

# Construction of an electronic supplementary lighting system for a greenhouse.

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## ABSTRACT

*This document shows a proposal for the construction of an electronic system for controlling the supplementary light intensity of 10 commercial LED lamps for plant growth in a greenhouse. The system consists of an electronic device composed of a power module specially designed for the system and a control module. The control module was implemented with an arduino mega development board programmed with a proportional classic control. Using 3 equations of the TOMGRO mathematical model, it is shown that the presented system allows the increase of a tomato crop (*Solanum lycopersicum* L.) for the state of Puebla, Mexico, in a 32 m<sup>2</sup> greenhouse, with other physical conditions constant and a variable amount of lighting, during a period of 80 days.*

**Keywords: Tomato, Supplemental light, greenhouse, proportional control, Led lamp.**

## 1. INTRODUCTION

Plants are an important source of nutrition for humans. Climatic changes, pests and diseases in plants have caused a decrease in crop yield, coupled with this, the excessive use of pesticides

has motivated the choice to plant in controlled environments.

The concept of indoor farming and plant production systems in controlled environments has emerged as a reliable and sustainable alternative means of crop production. Adequate lighting is essential for the optimal growth of plants indoors [1].

Currently, there are dozens of places of production of indoor crops, in some countries, for example Japan, China and the Netherlands, etc. [6] manage to take advantage of this technology to increase your earnings. A widely used technique to increase crop production is supplementary lighting of greenhouses [2], [3], which consists of supplying the necessary amount of light to crops, since both exceeding and falling below the recommended levels of luminosity alter the photosynthesis [4]. For this reason, a proposal of a circuit is shown electronic device to increase the yield of the tomato crop by manipulating the light intensity of a bulb with full spectrum commercial LED technology.

The mathematical model TOMGRO and reduced greenhouse [5] was used as a simulator of the results of the system in the harvest of a greenhouse

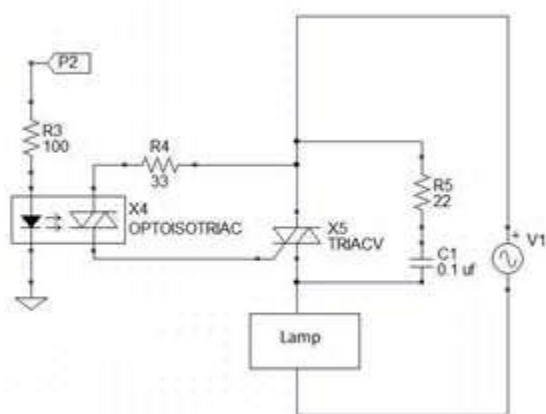
for a period of 80 days. This model was validated through the construction of a meteorological station carried out by the Colegio de Postgraduados

of the state of Puebla, located in the Sierra Norte de Puebla.

The main parameters of the model were measured during a harvest period, obtaining their statistical behavior, later carrying out the simulation of the mathematical model of the crop, the same results were obtained when comparing with the statistical data that made the meteorological station. This information was provided to this work thanks to the collaboration between the Colegio de Postgraduados del Estado de Puebla and the Benemérita Universidad Autónoma de Puebla.

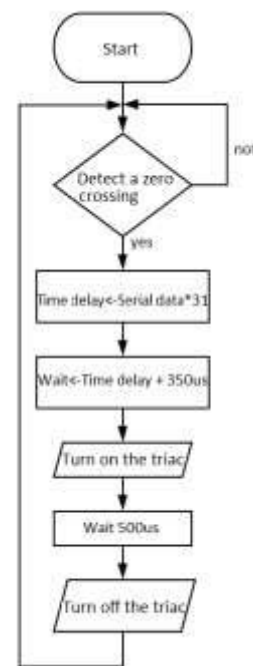
## 2. DESIGN AND CONSTRUCTION OF THE DEVISE ELECTRONIC CONTROLLER OF LIGHTING

For all the above, a circuit was designed that modifies the phase angle to control the intensity of light from a lamp. The input stage that controls the phase angle is implemented with a TRIAC MAC12NG and a MOC3010 photocoupler, whose trigger pulse is generated by a microcontroller PIC16F628A. In Figure 1 shows the power circuit, de marker P2 is connected on a microcontroller output pin.



