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Development of prototype and measurement, control and automation system in real time for small production greenhouses

Desarrollo de prototipo y sistema de medición, control y automatización en tiempo real para invernaderos de pequeña producción

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Abstract

The main objective of this work is to develop a real-time control system and accessible instrumentation for small production greenhouses located in the State of Guanajuato; whose goal is to increase production, make optimal use of the irrigation system and efficient water management. For this, a prototype of a greenhouse irrigation system was built with the inclusion of temperature sensors, environmental relative humidity, flowmeters, solenoid solenoid valves and soil humidity sensors, these values are compared with a numerical model to corroborate the magnitudes obtained and assess the delivery of flow and irrigation time in each section of the laboratory greenhouse. The development of a graphical interface in LabVIEW for the control and operation of sensors and the complete irrigation system stands out, being this quite intuitive and easy to use for a farmer. The results obtained from the work show differences between the measured and modeled of the hydrodynamic variables in a range of 8 to 10%, where it is concluded in an improvement in the development of the code in Arduino for its optimization in response time and migration to mobile platforms.

Greenhouse, Control, Measurement

Resumen

El presente trabajo tuvo como objetivo principal el desarrollar un sistema de control en tiempo real e instrumentación accesible para invernaderos de pequeña producción ubicados en el Estado de Guanajuato; cuya meta es aumentar la producción, hacer un uso óptimo del sistema de riego y manejo eficiente del agua. Para ello se construyó un prototipo de sistema de riego de invernadero con la inclusión de sensores de temperatura, humedad relativa ambiental, caudalímetros, electroválvulas solenoide y sensores de humedad de suelo, estos valores son comparados con un modelo numérico para corroborar las magnitudes obtenidas y valorar la entrega de caudal y tiempo de riego en cada sección del invernadero del laboratorio. Se destaca el desarrollo de una interfaz gráfica en LabVIEW para el control y operación de sensores y del sistema completo de riego, siendo este bastante intuitivo y de fácil manejo para un agricultor. Los resultados obtenidos del trabajo arrojan diferencias entre lo medido y modelado de las variables hidrodinámicas en un rango del 20 al 30%, donde se concluye en una mejora en el desarrollo del código en Arduino para su optimización en tiempo de respuesta y migración a plataformas móviles.

Invernadero, Medición, Control

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Introduction

Smart greenhouses are structures designed to provide a controlled environment for growing plants (Diaz et. al., 2019). These greenhouses use advanced technology to monitor and control factors such as temperature, humidity, light, and air composition.

These greenhouses are often equipped with sensors and automation systems that allow growers to monitor and control the growing environment remotely (Xia et. al., 2020). For example, sensors can measure temperature and humidity in real time and automatically adjust heating, ventilation, and irrigation systems to maintain an optimal environment for plant growth (Garcia et. al., 2020).

The main difference between a traditional greenhouse and a smart greenhouse lies in the degree of automation and control that can be achieved through the use of advanced technology (Wang et. al., 2018).

In a traditional greenhouse, growers rely mainly on their experience and knowledge to regulate environmental conditions, such as temperature, humidity, and lighting. This may involve manual adjustments in opening and closing windows, manual watering of plants, and constant monitoring of conditions inside the greenhouse (Li, et. al., 2018) (Li et. al., 2020).

On the other hand, a smart greenhouse incorporates technology to automate and optimize these processes. Sensors continuously monitor environmental conditions, collecting accurate data on temperature, humidity, soil quality, among others. This data is used by automated control systems to adjust and maintain the ideal parameters for plant growth.

Some of the specific differences between a traditional greenhouse and a smart greenhouse are (Liu et. al., 2019):

1. Precise control of conditions: In a traditional greenhouse, farmers must make manual adjustments based on their experience and observation. In contrast, a smart greenhouse uses sensors and automated systems to monitor and adjust environmental conditions precisely and constantly.

2. Resource optimization: Smart greenhouses are designed to maximize efficiency in the use of resources such as water, energy and nutrients. Irrigation and fertilization systems can be adjusted according to the specific needs of the plants, avoiding waste and optimizing growth.

3. Programming and automation: Smart greenhouses can be programmed to mimic natural light and temperature cycles, simulate seasons, and adapt to different stages of plant growth. In addition, many tasks can be automated, such as regulating lighting, ventilation and irrigation, reducing the manual intervention required.

