Electrical Conductivity and Water Flow Control of a NFT System

J. Jaimes-Ponce, J. U. Liceaga-Castro, R. Alcántara-Ramírez, and I. I. Siller-Alcalá

Abstract**—**The reduction of the space for irrigation and increasing market demands in quality and health of the vegetables, are factors that have made hydroponic techniques become potentially attractive, especially NFT. In this paper the design and implementation of a control system for a hydroponic system of nutritious film NFT (Nutritious Film Technique) to control the flow and electrical conductivity (EC) of nutritious solutions in growth channels is presented. A full description of the electronics components, sensors and signal conditioning together with a description of the software is presented. The controller is based on the classical PID controller, which is easy to implement and operate and, moreover, it is relatively cheap. The case of study is the control system of a hydroponic system for a kind of spinach known as "Spinaciaoleracea". The hydroponic system is composed of a greenhouse tunnel with an area of 6x5 m2. Also, the components, which are available in México, are EC sensor (HI3001), sensor of pressure MPX10DP, electro valves, three water pumps, analogical electronic components and a microcontroller (PIC18F4550). It must be stressed that this hydroponic system will be installed in the roofs of houses and buildings of México City**.**

Keywords**—**Control applications, Hydroponic systems, Instrumentation, Microcontrollers, PI controllers.

I. Introduction

Vegetables, grains and any plant in general require water and soil to growth and to perform its natural physiological processes. Due to the continual grow of the human population and the consequently reduction and contamination of land and water for agriculture purposes has incentivized the search for different methods to produce food, [1]. The former has led to the development of hydroponic systems. Contrary to other kind of greenhouses a hydroponic system keeps the roots of the plants out of the soil -naked roots- in a low deep channel with a recycled flow of nutrients, water and oxygen. This technique is known as Nutrient Film Technique (NFT), [2]. NFT is a highly recognized strategy due to its high quality and productivity. That is, the resulting products are of excellent quality and in a very short time. The main advantage of hydroponic systems is that they do not require land and can be installed practically anywhere; however, these systems require the implementations of controllers to create or maintain good conditions in humidity and temperature and in the supply of nutrients and water. Nevertheless, to optimize the plants growth and quality it is necessary to synchronize the supply of water and salts demanded by the plants in a very short period of time. Therefore, the implementations of monitoring and control systems are required for a good operation of the NFT, [3].

In México the level of technology applied in most of the hydroponic systems is very low; that is, the control systems implemented to control the electrical conductivity, water flow, temperature and pH are well below the requirements of this kind of processes. This is reflected in extremely low levels of quality and productivity. On the other hand, the implementation of more complex and sophisticated controllers result in very expensive systems which additionally are extremely difficult to operate. The PID controller is an adequate solution for this kind of problems for its simplicity and because it has proved to be a highly robust controller with high performance, [4]. Also, digital PID controllers are cheap and easy to implement, similar to the objectives established in [5]. Therefore, in this paper the design and implementation of a water flow and electric conductivity control system in a spinach NFT system is presented. Nonetheless, special attention must be put in the sensors and signal conditioning electronics is such a way that the reliability hole control system is assured. Therefore, together with a description of the control system a full description of the electronics and software of the sensor signal conditioning is presented in this paper.

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II. General Description

A. Hydroponic System NFT

The recycling system NFT was developed by the Glasshouse Crop Research Institute in England during the decade of the sixties of the last century. It consists of the constant circulation of a thin film of nutrients passing through the roots of the plants without any loses or external contact resulting in a closed type system. The root mat develops partly in the stream of recirculating solution and partly above it, in order to ensure the root system has access to adequate oxygen levels. Under ideal conditions in the NFT system the absorption of the nutrients depends only on the plants demands which are determined by the environment conditions. Hence, the absorption of minerals by the plant's roots is controlled by natural growth requirements of the plant. The NFT system requires the addition of up to 12 different kind of nutrients; many of them in very small quantities except by nitrogen and potassium.

