IEEE ICA/ACCA 2016 - ISSN 0719-5567, VOL. 22, Pages 27-32, CURICÓ, CHILE, 19-21 de Octubre 2016

Automatic Control of Drip Irrigation on Hydroponic Agriculture: Daniela Tomato Production

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***Abstract*— The irrigation control and monitoring of the involved variables in the plant growth are actions that farmers must implement in their crops to save water resources and assessing the growth of the Daniela tomato plant. This work presents the control drip is applied to hydroponic farming in which is developed an interface between human and machine in a free software allowing continuous monitoring of moisture, pH, temperature and electrical conductivity of soil through the sensors housed in the crop root zone also, the controller performs the conditioning sensors, actuator control resource to irrigate water, and nutrient solution, and monitoring via web. The field implementation of the system is carried out in a tunnel-type greenhouse designed under the requirements of a hydroponic system. Finally to show the results we evaluate two experiments: Experiment one: determining hydric resourses, and nutritional requirements needed by the culturing based on monitoring of physical variables. Experiment 2; assess how media type tomato fruit have more weight and diameter.**

Keywords*— *HMI, Hydroponics, Drip Irrigation Control, Daniela tomato, Free Software

I. Introduction

Degradation is the loss of soil productive capacity in the short or long term, and it is the main problem facing the Latin America and the Caribbean floors. It is much more pronounced in Mexico and Central America, *e.g.*, water erosion affects 75% of the El Salvador area, Cuba reports that 80% of the territory is affected by some erosion process, the 49% of Chilean and Ecuadorian territory is under varying degrees of erosion, while in the Andean regions of Colombia are affected 80% by erosion [1]. Statistical studies on soil degradation through data collected over the past two decades result in a 40% erosion worldwide [2], it is caused by: increasing the population by 1.6% per year according to OMS1 [3], overgrazing, mechanized agriculture and urban sprawl. It is estimated by 2050, the population increase will require 70% more food than at current levels, but with the improvement of production systems and irrigation technology can reduce the consequences of soil degradation and conflicts between producers access to hydric resources.

In other countries despite the lack of fertile soil and scarce water resources they have developed new cultivation techniques with excellent results becoming the largest producers of soilless culture in the Mediterranean area as Almeria, Murcia, Granada [4]. These new techniques applied to traditional agriculture are called Precision Agriculture, it is a set of techniques that allow the crop localized management [5], its main feature is the integration of various technologies such as GPS, database geographical programs and sensors that allow the collection of data for electric controlling and monitoring of the involved variables in plant growth [6, 7, 8, 9].

Now a day in several countries are being implemented different soilless systems, farmers who choose to grow their products without using land as the basis for the growth of the same, they implement hydroponic farming, which is "growing in solid substrate for anchoring the roots" MAGAP [10]; in Almeria there are thousands of hectares of hydroponic crops, areas which are one of the most important centers worldwide as far as the implementation of these cropping systems are concerned; the objective of this technique is the production of different types of vegetables in short and medium term, e.g. lettuce, tomato, pepper, among others.

Also, one of the most important variables is hydroponics irrigation control to optimize water resources and obtain better quality in production. Analyzing the technologies implemented previously with respect to irrigation control and monitoring variables involved in plant growth, it is seen that systems have been developed data acquisition and supervisory control SCADA to manage the control elements of a system drip irrigation, it is intended to automate the irrigation water resources [11, 12, 13], but these systems have the disadvantage to be closed, high-cost, extremely complex and difficult to implement.

In this context, the motivation of implementing a control drip irrigation water resource and nutrient solution for growing Daniela tomato based on hydroponic farming and continuous monitoring of variables such as moisture, pH, temperature and electrical conductivity arises soil through the sensors located in the root zone of the crop appear, in which is developed a Human-Machine Interface in a free software, which has the advantage of being configurable, it is free, easy and fast implementation, furthermore the monitoring may be viewed through the web, in order to incorporate new technologies to assist in making decisions quickly, the

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optimal management and conservation of water resources for irrigation, proper plant nutrition, as well as saving money and manpower.

This work is divided into VII Sections including the Introduction, Section II formulation of the problem is considered in the design of automatic control drip irrigation in closed loop; whereas in Section III analysis of physical variables is presented showing the optimum values for plant growth; Section IV it is shown the control system of automatic drip irrigation, *i.e.*, the field implementation of the algorithm control in closed loop; while HMI design is shown in Section V, experimental field trials and the results of the two experiments are shown in Section VI; and finally the conclusions are presented in Section VII.