4. Remote monitoring and control: Smart greenhouses allow growers to monitor and control greenhouse conditions remotely. This means they can receive notifications on their mobile devices about any changes in conditions, as well as adjust parameters from anywhere with an Internet connection.

Therefore, a smart greenhouse uses advanced technology, sensors and automated systems to provide precise and optimized control of plant growth conditions (Li et. al., 2020). This allows for greater efficiency, more rational use of resources and optimization of agricultural processes, compared to a traditional greenhouse that relies heavily on the experience and manual intervention of the farmer (Martinez, et. al., 2019) (Rallo et. al., 2019).

The present research work presents measurement and control development to optimize not only water distribution lines for irrigation by seeking to make water use more effective, but also the monitoring of environmental variables (air humidity, temperature, etc.) as well as a monitoring of greenhouse conditions for decision making.

It is worth mentioning that the development of low-cost control and monitoring allows small greenhouse growers of both crops and ornamental plants to have within reach a system that helps them to control irrigation times.

On the other hand, the development of this control and instrumentation proposal will allow future projects and research to have a reliable basis that they can analyze, increasing their range of options and deciding whether it is useful or not without having to conduct research on their own to find out. Finally, once the general objective of this research has been achieved, it will be a beneficial contribution not only for the economic and hydraulic sector, but it will also mean an advance for those producers who need to control and monitor their productions.

Materials and Methods

Governing equations

For the analysis of pressure flow in pipes, the energy equations are used, associated with the continuity equation and the friction and fitting loss formulations (Figure 1). The variables involved in simple pipe problems are as follows:

Variables related to the pipe itself: pipe diameter (d), pipe length (l) and absolute pipe roughness (ks).

Variables related to the fluid: fluid density (ρ) and fluid dynamic viscosity (μ).

Variables related to the system layout: Minor loss coefficients (hm) in all necessary fittings, including valves, as well as friction losses (hf) (Potter et al., 2002).

Variables related to fluid driving energy: Head between inlet and outlet reservoir (H) or pump power (P).

Other variables: Gravity acceleration (g) and flow rate or average velocity in the pipe (Q or v). By using the Bernoulli (eq. 1), Colebrook-White (eq. 2) equations together with the Darcy-Weisbach equation (eq. 3) we have:

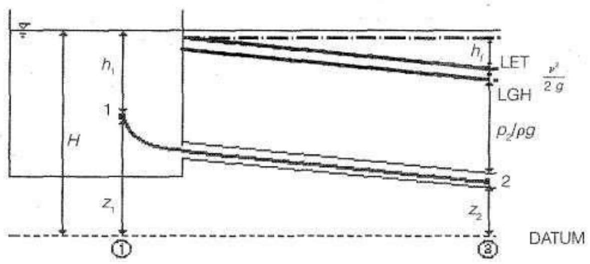


Figure 1 Representative diagram of a pipe. Point 1 is located well inside the tank in such a way that its velocity is approximately O. Point 2 is located downstream in the flow within the pipe

Source: (Saldarriaga, 1998)

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+z_1=H_p+\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+z_2+H_f \qquad (1)$$

$$\frac{1}{\sqrt{f}}=-2log_{10}\left(\frac{e}{3.7D}+\frac{2.51}{Re\sqrt{f}}\right) \qquad (2)$$

$$H_f=f\frac{L}{D}\frac{V^2}{2g} \qquad (3)$$

An equation (4) in terms of velocity that combines equations (1 to 3) and can be applicable for irrigation piping systems in greenhouses:

$$V=\frac{-2\sqrt{2gDH_f}}{\sqrt{L}}log_{10}\left(\frac{e}{3.7D}+\frac{2.51\nu\sqrt{L}}{D\sqrt{2gDH_f}}\right) \qquad (4)$$

This last equation is the basis for the solution of the simple pipe system that forms the greenhouse.

Greenhouse Physical Model

The construction of the piping system for irrigation in a greenhouse was a prototype in the applied mechanics laboratory of the Life Sciences Division of the Irapuato-Salamanca Campus; in it, six downspouts were placed to micro-sprinkler irrigation supply tables as shown in figure (2).

Figure 2 Irrigation system based on six drops with a aspersion

Each downspout has a DC-12V solenoid valve, a flow meter and a soil moisture sensor HL69, this distribution is shown in figure (3).

Figure 3 Detail of installation of lowering in irrigation table

Likewise, there are DHT sensors in each corner of the circulation system that allow obtaining the parameters of temperature and humidity, as shown in figure (4).