**Fig 1: Power circuit.**

From a personal computer, the user sends the desired light intensity value. An Arduino mega development board receives the data, converts it to the range from 0 to 256 and sends it to the phase control circuit. The serial port is read, and a zero crossing is expected. Then a delay time for the output signal of 127 v is calculated. After the delay time, a 500 s pulse is generated that activates the TRIAC.



**Fig 2: Flow diagram of the microcontroller program.**

### 2.1 Lamp

For the lighting of the greenhouse, a 45-watt Osunby brand led growth lamp for indoor plants was used to obtain the maximum growth, the quality of light and the growth of the crop were ensured accordingly. to studies of the effects of lighting on plant growth [7].

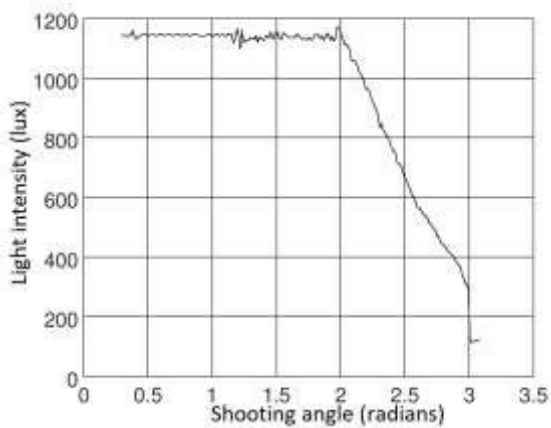
The lamp has the following characteristics:

- (1) Full spectrum of light. From infrared (730-735 nanometers) to ultraviolet (390-395 nanometers).

(2) Large number of hours of service life (50000 hours).

(3) Conventional power supply (127 V / 60 Hz).

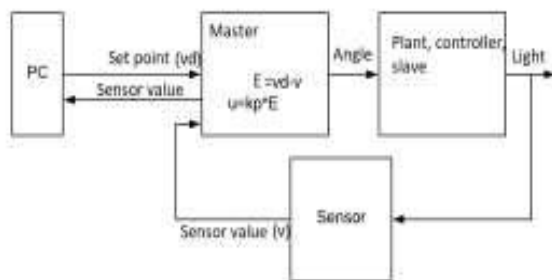
The TSL2591 sensor was used to detect the illumination of the lamp. From the power circuit and the illumination sensor, the lamp could be characterized to find the linearization interval. In the figure 3, you can see that it is possible to control the lamp from 2 to 3 radians of phase.



**Fig 3: Lamp characterization.**

## 2.2 Control

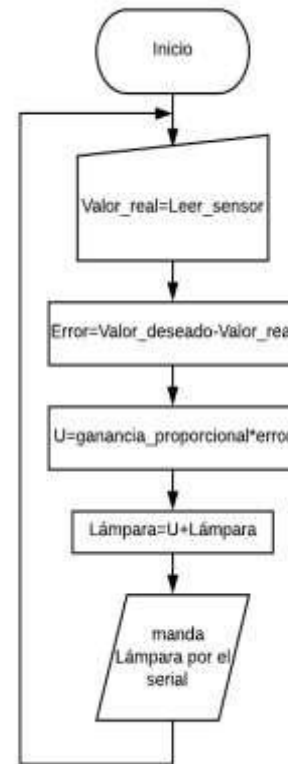
Figure 4 shows the close loop of control.