II. PROBLEM FORMULATION

Nowadays, the food field accounts for 30% of total electricity consumption in the world; while crops and livestock use 70% water. It is estimated that 1,800 million people will live in countries or regions with absolute water scarcity by 2025, this due to climate change, the increasing scarcity of water and its waste, soil degradation and deterioration of the base natural resources, which affect the environment. [14] That is why human being has suffered a series of changes both social and in economical sides, one of these factors is feeding [15,16, 17], people do not know what they eat and the origin of such product, they are looking for a balanced diet that contains healthy and nutritious foods that provide the needed energy for a healthy life, into this diet we have vegetables which are contaminated with different types of chemicals and batteries generated by soils and polluted rivers that cause bad product [18,19].

Facing this problem arises the need to look for new forms of crops to improve the product quality and protect the health of human beings. In this context, this work focuses on the tomato crop based on hydroponic farming. The Daniela tomato variety is the most cultivated vegetable in the world for its nutritional content and its consum in the daily diet, this kind of tomato has a strong presence in the market and adapts to different types of soils and climates obtaining higher yields than other similar variables, other features of this plant are the easy storage, handling and transport, good consistency, juicy and high quality [20, 21].

This variety of tomatoes grown outdoors need soil rich in organic matter and large water resources but, when these are grown in greenhouses and under hydroponic conditions, these plants tolerate the salinity conditions of soil better and water consumption is 45 % less than the cultivated abroad [22, 23]; also, this structure helps to intensify the production establishing appropriate measures to accelerate the development of the culture conditions, allowing higher productivity of the plant at any time of year, as well as obtaining two or more cycles of crop in the same year, that is why in this work is considered the irrigation control and continuous monitoring of the variables involved in plant growth which have to take place in a greenhouse tunnel of 72 m2.

In the greenhouse, for transplantation of Daniela variety tomato plants is done in six containers of 32 inches wide each one, where each plant is separate 30cm making 194 plants as total, 33 in the first, 34 in the second, the third 32, fourth 30, fifth 34 and 31 in the last container. Plants rest on two types of substrates: i) Rice hulls is placed at the bottom of the six containers as shown in Fig 1., in order to maintain moisture for plant roots; and, ii) The BM2 substrate is placed above the substrate rice husk in containers except the fifth where the BMPRO substrate is placed, this in order to assess which type of a tomato substrate occurs more weight, diameter and quality

Fig. 1. Collation of BM2 and BMPRO substrates respectively.

In this context, the control algorithm is implemented in closed for automatic control of drip irrigation of water resource and nutrient solution for growing Daniela tomato based on hydroponic farming and continuous monitoring of physical variables such as tie moisture, pH, temperature and electrical conductivity of the soil through the Vernier sensors housed in the root zone of the crop, so the HMI is developed in free software monitors for Arduino. Fig.2. It shows the control system of drip irrigation and monitoring of variables involved in plant growth locally and remotely.

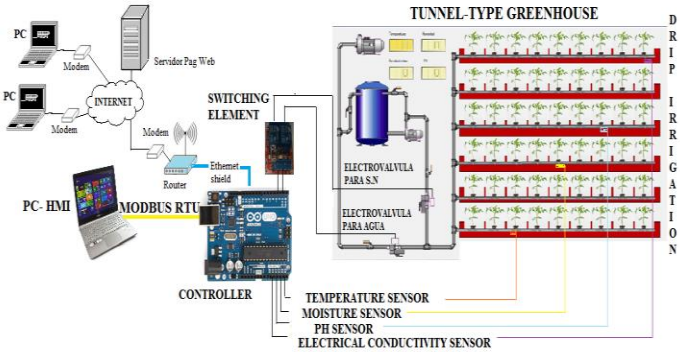


Fig. 2. Automatic control system of drip irrigation.

III. ANALYSIS OF PHYSICAL VARIABLES

Physical variables to be controlled for automation of irrigation water resource and nutrient solution must meet certain conditions for this has been made an analysis of the variables showing reference to the optimum values for the healthy growth of the Daniela tomato crop based on the requirements of a hydroponic system. In the analysis of the variables is also shown the damage that can cause the crop for high or low concentration of each variable. Table I illustrates the variables to be considered in the design of the algorithm control in closed loop, and also for setting alarms for high or low level in the HMI implemented.