B. Nutritious Solution

Nutritious solution plays an important role in the quality and productivity of lettuce. In a hydroponic system, the plants growth by absorbing the nutrients salts dissolved in water. The selection of these salts depends of different factors; one of the most important is how soluble is the salt.

The Electrical Conductivity (EC) of a Nutritious Solution has an influence in the chemical composition of the plants. If the EC increases the K^+ increases reducing the Ca^{2+}; also, the P concentration is incremented and, in less quantity, the $NO_3^-$with the subsequent reduction of SO_4^{2-}. Moreover, if the EC is increased more than 6dSm^{-1} it will induce a hydric deficiency and an increment of the K^+ relation (k^++Ca^{2+}+Mg^{2+}+NH_4^+). On the other hand, an EC decrement, less than 2 dSm^{-1}, may induce nutritional deficiencies, [6].

In the nutritious solution are concentrated the micro and macro nutrients required (SM) for a healthy growth of the plants. The concentration of these nutrients is depicted in Table 1 and Table 2 for the macro a micro nutrients, respectively, [7-11].

Fertilizante	PM	PE	Cationes (meq L^{-1})					Aniones (meq L^{-1}			
			K^+	Ca^{2+}	Mg^{2+}	NH_4^+	H^+	NO_3	H_2PO_4	SO_4	g/400L
$Ca(NO_3)_2$ $4H_2O$	236	118		8				8			377.60
NH_4 H_2PO_4	115	115				1			1		46.00
KNO_3	101	101	4					4			161.60
K_2SO_4	174	87	2							2	69.60
$MgSO_4$ $7H_2O$	246	123			4					4	196.80
H_3PO_4	98	98					0.5		0.5		13.6 ml
H_2SO_4	98	49					1			1	12.81 ml
∑parcial cat-ani			6	8	4	1	1.5	12	1.5	7	
∑ cat-ani			20.5					20.5			

Table 1 SM solution: Macronutrients

Nutrimento	mgL^{-1}
Fe	3
Mn	0.5
Cu	0.1
Zn	0.1
B	0.1

Table 2 SM solution: micronutrients

C. Electric Conductivity (EC)

The electric conductivity (EC) measures the concentration of salts in a solution in dS/m; although it does not indicate which salts are present. Also, as the EC depends on the temperature of the solution any EC measure must indicated the temperature at which it was performed; that is, 20°C according to the norm AFNOR or 25°C according to the CEE norm (CE a 25ºC » 1.112 x CE a 20ºC).

D. Irrigation System

The hydroponics hydraulic system is shown in figures 1-3. It is formed of 3 tanks: tank 1 is the main tank and is in there where the salty solution with the nutrients and the water concentration determined by the EC is deposited; Tanks A and B contains a highly concentrated solution of salts and clean water, respectively.

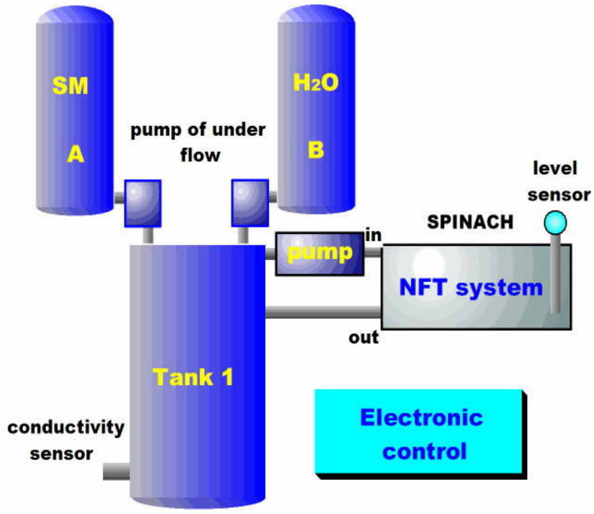


Fig 1 Irrigation System with EC control

Fig 2 Tanks A and B

Fig 3 NFT system

III. EC CONTROL SYSTEM

To the correct development of the project the implementation of an EC control system and the salty solution is required. Even more, it is also required to control the flow of this solution. As mention above it is also necessary to monitor the temperature to correctly measure the EC.