**Fig 4: Control system block diagram.**

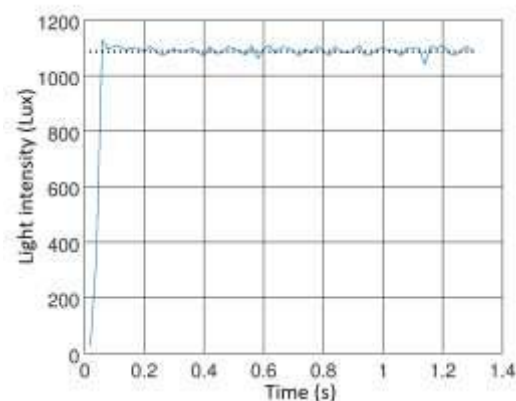
With the brightness sensor and the lamp, the control loop is closed. The same Arduino mega development board was used as a controller, in

which a proportional gain control algorithm was implemented. The proportional control gain was tuned or by trial and error until the value of 0.4 was found. The programing algorithm is shows in figure 5.



**Fig 5: Controlflow diagram.**

The control reaches the desired point and is maintained with an approximate variation of 15 lux. The system response shows in Figure 6.



**Fig 6:Graph of the behavior of the control system.**

Finally, a DS3231 real-time clock module was added to the Arduino development board to automatically turn the system on during the day and off at night.

### 3. IMPLEMENTATION

The system was implemented in a greenhouse 8 meters long by 4 meters wide. The greenhouse has a plastic coating and is supported by square commercial steel tubulars with a white paint coating. The greenhouse was attached by screw suggestion. The tubulars were joined by screws, in addition the coating is joined to the tubulars with a screw. The 10 lamparas were installed throughout the greenhouse to illuminate the entire surface of the greenhouse with their light. The sensor and de electronic circuit were placed an extreme of greenhouse. A picture of installation shows in figure 7.



**Fig 7:Photograph showing the result of the connections of the lamps inside the greenhouse.**

### 4. HARVEST SIMULATOR

To do a simulation of the harvest with the effects of the lighting system, the dynamic model of 3 equations of state was used.

#### 4.1 Number of nodes

The node development rate (developed plant) is modeled as a maximum node appearance rate per

day (Nm) multiplied by a function that reduces vegetatedevelopment at non-optimal temperatures on an hourly basis every day.

$$\frac{d}{dt}N = N_m f_m(T_g) \quad (1)$$

**Table 1. Nomenclature of the equation of the nodes.**

Symbol	Units
$N$	Dimensionless
Nm	Nodes $d^{-1}$
$T_g$	$^{\circ}C$

$f_m(T_g)$ , It is the reduction of vegetative development under temperatures not optimal.

$$f_m(T_g) = \begin{cases} 0, & T_g \leq 8^{\circ}C \\ 0.55, & T_g = 12^{\circ}C \\ 1, & T_g = 30^{\circ}C \\ 0, & T_g \geq 50^{\circ}C \end{cases} \quad (2)$$

#### 4.2 Canopy dry matter

The dry matter of the canopy is given by expression 3.

$$\frac{d}{dt}W_c = E (P_g - R_m(W_r + W_c)) f_c \quad (3)$$

**Table 2. Nomenclature of the equation 3.**

Symbol	Units
$W_c$	$g \text{ tissue } m^{-1} d^{-1}$
$W_r$	$g \text{ tissue } m^{-1} d^{-1}$
$R_m$	$(gCH_2O)/(g \text{ tissue } d)$
$E$	$(g \text{ tissue})/(gCH_2O)$
$P_g$	$g \text{ tissue } m^{-1} d^{-1}$
$f_c$	dimensionless

Where

$$P_g = D \frac{\tau C p(T_g)}{k} \ln \left| \frac{\alpha k I_0 + (1-m)\tau C}{\alpha k I_0 e^{-kLAI} + (1-m)\tau C} \right|$$

(4)