TABLE I. Analysis of physical variables

PHYSICAL VARIABLES	OPTIMAL VALUES	DAMAGE N.B	DAMAGE N.A
Temperature	21-26 °C	Party Cat face	Heat stress. Radial slit
Moisture	60-75 %	Destrucción de pelos radiculares	Wilting of plants. Radial slit.
PH	5.8-6.6 n	Waste of nutrient solution by 50%.	On plant nutrition
Electrical Conductivity	1,5-3,5 ds/m	Radial slits.	Cracked concentric

N.B. Low; N.A. High.

IV. CONTROL SYSTEM OF AUTOMATIC DRIP IRRIGATION

This section describes the detailed implementation of the control system of automatic drip irrigation and continuous monitoring of physical variables involved in Daniela tomato plant growth that is why the design is mainly divided into 6 modules as Fig. 3 is illustrated.

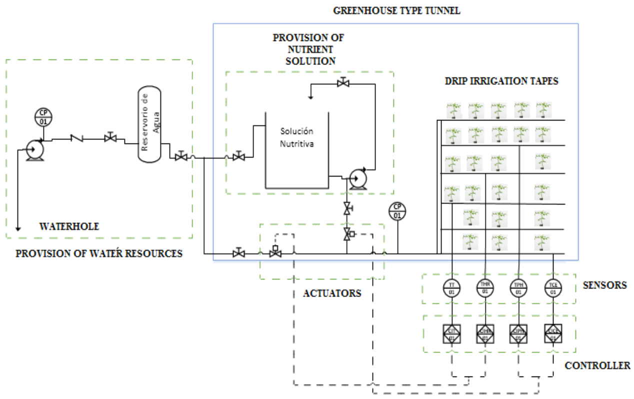


Fig. 3. Diagram of P & ID control system irrigation implemented

In this module, the water resources for irrigation is drawn from a well that is next to the control room with their respective filters which is coupling a water reservoir and a pump tank of 1hp to keep a constant pressure on the main irrigation line 10psi; *ii) Provision of nutrient solution* In this module, the nutrient solution developed for irrigation is in the reservoir tank of 60 liters which is connected to a 1/2 hp pump to maintain a constant pressure on the main irrigation line 10psi; *iii) Sensors* In this module, for measuring of temperature, humidity, pH and electrical conductivity of the soil we have used the Vernier sensors housed in the root zone of the crop and at different depths. To install sensors is made a perforation or hole on the side of the selected plant until discover the roots of the same, as shown in Fig. 4, in that place the sensor is placed and filled with part of the substrate extracted in drilling. In that way the sensor is perfectly surrounded by hollow substrate without creating air pockets, if it happens sensor readings would be incorrect. Electrical

Fig .4. Perforation or hole for the sensor placement.

connection of the sensor and communication with Arduino and the computer is verified;

iv) Controller This module is about the Arduino Uno board, operations and presented results of the HMI are implemented by the code program made on this card. The program is structured in four routines: *i) communication and measurement*, in this routine the program communicates with each of the sensors via Modbus RTU communication for Arduino. Established communication, the sensors deliver the relevant measuring the level of each physical variable in the field and this data is the inputs to the algorithm of closed loop control; *ii) monitoring*, the routine orders received data from each sensor and then display on the HMI screen made in Monitors for Arduino through tabs monitoring temperature, humidity, pH and electrical conductivity of the soil; *iii) controller,* it is an algorithm control that operates closed loop where the control action is yes or no, this is because the electro-valve solenoids irrigation has only two operating states open or closed, the algorithm determines the opening and closing of each actuator independently to water resource or nutrient solution, depending on the sensing level of humidity or temperature and pH or soil electrical conductivity respectively; temperature and humidity of water resources for irrigation; pH and conductivity for irrigation nutrient solution. The objective of this action is to maintain the levels of these variables in the established ranges in accordance with Table I. The control law acts according to a hysteresis loop in two operating limits (see Table II), the upper limit and lower limit; finally, *iv) web server*, in this routine another Arduino is placed in parallel and it is placed in the Ethernet Shield card which is used to give an IP direction to arduino, it must be connected to the router which communicates the arduino with the computer and the web.

TABLE. II. Law of control programmed in the controller.