The electronic system is formed by 2 basic blocks: the first one is a digital information system and the second one is formed by the variable sensors together with the required signal conditioning electronics.

III.1 GENERAL DESCRIPTION

A. Conductivity Sensor

To measure the EC the HI3001 sensor was use. The sensor, shown in figure 4, from Hanna Instrument was inserted inside the tank1. This sensor was implemented with a Wheatstone bridge to avoid the electrolysis effect, as shown in figure 5, and was calibrated using distilled water.

The HI3001 sensor has 4 rings identified as rings 1, 2, 3 and 4. These rings are pairing in two groups; that is, ring 1-2 and rings 3-4 forming a set of two sensors in the same instrument. Each pair of rings is a sensor therefore each of them requires a Wheatstone bridge shown in figure (5).

Fig 4 HI3001 sensor

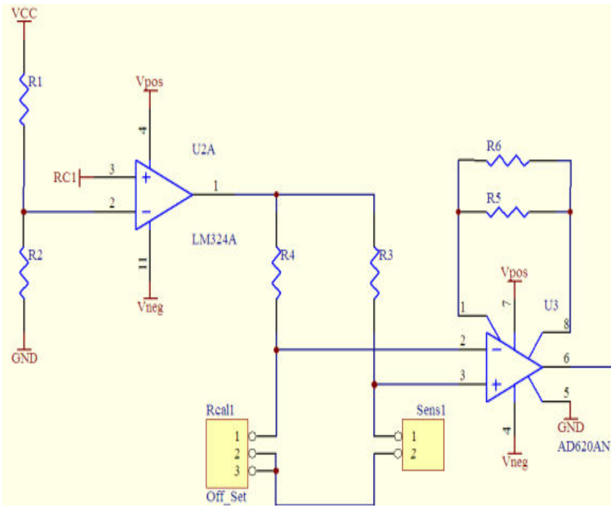


Fig 5Electric diagram for the implementation of the conductivity sensor

It is also necessary to eliminate the possibility of the undesired electrolysis effect. Hence, a bipolar square signal of 1 KHz is applied to the sensor. This bipolar signal is generated by the microcontroller in the RC2 pin to feed the positive input of the U2A opam and compared to the voltage of the voltage divisor of resistances R1 and R2. The bipolar output of U2A is the used to polarize the Wheatstone bridges formed by resistances R4, R5, Rcall, and the conductivity sensor Sens1.

Once the Wheatstone bridges is calibrated adjusting resistance Rcall the differential voltage is amplified by the AD620 instrumental amplifier U3 with a gain given by resistances R5 and R6. The U3 output voltage is then feed to the microcontroller's AD converter.

The final measure is obtained by calculating the average of sampled measurements of each sensor at different times.

Because the conductivity depends on the temperature this is sensed using the LM35 sensor which is encapsulated to be immersed in nutrition solution. Once the temperature and the CE have been obtained an adjustment according to the previous characterization of the HI3001 is performed.

B. *Pressure Sensor*

The level of liquid in the interior of channels, in which the roots are confined, is measured indirectly by sensing the pressure of the column of liquid. The pressure sensor MPX10DP, shown in figure 6, has a time response of 1msec and was implemented with the signal conditioning circuit shown in figure 7. This sensor is compensated in temperature within a range of -40C° to 125C°, with a maximum error of ±5% out of the range of 0C° to 85C°. Also, it is polarized with 6 VDC.