**Table 3. Nomenclature of the equation 4.**

Symbol	Units
$D$	$(\mu\text{mol CO}_2)/(\text{m}^2\text{s})$
$\tau$	$(\mu\text{mol CO}_2)/(\text{m}^2 \text{ leaf s})$
$C$	$(\mu\text{mol CO}_2)/(\text{mol air})$
$p(T_g)$	dimensionless
$\alpha$	$(\mu\text{mol CO}_2)/(\mu\text{mol foton})$
$k$	dimensionless
$I_0$	$(\mu\text{mol foton})/(\text{m}^2\text{s})$
$m$	dimensionless
$LAI$	$(\text{m}^2 \text{ leaf})/(\text{m}^2\text{s})$

Where

$$p(T_g) = \left[ 1 - \left( \frac{\Phi_h - T_g}{\Phi_h - \Phi_1} \right)^2 \right] \quad (5)$$

**Table 4. Nomenclature of the equation 5.**

Symbol	Units
$\Phi_h$	$^\circ\text{C}$
$\Phi_1$	$^\circ\text{C}$

Where

$$R_m = K_m e^{0.0693(T_g - 25)} \quad (6)$$

**Table 5. Nomenclature of the equation 6.**

Symbol	Units
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$K_m$	$^\circ\text{C}$
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Where

$$I_0 = \begin{cases} I_m \sin(2\pi(t_d - 6)), & I_0 > 0 \\ 0, & I_0 \leq 0 \end{cases} \quad (7)$$

**Table 4. Nomenclature of the equation 6.**

Symbol	Units
$I_m$	$(\mu\text{mol foton})/(\text{m}^2\text{s})$
$t_d$	$d$

Finally

$$LAI = \frac{\rho\delta}{\beta} \ln(1 + e^{\beta(N-nb)}) \quad (8)$$

**Table 6. Nomenclature of the equation 8.**

Symbol	Units
$\rho$	$\text{number}/\text{m}^2$
$\delta$	$\text{m}^2 \text{ leaf}/\text{node}$
$\beta$	$\text{node}^{-1}$
$nb$	$\text{node}$

## 4.2 Dry root

The root dry matter equation is like the canopy equation, the function that models growth is presented in expression 3.

$$\frac{d}{dt} W_c = E (P_g - R_m(W_r + W_c)) (1 - f_c) \quad (9)$$

## 4.3 Integrated dynamic system

The complete dynamic system of the greenhouse is shown below

$$\frac{d}{dt}N = N_m f_m(T_g)$$

$$\frac{d}{dt}W_c = E (P_g - R_m(W_r + W_c)) f_c$$

$$\frac{d}{dt}W_c = E (P_g - R_m(W_r + W_c)) (1 - f_c)$$

(11)

These variables were chosen from the original TOMGRO model, which can contain more than 109 variables.

To simulate the system, the numerical values of the TOMGRO model can be found in the literature, however, for this work some of them were slightly modified, this is mainly due to the region of Puebla, México, where the crop grows and were provided by the Colegio de Postgraduados del Estado de Puebla. (COLPOS) The modified values are presented in table 8.

**Table 8. Parameters.**

Parameter	Quantity	Parameter	Quantity
$N_m$	0.021	$E$	0.7
$D$	0.108	$\tau$	0.0664
$C$	350	$\alpha$	0.056
$m$	0.1	$\Phi_h$	30
$I_m$	800	$\rho$	4
$\Phi_1$	5	$\beta$	0.38
$\delta$	0.074	$k$	0.58
$nb$	0.38	-	-

#### 4.4 Simulation

The simulation was done in MATLAB. The temperature was kept at a constant value of 18 °C at night and 23 °C during the day, as recommended by the specialists [8]. And for the lighting was kept at 800( $\mu\text{mol foton}/(\text{m}^2\text{s})$ ).