PHYSICAL VARIABLES	CONDITION	ACTION CONTROL
Temperature	$\theta vh < \theta h - inf$ $\theta vh > \theta h - sup$ $\theta h - inf > \theta vh > \theta h - sup$	$u(k) = 1$ $u(k) = 0$ $u(k) = u(k-1)$
Moisture	$\theta vt < \theta t - inf$ $\theta vt > \theta t - sup$ $\theta t - inf > \theta vt > \theta t - sup$	$u(k) = 1$ $u(k) = 0$ $u(k) = u(k-1)$
PH	$\theta vph < \theta ph - inf$ $\theta vph > \theta pr - sup$ $\theta r - inf > \theta v > \theta r - sup$	$u(l) = 1$ $u(l) = 0$ $u(l) = u(l-1)$
Electrical Conductivity	$\theta vce < \theta ce - inf$ $\theta vce > \theta ce - sup$ $\theta ce - inf > \theta vce > \theta ce - sup$	$u(l) = 1$ $u(l) = 0$ $u(l) = u(l-1)$

*Actuators, i*n this module are the two solenoid valves of 24 volt, arranged, which perform the action of ON-OFF control, these actuators have an irrigation unit, *i.e.*, the first solenoid valve is used for the provision of water resources, and the second solenoid valve for the provision of nutrient solution, both operate by the irrigation controller (Arduino) independently.

Drip irrigation system, in this module, for controlling the drip is implemented the pressurized irrigation drip -placed drip with self-compensated emitters 3.5litros / hour in each 30cm through drip tape placed on each container and connected to the irrigation line, as shown in Fig. 5

Fig.5. Elements of the drip irrigation system.

V. HMI Design

The design of the Human-Machine Interface, HMI, is presented in this section, continuous real-time monitoring of physical variables involved in tomato plant growth as well as viewing the onset, duration and run time of water resource and nutrient solution is carried out in the Monitoriza for Arduino, available free software.

Respect to the visual design, the implemented application consists of a main window with six tabs. i) *Temperature monitoring,* (ii) *Moisture monitoring* respectively, in these tabs present the moisture and temperature measuring that each sensor gives, a history of the evolution of moisture and temperature, time start, end and duration of the last dose of irrigation water resources, the current state of the electro-valve irrigation and the reference values of humidity and temperature to effect control; iii) *pH Monitoring*, (iv) *Monitoring of electrical conductivity* y (d) respectively, in these tabs present the pH measuring and the current electrical conductivity that each sensor provides, a history of the pH evolution and electrical conductivity, time start, end and duration of the last dose irrigation nutrient solution, the current state of the electrovalve irrigation, and the reference values of pH and electrical conductivity to effect control; (V) *Trends*, in this tab trends all the physical variables involved in Daniela tomato plant growth, as shown in Fig. 6. Finally (vi) *Process*, in this tab. I could display the P&ID for drip irrigation control and monitoring of the aforementioned variables; It also presents the animation of drip irrigation and water resource nutrient solution through the drip tape; turning on and off of the solenoid valves for control action as well as the filling and vacuum reservoir tank., as shown in Fig. 7.