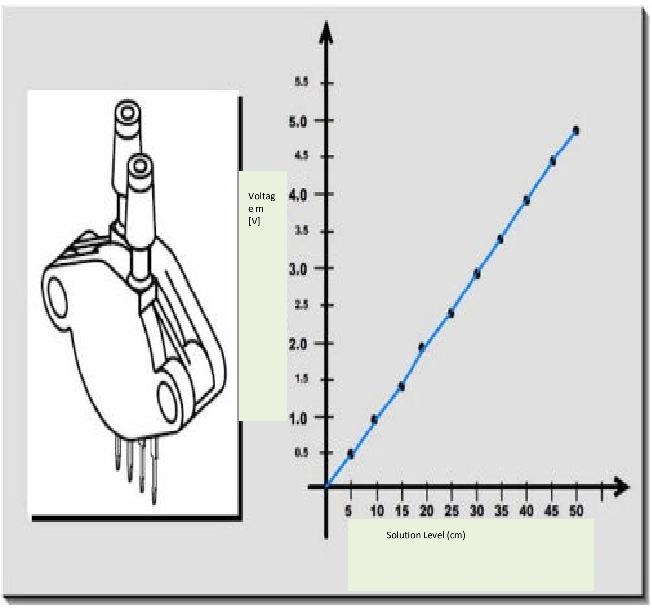


Fig. 6 MPX10DP pressure sensor

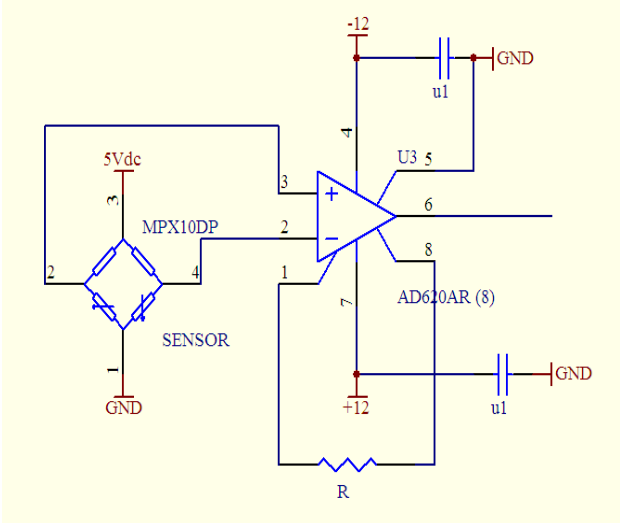


Fig 7Instrumentation Amplifier of signal conditioning for the MPX10DP sensor

The signal conditioning of the MPX10DP sensor is relatively simple because it is a sensor specifically designed whose operation can be modeled as a Wheatstone bridge. Nonetheless, these kinds of sensors are highly affected by the noise produced by the turbulence of the liquid inside the tank. Hence, it is necessary to design a noise suppressor based on a differential amplifier with high CMRR. This amplification is done with the integrated circuit AD620 form Analog Devices Inc.

C. *Valves*

The flow control system of the salty solution in the NFT system requires of 3 electro valves of 24V (figure 8). In this control system the valve V-1 recycle the solution to allow a good oxygenation and a homogeny solution; the second valve V_2 regulates the solution flow to the NFT system and, finally, the third valve V-3 controls the level of the salty solution as shown in figure 9.

Fig. 8 Irrigation Solenoid Valves

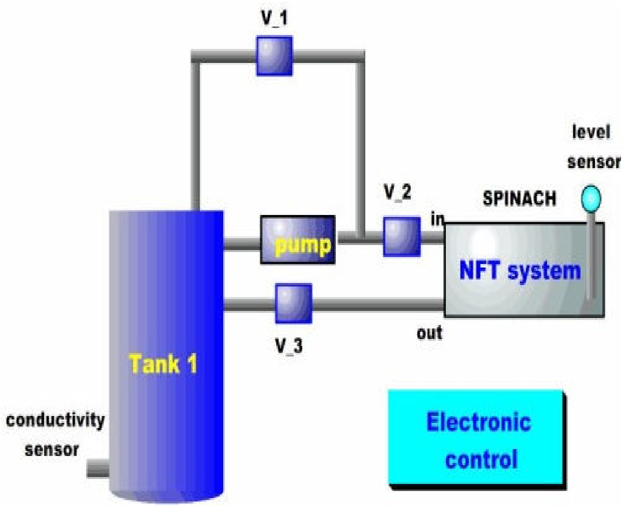


Fig. 9 Irrigation control system

D. Low Flow Pump

To regulate the MS solution and water 2 submergible pumps of low flow were implemented-. These pumps are activated in line and therefore a power actuator is required to operate them from a microcontroller or manually. The pumps and the power actuator are shown in figures 10 and 11 respectively.

