It illustrates two elements for the axis z: the first one is the electrovalve for the irrigation and the second one is the humidity sensor.

4.4 Communication

The client application has a direct communication to the central system. Master and slave components communicate through Bluetooth using a data format created for this project in order to avoid data loss. Then, when the master sends information to the slave, the slave produces a response and viceversa; nevertheless, if the master or the slave go offline, the response is not received; then, the action is sent again and when the offline device goes online they recover the communication.

The central system responses using JSON format. Then, each component has a process to generate this format depending on the type of the response requested. The fundamental part of the project is in the communication between the master and the slave components. The master component is constantly consulting the API-REST as well as the operations that are carried out in the future. Table 2 presents the data that the master must send to the slave to perform the operation depending on the type, i.e., humidity reading, temperature reading, go to plant or make irrigation. Once data is sent to the slave, it returns the responses of the response slave column.

Table 2. Data between Master slave

Operation (op)	Data	Response slave
Temperature	type op	Measurement temperature
Humidity	type op, Pos x, Pos y	Measurement humidity
Go to plant	type op, Pos x, Pos y	Ok
Irrigation	type op, Pos x, Pos y, Time irrigation	Volume water

5 Results

We performed a case study, which correspond to the implementation of the system in one crop established in Bogota, Colombia, located at the coordinates: North Latitude: $4°35'56''$ and West Longitude: $74°04'51''$. The temperatures from December to March are high, but from April to October are lower. The height at sea level is 2.625 m. Tomato was taken as a study crop. The relative humidity ranges was between 70% and 80%. Root length density ranged was between 0.5 cm and 1.5 cm [9]. The ideal tomato temperature can be divided into three stages:

- Germination. According to [1], the temperature for germination is between 16 and 30 °C.
- Growth development. According to [1], the temperature for growth development is between 12 and 30 °C.
- Fructification. The ideal temperature is between 15 and 22 °C.

Then, in general, the values between 18.3 and 32.2 °C were considered ideal air temperatures for tomato during the growing season [5].

We tested the system in a crop composed of thirty plants. The distance between rows was 0.7 m and the distance between plants was 0.4 m. The crop was observed from the day 55 for the fructification stage. We studied ten plants of the thirty plants of the crop. Five plants were irrigated using the system, while other five plants were irrigated manually. During 30 days the system made the water balance for the five selected plants and manual irrigation was carried out for other plants. The irrigation was done every day at 6:00 am by drip establishing different water levels.

Humidity is measured from 0% to 100%, where 0% means that the soil is completely dry and 100% is completely wet. Throughout the process of plant development, humidity must be maintained between 40% and 70% as ideal factor.

On the one hand, Fig. 5 shows the humidity of the five plants irrigated manually, where the highest humidity was 98% achieved by the plants 2 and 3, while the lowest humidity was 0.3% achieved by the plant 3. On the other hand, Fig. 6 shows the humidity of the five plants irrigated by the system, where the highest humidity was 71.76% achieved by the plant 5, while the lowest humidity was 39.63% also achieved by the plant 5.

With this in mind, we can observe that the humidity levels for the plants irrigated by the system are in almost all cases between the ideal factors i.e.,