Figure 4 Location of the DHT sensor in a corner of the irrigation system

The physical model is fed by a 90 liter tank and a 0.5 HP pump, as well as ball valves for pipe sectioning.

At one end of the installation, there are cable drops for the control of the installation, in figure (5), the connection of the system to a computer is shown.

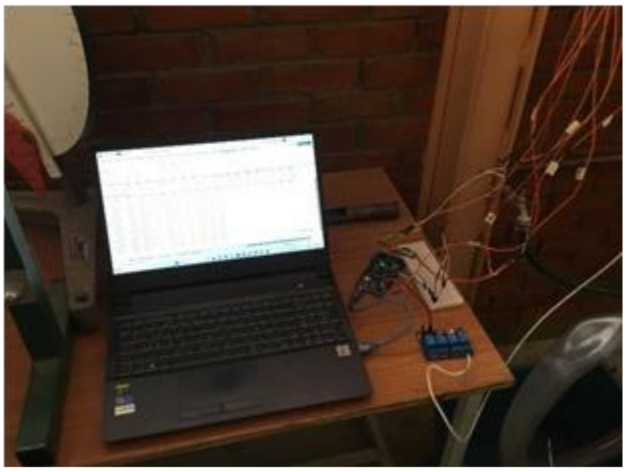


Figure 5 Connection of wires to Arduino and monitoring of values and control of sensors

The physical model of irrigation system installations is numerically modeled to obtain previously the design and characteristics of diameters, pressures, flows and velocities in all pipes.

Numerical Model

The numerical model used to calculate the hydrodynamic variables of the fluid in the pipe was the PIPE FLOW Expert, the software determines the flow, velocities and pressures at the nodes or points of interest. Figure (6) shows the design of the greenhouse piping system.

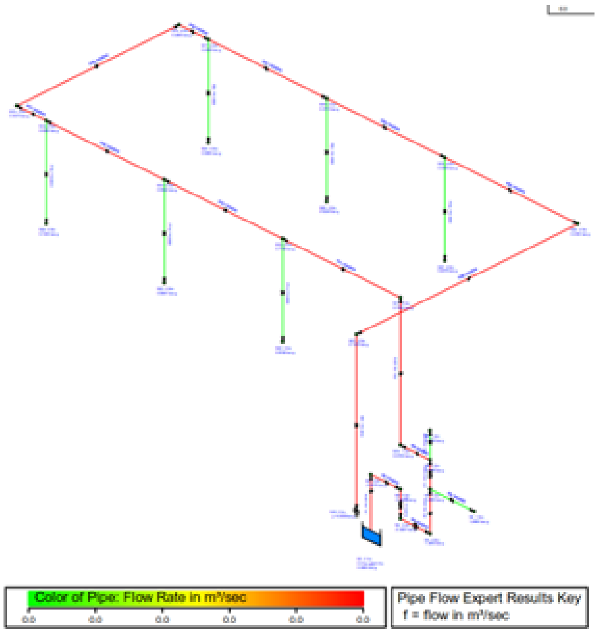
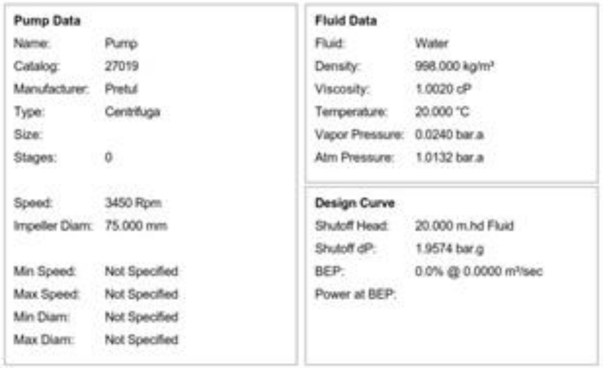


Figure 6 Greenhouse piping system and flow results in the system

The initial values are shown in figure (7).