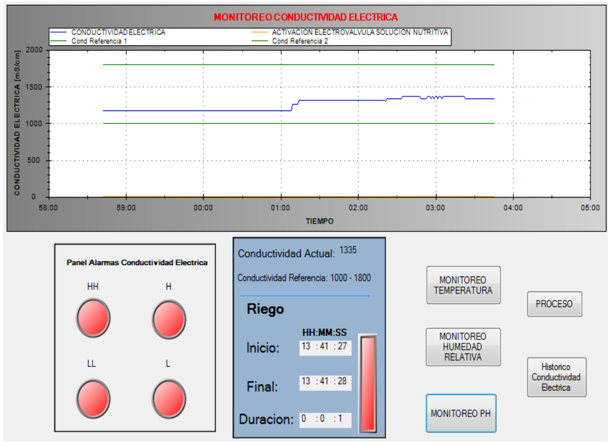


Fig. 6. Monitoring electrical conductivity

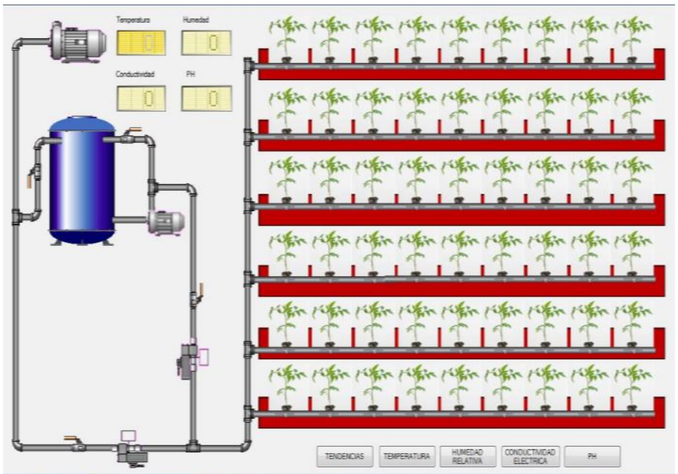


Fig.7. Process design of the control system of drip irrigation.

While in la Fig. 8. It shown monitoring by web server. This tab shows historical monitoring of physical variables, where you can choose the dates viewing of stored data.

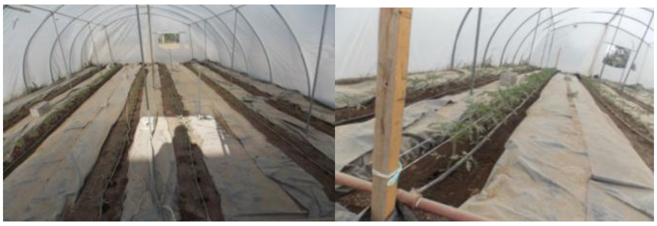

Fig. 8. Monitoring by web server

VI. Experimentation Results

Experiment 1: the objective is to maintain the physical variables such as humidity, temperature, pH and electrical conductivity at a certain level according to Table 1 to determine the water and nutrient requirements needed by the hydroponic Daniela tomato plant. In this experiment the operator defines the boundaries of each minimum and maximum variables LOW-LOW, LOW, HIGH, HIGH-HIGH for action control actuators and determination of alarm system. For drip irrigation water resources is taken into account moisture and soil temperature; for irrigation of nutrient solution takes into account the pH and electric conductivity of the soil, allowing to control of the amount of water supplied and nutrient supplied to the Daniela tomato plant. At this point, it is set to a period of two months - time where was obtained the first red fruits- for getting an average amount of water supplied and the amount of nutrient solution delivered to the tomato plants.

Experiment 2: it has as objective to assess in what kind of substrate to monitor these variables the tomato hydroponic fruit has greater weight and diameter. That is why in the tomato harvest period is made an average of weight and diameter about Daniela tomato comparing the product of two containers, a container with BMPRO substrate and another with BM2 substrate. In both experiments, the irrigation controller takes as input signal (or decision) to the measurement provided by the sensors to 15cm deep.

Here, it is shown the Daniela tomato plant growth by making the monitoring of variables of humidity, temperature, pH, soil electrical conductivity and the control of water resources for irrigation and nutrient solution, it should be mentioned that plant transplantation was on 7 September 2015. Fig 9 shows the growth plant at 7 days after transplantation, corresponding to September 14, 2015.



(a) 7 days after transplantation (b) 12 days after transplantation

(c) after a month three days (d) after two months and nine days

Fig. 9 Growth Daniela tomato plant

Daniela tomato plant transplanted into soil, four meters of greenhouse tunnel built for this project paid off at eight months, but it is remarkable the pest that is present, as shown in Fig. 10.

In Fig. 10. Is shown the growth of tomato plant under the implemented system, it is evident that the tomato fruit load and the size of the plant is increased compared with plants grown in soil.

(a) Tomato plant transplanted into (b) Maximum growth of plants

Fig. 10 Daniela tomato plant transplanted into soil

VII. Conclusions

From the technological aspect, the development of a tool to monitor and effectively control the drip irrigation system based on the measurement continues in temperature, humidity, pH and electrical conductivity on the floor using Vernier sensors in the root zone is highlighted culture. The implemented system presents is an entertaining, accurate and fast. The behavior of the system provides the watering operator a tracking tool and a database agronomist; the variables control helped to tomato production did not present potential nutritional deficiencies, and which is not observed a disease so far in the crop.

The controller performs irrigation scheduling effectively, delivering the required dose of water resources to meet the requirements of the plant, avoiding excessive doses, furthermore the proper nutrition of the plant is controlled by allowing the development time of the plant lower, obtaining the first green fruits a month making possible to obtain much production in the year.