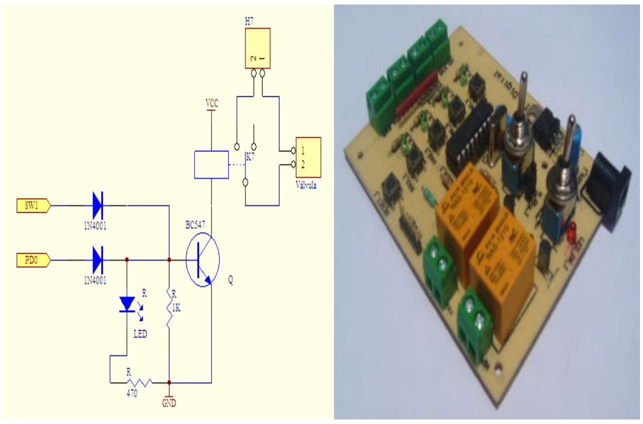


Fig. 10 Circuit and circuit tablet of the power actuator


Fig. 11 Submergible pump 115V 60HZ, HX2500

E. USB Communication

One of the most important characteristics of the microcontroller PIC18F4550 is the possibility of communication via a USB module as depicted in figure 12. This module facilitates the communication with a computer by means of Visual Basic. Therefore a simple application using Visual Basic to store information in a very simple format was developed.

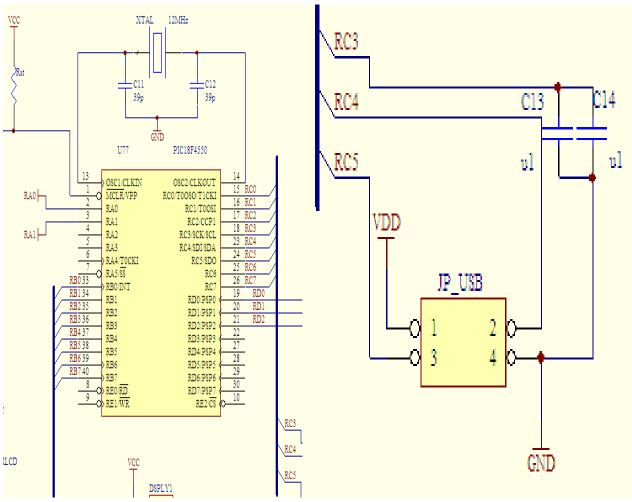


Fig. 12 Microcontroller and USB connection

III.2 PID Controller

The PID (Proportional-Integral-Derivative) controller was implemented via the microcontroller, [12]. This controller will regulate the EC between 1.9 and 2.1 dS m-1. The differential equation of a PID is given by:

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d e(t) \right] \quad (1)$$

This equation is approximated by the difference equation

$$u(k) = K_p \left[e(k) + \frac{1}{T_i} \sum_{j=0}^{j=k} e(j) \frac{T_m}{T_i} + \left(e(k) - e(k-1) \right) \frac{T_d}{T_m} \right] \quad (2)$$

Where Kp is the proportional gain, Tm is the sampling time and Ti and Td are the integration time and derivative time, respectively; e(k) is the error at time k. The error e(k) is determined by the difference between the desired value of the EC and its actual value.