Pump Data
Name: Pump
Catalog: 27019
Manufacturer: Pretul
Type: Centrifuga
Size:
Stages: 0
Speed: 3450 Rpm
Impeller Diam: 75.000 mm
Min Speed: Not Specified
Max Speed: Not Specified
Min Diam: Not Specified
Max Diam: Not Specified

Fluid Data
Fluid: Water
Density: 998.000 kg/m³
Viscosity: 1.0020 cP
Temperature: 20.000 °C
Vapor Pressure: 0.0240 bar.a
Atm Pressure: 1.0132 bar.a

Design Curve
Shutoff Head: 20.000 m.hd Fluid
Shutoff dP: 1.9574 bar.g
BEP: 0.0% @ 0.0000 m³/sec
Power at BEP:

Figure 7 Pump and fluid data in Pipe Flow Expert

Likewise, table (1) shows the pipes used that are PVC Hydraulic Sch. 40, with diameters of 1 inch (25 mm) and 0.5 inch (15 mm), where at the end the values of the flow, velocity and inlet and outlet pressures in each pipe are observed respectively.

Pipe Id	Pipe Name	Material	Inner Diameter	Mass Flow	Flow	Velocit y	Entry Pressure	Exit Pressure
	and Notes		mm	kg/sec	/se c	m/sec	bar.g	bar.g
1	P1	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.069	-0.058
2	P2	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	-0.058	-0.087
3	P3	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	-0.087	-0.350
4	P4	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	-0.350	1.325
5	P5	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	1.325	1.286
6	P6	PVC (ANSI) Ced. 40	26.645	0.000	0.000	0.000	1.286	1.286
7	P7	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	1.286	0.998
8	P8	PVC (ANSI) Ced. 40	26.645	0.000	0.000	0.000	0.998	0.980
9	P9	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.998	0.971
10	P10	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.971	0.783
11	P11	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.783	0.719
12	P12	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.719	0.875
13	P13	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.719	0.654
14	P14	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.654	0.809
15	P15	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.654	0.590
16	P16	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.590	0.744
17	P17	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.590	0.558
18	P18	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.558	0.461
19	P19	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.461	0.436
20	P20	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.436	0.589
21	P21	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.436	0.371
22	P22	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.371	0.523
23	P23	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.371	0.307
24	P24	PVC (ANSI) Ced. 40	15.799	0.000	0.000	0.000	0.307	0.458
25	P25	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.307	0.235
26	P26	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.235	0.138
27	P27	PVC (ANSI) Ced. 40	26.645	1.414	0.001	2.540	0.138	0.000

Table 1 Pipe data in Pipe Flow Expert and results

The results of the numerical model were compared with those measured in the physical model by means of the flow meter sensors.

Results and application

As a result of the operation, control and instrumentation of the greenhouse, a graphic interface was designed in LabVIEW, which allows the integration of the Arduino code and the virtual control of the greenhouse sensors that activate the operation and start-up of the low irrigation system. the following initial conditions:

Variable	Start value	Stop value	peration value
Temperature	24 °C	18 °C	20 °C
Relative humidity	70 %	80 %	75 %
Ground humidity	35 %	55 %	42 %

Table 2 Initial condition and operation conditions values in greenhouse

In the user interface GUI (figure 8), the condition of the system shutdown before starting operations is displayed.

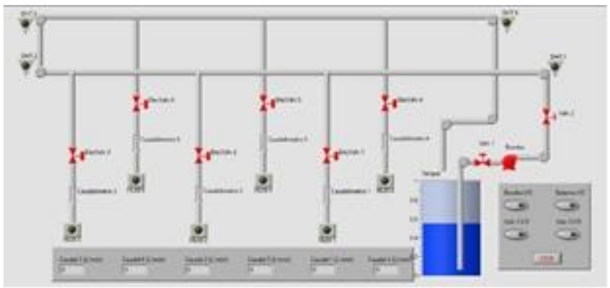


Figure 8 LabVIEW- GUI greenhouse control

Subsequently, the system is turned on (figure 9), obtaining initial values of temperature, relative humidity of the environment and soil humidity to compare with the values that start the irrigation system by opening the solenoid valves and measuring the flow supplied to each section or table depending on the crop and soil moisture conditions.

Figure 9 Start of operation of the greenhouse system

This soil moisture, by indicating a value below the minimum operating value, allows the opening of the solenoid valve to be activated to irrigate the section and quantify the flow that is supplied, as well as the dew time (figure 10); once the maximum system shutdown value for soil moisture has been reached, the solenoid valve closes, ending the water supply in that section according to crop needs.