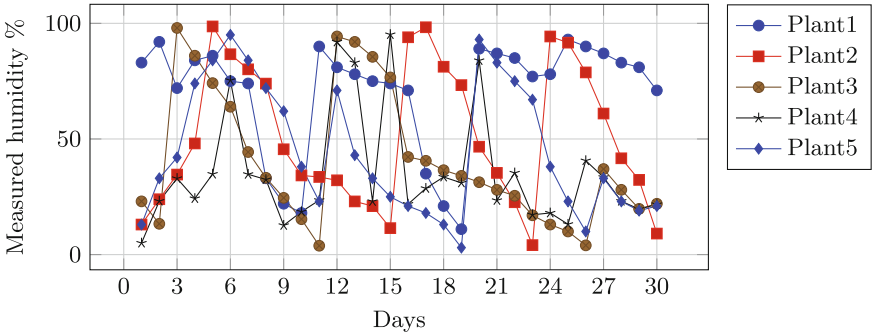

Fig. 5. Humidity measured in plants irrigated manually

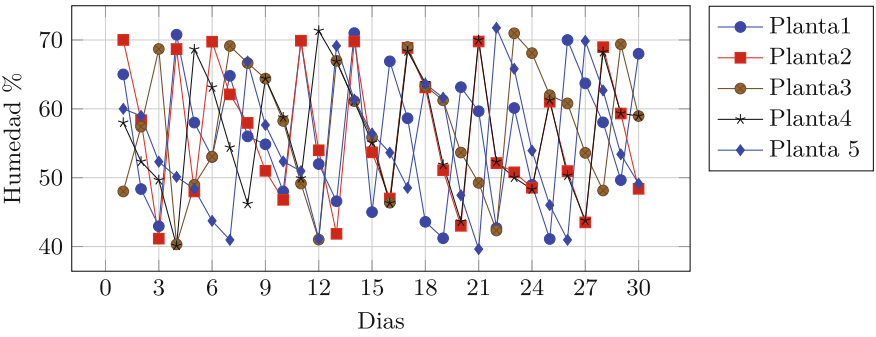

Fig. 6. Humidity measured in plants irrigated with the system

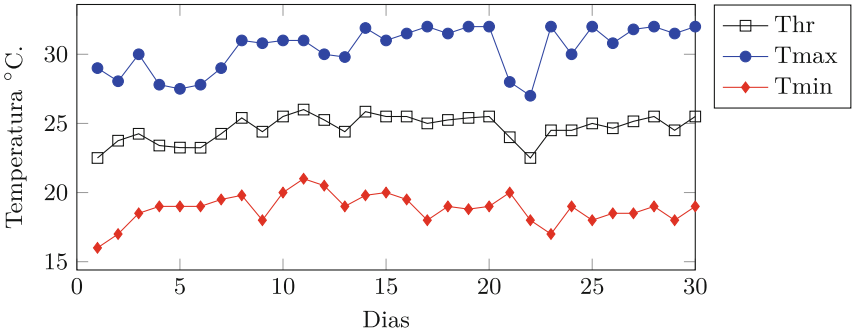

Fig. 7. Experimental temperature readings.

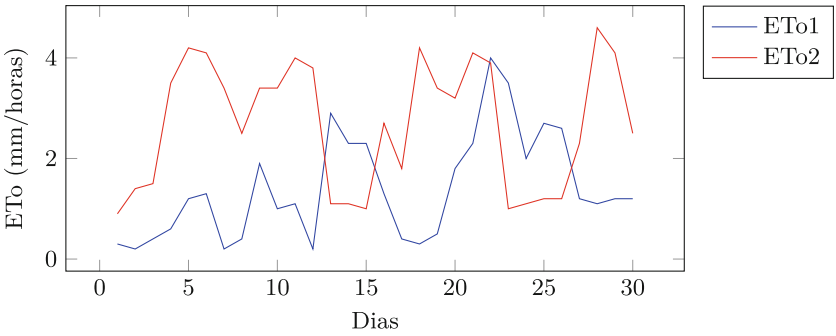

Fig. 8. Experimental data ETo.

between 40% and 70%, while the humidity levels for the plants irrigated manually are out of the ideal factors. Thus, based on the experimentation and the corresponding results, the system ensures a better irrigation process and also saving water in the crop.

In addition, Fig. 7 presents the average (*Thr*), minimum (*Tmin*) and maximum (*Tmax*) temperature per day for this period of time. These readings were obtained by the sensor installed in the prototype. Thus, the temperature oscillates between 32.00 and 16.00 °C.

Figure 8 presents the *ETo* readings in two time ranges: 06.00–07.00 (ETo1) and 14.00–15.00 (ETo2) during the thirty days. These results were dependent on *Thr* according to the min and max temperature readings 24 hours back. Then, in the crop the *Eto2* was higher in the days 1 to 13, 16 to 21 and 28 to 30. For *Eto1* it oscillated between 0.2 to 4.0 (mm/hour) and for *Eto2* it had a variation between 0.9 to 4.6 (mm/hour).

5.1 Information System

We developed a information system called *RIWA*. It reports the amount of water to each selected plant. In addition, it shows the name of the plant to which the ET calculation is made, the humidity, and the temperature at the moment of irrigation. It also informs the date in which the process was done, as shown in Fig. 9

In addition, *RIWA* allows creating the plants that are in the crop and those that the farmer wants to add. Each plant includes the attributes: name, species, alias, ideal factors such as temperature, humidity, and the amount of water. Moreover, we can simulate a crop in the system, where we can locate the plants in the area.

For the information system, we used Node.js for two reasons: it executes asynchronous processes for each operation in irrigation scheduling after saving data in order to allow the master component order operations with these values and it pulls out data in JSON format from requests HTTP in components communication.