The physical variables are then modeled as seen in the equations:

$$T_g = \begin{cases} 18^\circ\text{C}, & I_0 \leq 0 \\ 23^\circ\text{C}, & I_0 > 0 \end{cases} \quad (12)$$

When the system is on.

$$I_0 + I_{in} = \begin{cases} I_m, & I_0 > 0 \\ 0, & I_0 \leq 0 \end{cases} \quad (13)$$

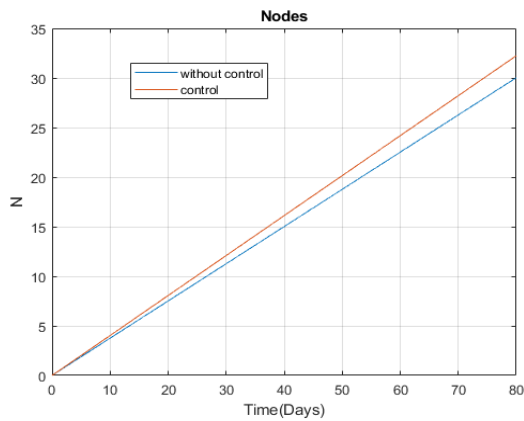
where  $I_{in}$  represents the light intensity input of the proposed lighting system.

The MATLAB function ode45 (Runge Kutta 4/5) was used to solve the resulting differential equation, the initial values were 0 for the plant variables. The sampling time was 30 minutes and the total time was 80 days.

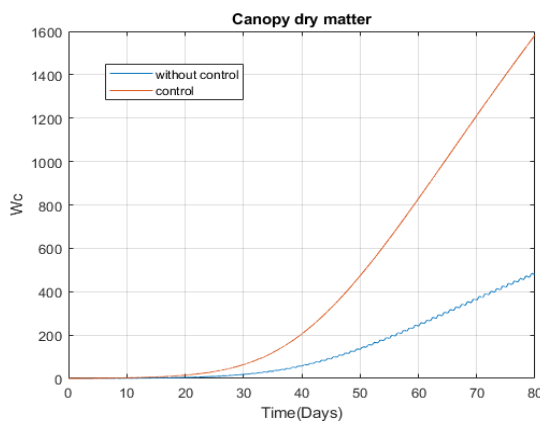
#### 5. Results

Plant growth with natural light was compared against growth with the supplemental Light system. The results of the growth of the dry biomass of the canopy and nodes are shown since these terms depend on the luminance parameter.

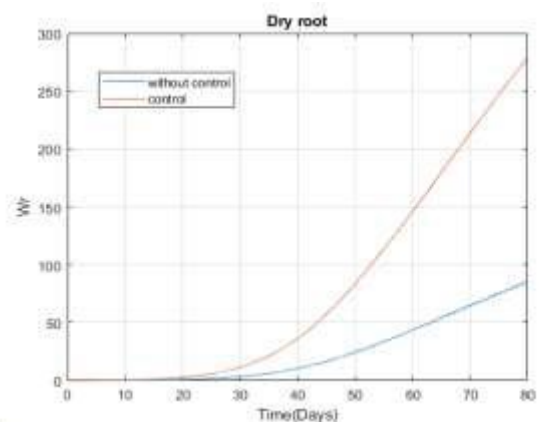
From the graphs, there is growth when using a supplementary light system such as the one suggested in this work.



**Fig 7: Comparison of node increment of a greenhouse crop versus a crop with a supplemental light system.**



**Fig 8: Comparison of the increase in dry matter of the canopy of a greenhouse crop against a crop with a supplementary light system**



**Fig 9: Comparison of root dry matter from a greenhouse crop versus a crop with a supplemental light system.**

## 6. Conclusions

It was shown that the use of a complementary lighting system such as the one proposed in this writing produces growth in the tomato crop, for the central region of Puebla with the other physical conditions conducive to growth. From figures 7, 8 and 9 the greatest increase occurs in the biomass of the canopy, and the biomass of the root. Simulation demonstrates the importance of using a supplemental lighting system in a greenhouse.

## 7. ACKNOWLEDGMENTS

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