Figure 10 Start of irrigation system in sections 1 and 4

The values of the flows and velocities in pipes for sections 1 to 3 are shown in table (3)

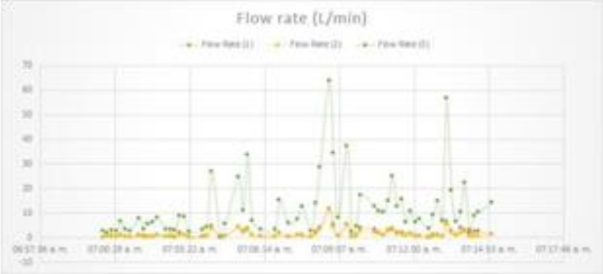
Time	FlowRate (1)	Velocity (1)	FlowRate (2)	Velocity (2)	FlowRate (3)	Velocity (3)
	(L/min)	(m/s)	(L/min)	(m/s)	(L/min)	(m/s)
07:00:00 a. m.	0.13	0.02	0.13	0.02	2.53	0.33
07:00:10 a. m.	0.80	0.11	0.67	0.09	2.00	0.26
07:00:21 a. m.	0.80	0.11	0.27	0.04	2.93	0.39
07:00:31 a. m.	0.53	0.07	0.40	0.05	2.80	0.37
07:00:42 a. m.	0.93	0.12	1.07	0.14	6.53	0.86
07:00:52 a. m.	0.27	0.04	0.40	0.05	3.33	0.44
07:01:03 a. m.	0.40	0.05	0.27	0.04	2.80	0.37
07:01:24 a. m.	0.93	0.12	0.67	0.09	7.87	1.04
07:01:34 a. m.	0.67	0.09	0.13	0.02	3.47	0.46
07:01:45 a. m.	0.40	0.05	0.27	0.04	5.73	0.75
07:01:55 a. m.	0.40	0.05	0.40	0.05	6.13	0.81
07:02:06 a. m.	1.20	0.16	1.07	0.14	8.13	1.07
07:02:27 a. m.	0.40	0.05	0.40	0.05	3.20	0.42
07:02:37 a. m.	0.67	0.09	1.07	0.14	3.20	0.42
07:02:47 a. m.	0.13	0.02	0.40	0.05	2.93	0.39
07:02:58 a. m.	2.00	0.26	1.20	0.16	8.80	1.16
07:03:08 a. m.	1.07	0.14	1.20	0.16	8.53	1.12
07:03:19 a. m.	0.27	0.04	0.13	0.02	2.40	0.32
07:03:50 a. m.	0.27	0.04	0.67	0.09	3.20	0.42
07:04:01 a. m.	0.80	0.11	0.67	0.09	4.13	0.54
07:04:11 a. m.	4.67	0.61	3.73	0.49	26.93	3.54
07:04:32 a. m.	0.00	0.00	0.13	0.02	0.27	0.04
07:04:43 a. m.	0.80	0.11	0.80	0.11	5.47	0.72
07:05:14 a. m.	4.40	0.58	4.13	0.54	24.53	3.23
07:05:24 a. m.	2.67	0.35	2.00	0.26	10.93	1.44
07:05:35 a. m.	3.60	0.47	2.93	0.39	33.73	4.44
07:05:45 a. m.	1.07	0.14	0.93	0.12	6.80	0.89
07:06:06 a. m.	0.67	0.09	0.67	0.09	3.47	0.46
07:06:38 a. m.	0.53	0.07	0.53	0.07	3.33	0.44
07:06:48 a. m.	1.87	0.25	1.60	0.21	15.20	2.00
07:07:09 a. m.	0.53	0.07	0.40	0.05	6.00	0.79
07:07:30 a. m.	1.20	0.16	1.07	0.14	7.60	1.00
07:07:40 a. m.	1.07	0.14	0.67	0.09	12.53	1.65
07:08:01 a. m.	0.53	0.07	0.40	0.05	2.67	0.35
07:08:12 a. m.	2.27	0.30	1.47	0.19	14.00	1.84
07:08:22 a. m.	4.00	0.53	3.47	0.46	28.67	3.77
07:08:43 a. m.	11.87	1.56	11.33	1.49	63.87	8.40
07:08:54 a. m.	5.20	0.68	4.27	0.56	34.27	4.51
07:09:04 a. m.	0.80	0.11	0.67	0.09	8.00	1.05
07:09:25 a. m.	5.20	0.68	5.47	0.72	37.20	4.89
07:09:36 a. m.	0.40	0.05	0.27	0.04	2.40	0.32
07:09:46 a. m.	0.93	0.12	0.80	0.11	4.53	0.60
07:09:57 a. m.	4.00	0.53	2.53	0.33	17.33	2.28
07:10:28 a. m.	3.20	0.42	2.13	0.28	12.67	1.67
07:10:38 a. m.	2.00	0.26	1.73	0.23	10.80	1.42
07:10:49 a. m.	1.07	0.14	1.07	0.14	10.40	1.37
07:10:59 a. m.	2.93	0.39	2.80	0.37	15.07	1.98
07:11:10 a. m.	3.47	0.46	3.87	0.51	25.07	3.30
07:11:20 a. m.	2.00	0.26	1.47	0.19	12.80	1.68
07:11:31 a. m.	2.00	0.26	1.33	0.18	15.60	2.05
07:11:41 a. m.	0.93	0.12	0.93	0.12	6.13	0.81
07:11:52 a. m.	1.73	0.23	1.33	0.18	10.67	1.40
07:12:02 a. m.	0.80	0.11	0.67	0.09	6.13	0.81
07:12:13 a. m.	0.80	0.11	0.67	0.09	7.60	1.00
07:12:33 a. m.	0.13	0.02	0.40	0.05	3.73	0.49
07:12:44 a. m.	0.93	0.12	0.53	0.07	9.20	1.21
07:12:54 a. m.	1.20	0.16	1.33	0.18	14.80	1.95
07:13:05 a. m.	0.40	0.05	0.40	0.05	6.80	0.89
07:13:15 a. m.	6.40	0.84	5.20	0.68	56.53	7.44
07:13:26 a. m.	2.80	0.37	2.13	0.28	19.20	2.53
07:13:36 a. m.	0.93	0.12	1.07	0.14	6.53	0.86
07:13:47 a. m.	4.00	0.53	1.73	0.23	10.53	1.39
07:13:57 a. m.	2.93	0.39	2.27	0.30	22.53	2.96
07:14:08 a. m.	1.73	0.23	0.40	0.05	3.07	0.40
07:14:18 a. m.	2.40	0.32	0.27	0.04	8.80	1.16
07:14:29 a. m.	2.67	0.35	0.67	0.09	10.27	1.35
07:15:00 a. m.	1.47	0.19	1.47	0.19	14.27	1.88