References

[1] Organizacion de las Naciones Unidas para la Alimentación y la Agricultura, “Boletín del año Internacional de los Suelos de Amrica Latina y el Caribe”, Agosto del 2015.

[2] Organizacion de las Naciones Unidas para la Alimentación y la Agricultura, 2013. [Online]: Http://faostat3.fao.org/search/EROSI%C3%93N%20DEL%20SUELO%20/S

[3] Organización Mundial de la Salud, Noviembre del 2010. [Online]. http://sp.ria.ru/spanish_ruvr_ru/news/2014_01_01/La-poblaci-n-mundial-alcanza-7-2-mil-millones-de-personas-0330/.

[4] M. C. Juan, “La agricultura sin suelo en la región Mediterranea”, Departamento foticultural de la Estacion Experiemntal de Cajamar “Las Palmerrillas”, 2010.

[5] L.M. Matias, “Agricultura de Precisión”, Universidad de Palemo, Facultad de Ingenieria, Buenos Aires, Argentina, Tech, 2010.

[6] A, Bleicher, “Farming By The Numbers”, Spectrum, IEEE, VOL. 50, NO.6, 2013.

[7] K. Taylo. "Farming the Web of Things" , IEEE Intelligent Systems , vol. 28 , no. 6 , 2013.

[8] C.J. Rutten. "Invited Review: Sensors to Support Health Management on Dairy Farms" , J. Dairy Science , vol. 96 , no. 4 , 2013.

[9] B. Mario, M. Andres, S. Fernando y P. Federico, “Proyecto Agricultura de precisión”, Instituto Nacional de Tecnologia Agroecuaria.

[10] D. Guillermo, "Hidroponía en casa: Una actividad familiar," Sistema Unificado de Información Institucional, Ministerio de Agricultura y Ganaderia, pp. 5-10.

[11] Capraro F., Schugurensky C., Vita F., Tosetti S., Lage A., Patiño D. Intelligent irrigation in grapevines: a way to obtain different wine characteristics. 17th IFAC World Congress. Seoul. Korea.

[12] J. Gutierrez, " Automated Irrigation System Using a Wireless Sensor Network and GPRS Module", IEEE Instrumentation and Measurement Society, volume 63, no. 1, 2013.

[13] N. Karasekreter, "Developing agricultural irrigation technology compatible with national energy efficiency policy", Innovations in Intelligent Systems and Applications (INISTA), IEEE International Symposium on, 2013.

[14] Organización para la Alimentación y la Agricultura de las Naciones Unidas, junio del 2014. [Online].http://www.fao.org/fileadmin/user_upload/post-2015/FAO_TI_14themes_Spanish.pdf

[15] N. Guerrero, O. Campos and J. Luengo, "Factores que intervienen en la modificación de hábitos alimentarios no adecuados en la Provincia de Palena", Diplomado en Salud Publica y Familiar, Chile.

[16] P. Bolaños, "Evolución de los hábitos alimentarios. De la salud a la enfermedad por medio de la alimentación,España, Rep. 956-972.

[17] J. Gómez, and Salazar N, "Hábitos alimenticios en estudiantes Universitarios de ciencias de la salud de Minatitlán", facultad de enfermería, Minatitlan, México, 2010.

[18] L Traviezo J. Dávila, R. Rodríguez. O. Perdomo and J. Pérez, "Contaminación enteroparasitaria de lechugas expendidas en mercados del estado Lara. Venezuela", Argonne National Laboratory, Argonne, Venezuela, Parasitol Latinoam 59: 167 – 170.

[19] M. Calvo, D. Canaviri, O Cruz, and P. Campero, "Enterobacterias en lechugas expendidas en hipermaxi, ketal y mercado popular Rodríguez de la ciudad de LA PAZ", Universidad Mayor de San Andrés – La Paz, Bolivia.

[20] M. Resh, Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower, Seventh Edition, T. . F. Group, Ed. CRC Press, 2012.

[21] E. Saenz. "Strawberries collecting robot prototype in greenhouse hydroponic systems", Image, Signal Processing, and Artificial Vision (STSIVA), 2013.

[22] Yongxiang, "Greenhouse humidity system modeling and controlling based on mixed logical dynamical", Control Conference (CCC), 2014.

[23] L. Zhang. Model and Predictive Control Research of Four Water Hybrid System. Nanjing: Nanjing University of Science and Technology, 2013.

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