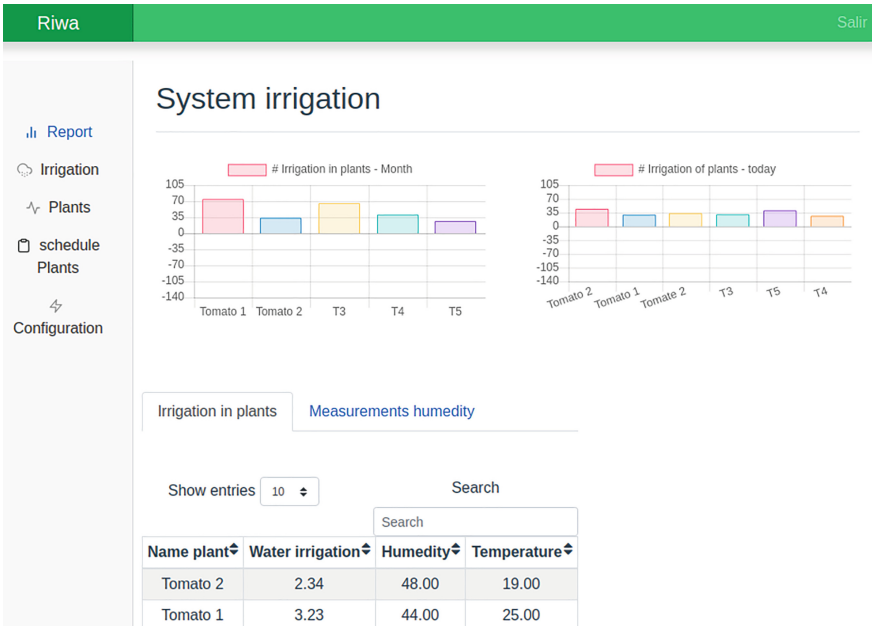

Fig. 9. Irrigation report

6 Conclusions

Based on the hardware and software system proposed, farmers can have an important tool to control the irrigation of a crop. In addition, this project facilitates the work of the farmers, since they do not have to develop the irrigation activity empirically because the prototype allows scheduling irrigation.

Using the input data, farmers can calibrate the irrigation estimate plant by plant. For the given temperatures and data of the crop, the *ETo* oscillated between 0.2 and 4.6 (mm/hour), the humidity of the plants under study was between 40% and 70%, which is considered optimal for their development. The water applied to all plants had a common margin of 2%. We think it was because they are all of the same species and ground. For future studies, it is necessary to carry out tests with different kinds of plants and soil, increase the distance between plants and rows in order to have a wider margin to irrigate plant by plant.

The experiments results allow concluding that irrigation is better in the morning when the temperatures is lower because it uses less water due to water loss by evapotranspiration ETo is lower.

References

1. Adams, S., Cockshull, K., Cave, C.: Effect of temperature on the growth and development of tomato fruits. Ann. Bot. **88**(5), 869–877 (2001)
2. Allen, R., Pereira, L., Raes, D., Smith, M.: Guidelines for computing crop water requirements. Geophysics **156**, 178 (1998)
3. Bradley, P., Marulanda, C.: Simplified hydroponics to reduce global hunger. In: World Congress on Soilless Culture: Agriculture in the Coming Millennium, vol. 554, pp. 289–296 (2000)
4. Camp, C.: Subsurface drip irrigation: a review. Trans. ASAE **41**(5), 1353 (1998)
5. Everhart, C.: The complete guide to growing tomatoes: a complete step-by-step guide including heirloom tomatoes (back-to-basics gardening) (2010)
6. Hoogenboom, G., et al.: Decision support system for agrotechnology transfer version 4.0. University of Hawaii, Honolulu, HI (2004). (CD-ROM)
7. Irmak, S., Haman, D.Z.: Evapotranspiration: potential or reference. IFAS Extension, ABE **343**, 1–3 (2003)
8. Joe Stevens, B.K.: Trends and outlook: agricultural water management in Southern Africa country report South Africa, pp. 10–18. International Water Management Institute (2015)
9. Machado, R.M., Maria do Rosàrio, G.O.: Tomato root distribution, yield and fruit quality under different subsurface drip irrigation regimes and depths. Irrig. Sci. **24**(1), 15–24 (2005)
10. Ritchie, J.: Soil water balance and plant water stress. In: Tsuji, G.Y., Hoogenboom, G., Thornton, P.K. (eds.) Understanding Options for Agricultural Production, vol. 7, pp. 41–54. Springer, Dordrecht (1998). https://doi.org/10.1007/978-94-017-3624-4_3
11. Shah, N., Das, I.: Precision irrigation sensor network based irrigation. In: Problems, Perspectives and Challenges of Agricultural Water Management, pp. 217–232. InTech, Rijeka (2012)
12. Shamshirband, S., et al.: Estimation of reference evapotranspiration using neural networks and cuckoo search algorithm. Am. Soc. Civ. Eng. **142**(2), 1–12 (2015)
13. Umair, S.M., Usman, R.: Automation of irrigation system using ANN based controller. Int. J. Electr. Comput. Sci. IJECS-IJENS **10**(02), 41–47 (2010)
14. Zhang, S., Wang, M., Shi, W., Zheng, W.: Construction of intelligent water saving irrigation control system based on water balance. IFAC-PapersOnLine **51**(17), 466–471 (2018)
15. Zheng, Q., Zhu, F., Mao, C., Lv, X.: A smart irrigation decision support system based on cloud, pp. 1–10. Undergraduate, Hohai University, Nanjing, China (2014)
16. Zotarelli, L., Dukes, M.D., Romero, C.C., Migliaccio, K.W., Morgan, K.T.: Step by step calculation of the penman-monteith evapotranspiration (fao-56 method). Institute of Food and Agricultural Sciences, University of Florida (2010)