Table 3 Flow values supplied to sections 1 to 3

It is worth mentioning that the response time is reduced by approximately 100 ms, adjustments are currently being made to reduce the response time of the system and make the code optimal (figure 11).

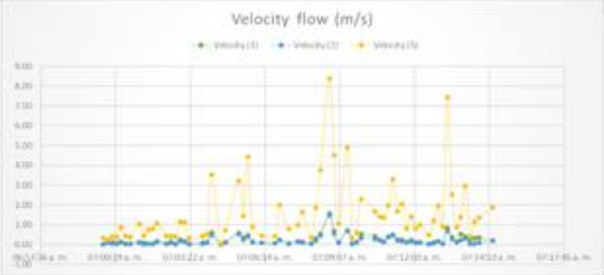
Figure 11 Arduino code section in green-house system

The speed and flow values obtained from the measurement are plotted with respect to time and depending on the needs of each crop, for this case, two irrigation needs of 0.0014 L/min (flow meters 1 and 2) and a third are used. of 0.015 L/min (flow meter 3), obtaining as shown in the graph (1).



Graphic 1 Flow rate in flow meter 1 to 3

Applying the continuity equation in pipes, the velocity of flow in the pipe is obtained as shown in graph (2).



Graphic 2 Velocity flow in flow meter 1 to 3

Conclusions

The development and construction of the instrumentation and control prototype has made it possible to obtain, operate and control different irrigation zones (downspouts or pipes) that have different irrigation needs, taking into account environmental parameters such as relative humidity and temperature, as well as the use of minimum values of soil or substrate moisture, the need to provide a certain flow rate for a determined irrigation time.

The comparison of the flow results obtained by the numerical modeling and those measured by the flowmeter system has a difference between 20% and 33% in magnitude, where it is estimated that this difference is caused by the efficiency curve of the pump and possible differences in construction conditions; however, the operation results with the use of the LabVIEW interface allow to have control of the system in its entirety and provide a necessary flow to each section depending on the requirements of the crop, such as irrigation sheet, irrigation time and control substrate moisture.

The relevance of the design and construction of this prototype allows to have a low installation cost in instrumentation and control, where the development of the graphic interface and the Arduino code can be provided to the farmer for its use, or with the necessary adjustments in number scaling of sensors to satisfy the needs of each crop inside a greenhouse.

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