The implementation of the PID in the microcontroller is very simple thanks to the possibility of using a high level programming language. The PID program is given by the next set of instruction:

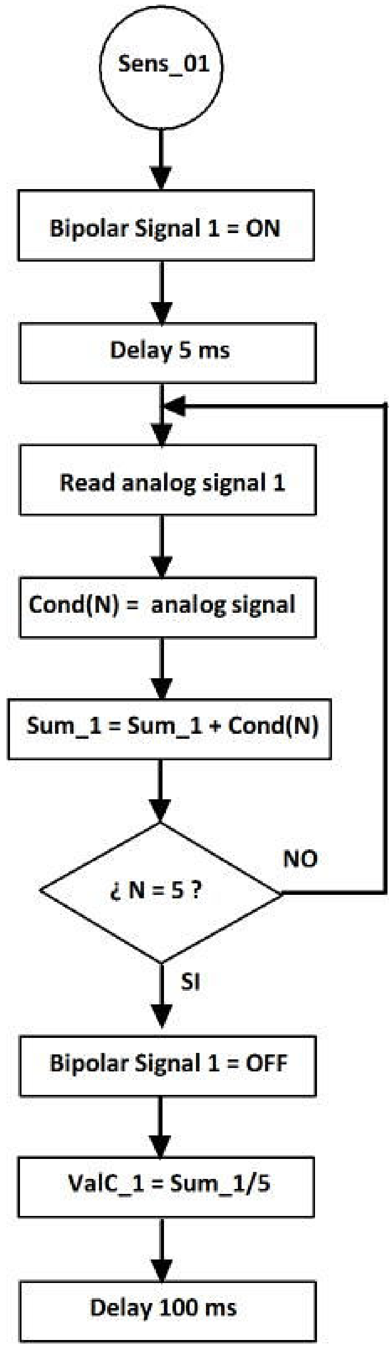
/……discretPID Controller …………
Sum_Err [i]= Error[i] * T_Sample+ Sum_Err[i]
; Integral
Ki_SumErr[i] = Ki * Sum_Err[i] ; Integral
Dif_Err[i] = Error[i] - Err_Ant[\i]
Kd_DifErr[i] = Kd*Dif_Err[i] / T_Sample
; Diferencia
Ct[i] = Kp * (Error[i] + Ki_SumErr[i] + Kd_DifErr[i]
Err_Ant[i] = Error[i]

On the most important advantages of this kind of implementation for the PID controller is that it is quite easy to change it into a PD or PI controller by setting Ki or Kd to zero. The error signal determines which pump will be activated: The pump from the solution tank if the salinity is low or the pump from the water tank if the salinity is above the set point.

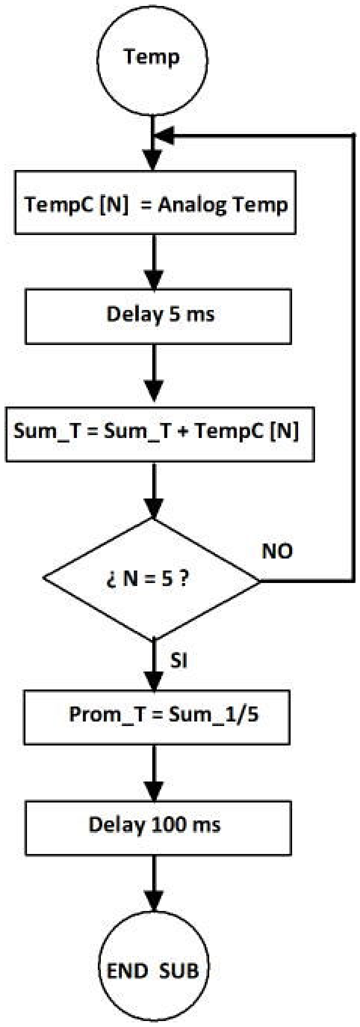
III.3 SOFTWARE

A. Electric Conductivity Measurement

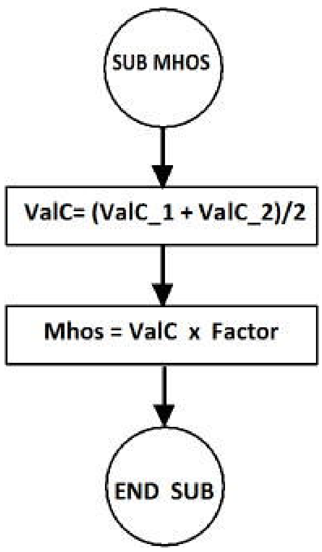
The EC measurement depends of the temperature with a variation of 2% per centigrade. Therefore, it is also necessary to measure the temperature together with the EC. This is done by taking the average of 5 measurements of the conductivity and temperature using the HI3001sensor described in Section 3.1. Thereafter, a correction factor based on the average of temperature is applied to the EC average. This is the data that will be used by the PID control law.
To perform the measurements the bipolar signal is activated for a couple of sensors or electrodes. These are activated separately to avoid measure interferences. The conductivity measurement is performed following the next flow diagram which is the same for the pair of rings of the HI3001 sensor:



The temperature measurement is obtained following the next flow diagram:



Finally the conductivity correction factor is calculated as shown is the next flow diagram:



IV. Results

So far in this project the measurements of the electrical conductivity, the level of the solution in the channels of the NFT system and the temperature has been performed and validated. These variables are the most important for this kind of processes. Also, the control system with the PID controller present excellent results and the growth of spinach is already in progress. As mention before, the salty solutions EC must be around 2 mS m-1 for an optimum nutrients supply. In figure 13 the real time EC PID control system response is shown. The initial value is 1.35 mS m-1 because of the use of simple running water. Although the maximum overshoot is 2.5 mS m-1 it does not represent a critical value for the EC required by the spinaches. Also, after 40 hr. the EC response reaches the its optimal value. It must be noted that the PH was controlled manually. Nevertheless, it is well known that the implementation of NFT systems increases the quality and level of agricultural products with the consequent improvement of the economy, [13].

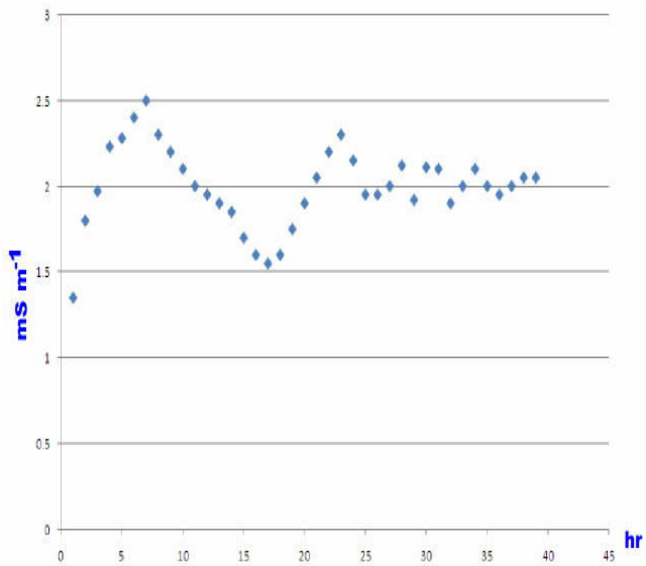


Fig. 13 EC PID control system response

V. Conclusions

The development of a project like the one presented here shows the goals that can be accomplish when it is realized with an interdisciplinary team. As a result, several ideas have surge to extend the project to the growth of different king of plants. In must be noted that each plant depends of different factors or variables and hence they demand different control strategies such as Ph. Temperature, levels of light, humidity, etc.

The future work includes the design of PH and humidity control system which are also very important variable for hydroponic systems. A disadvantage of these systems is that the calibration of the whole system takes a lot of time because of the time the plants takes to grow. Also, at the beginning the implementation of hydroponic system may result expensive; however, thanks to the development of project like the one presented here it is possible to reduce the costs and therefore they will become suitable for commercial purposes.

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