Journal of Systemics, Cybernetics and Informatics (2022) 20(4), 76-81
https://doi.org/10.54808/JSCI.20.04.76

Optimal plant growth through thermo mechatronic analysis

***J. Alan CALDERÓN Ch.**
Applied Nanophysics, Institute for Physics, Technical University of Ilmenau
Ilmenau, 98693, Germany
Engineering Department, Mechatronic Master Program, Pontificia Universidad Católica del Peru
Lima, 15088, Peru
*Corresponding and main author: alan.calderon@pucp.edu.pe

Julio TAFUR, Benjamín BARRIGA, Jorge ALENCASTRE, Gonzalo SOLANO and Rodrigo URBIZAGÁSTEGUI
Engineering Department, Mechatronic Master Program, Pontificia Universidad Católica del Peru
Lima, 15088, Peru

John LOZANO
Mechatronic Department, Northern (Artic) Federal University
Arkhangelsk, 163002, Russia
Engineering Department, Mechatronic Master Program, Pontificia Universidad Católica del Peru
Lima, 15088, Peru

Marvin CHANCÁN
Electrical Engineering and Robotics School, Queensland University of Technology
St Lucia QLD 4072, Australia

ABSTRACT[1]

This work is described as a proposal to apply modern control techniques and automation tools for optimal plant growth, also it was based on key agricultural strategies that were developed by ancient civilizations such as the Inca Empire. Many of them ancient techniques including the Inca engineering of andenes were forgotten or set aside through time. In this research, however, some of these key techniques are revisited to analyze and evaluate optimal plant growth using sensors and actuators that were not available in ancient civilizations. In addition, predictive and adaptive mathematical models are used for plant growth analysis of thermodynamic parameters such as temperature, humidity and potential of Hydrogen (pH). Furthermore, there were compared performances of sensors (electromechanical sensors) with designed sensors that were based in nanostructures, because of better study of the plant growth techniques.

Keywords: plant growth, thermodynamic systems, nanostructures, optimization, Anodic Aluminium Oxide (AAO).

1. INTRODUCTION

Optimal plant growth techniques developed by ancient civilizations are the foundations of modern agriculture. Most cultures around the world used diverse techniques depending on climate adversities and population feeding necessities. In this work, growing up of some plants is analyzed through the lens of ancient Peruvian agriculture techniques. Robust and faster sensors and actuators were used to avoid any kind of perturbation during plant growth. Hence, enabling the design of a mathematical model that was based on experimental data correlation with thermodynamic parameters of plants. Furthermore, advanced error analysis methodologies were used to achieve optimal results.

The figure 1 shows agriculture behavior that were represented in paintings of the Inca civilization.

Figure 1. Agriculture representation of the Inca Civilization [1].

Many techniques as the engineering of andenes (platforms) were developed during past centuries around the world.

The best known examples of andenes are in Peru (see the figure 2) that are typically used in the Andes mountains due to successful results in agriculture by a natural temperature control in every step of andenes.

---

[1] The author wishes to acknowledge and thankful to Dr. Julio Cuisano, to MSc. Rosario Bravo and Eng. Javier Salazar, as many blind reviewers for their support in proofreading this manuscript.

Figure 2. Andenes of Inca agriculture [3].

Hence, in this research small andenes were designed and built according to grow up of plants, e.g., avocado. Physical variables as the plant length were measured and stored in order to compare each other and with this experimental data a mathematical model it was developed to obtain an optimal methodology, as the Incas did, to calculate the required amount of water and to keep appropriated temperature, pH and humidity values in every step of the anden. Two types of sensor were used for high precision data acquisition and comparison purposes: precision electronic and nanostructure-based sensors.

2. OPTIMIZATION

Plant growth is modeled in a general system and it is given by Eq. (1), in which the response y(t) is usually a nonlinear relation among the internal variables x(t) and excitation signals u(t) through a function γ.

$$y(t)=\gamma(x(t)),u(t),\theta) \quad (1)$$

Where θ represents internal parameters of the system. Therefore, the changes in x influence the dynamic of the system given by f, which is represented by Eq. (2).

$$\frac{dx(t)}{dt} = f(x(t), u(t), \theta) \quad (2)$$

By other side, while there are many measured variables Y, which get information from the studied system, it is possible to achieve an estimation of them by Eq. (3). X is the matrix that stores all input variables. This equation is obtained by deriving the cost equation (error) with respect to β.

$$\hat{\beta} = (X^T X)^{-1} X^T Y \quad (3)$$

Then the estimated output is given by Eq. (4).

$$\hat{Y} = X\hat{\beta} \quad (4)$$

Replacing Eq. (3) in Eq. (4):

$$\hat{Y} = X(X^T X)^{-1} X^T Y \quad (5)$$

In order to estimate the physical parameters of the system, it is possible to analyze polynomial models and then to adapt these coefficients accordingly.

The figure 3 depicts the loop of adaptation until to get the accepted value. According to get optimal correlation from experimental processed data, it was necessary to design the algorithm by adaptive/predictive model that depends on the coefficients that give information from “geometrical and material” parameters of the sensors.

Therefore, in this figure the block diagram of the used algorithm for the evaluations is depicted. In this algorithm, it is executed the error between the matrix of the desired variables with the measured variables. Hence, the adaptive coefficients are obtained along with the coefficients get information from sensors. Consequently, the optimal solution is obtained.

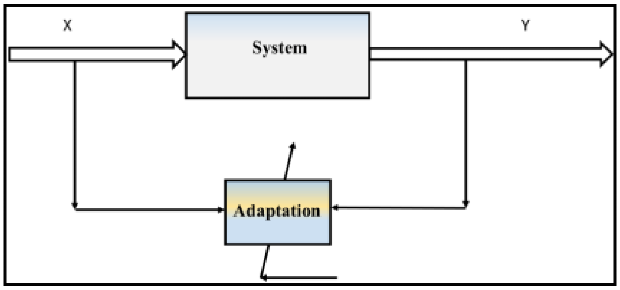

Figure 3. Adaptive scheme for the proposed model.

The cost function to find the appropriate parameters is given by Eq.(6).

$$\frac{\partial y}{\partial x} = (Y - r\theta)^T W^{-1} (Y - r\theta) \quad (6)$$

Where parameters are obtained after deriving as dependence of θ

$$\theta = (r^T W^T r)^{-1} r^T W^{-1} Y \quad (7)$$

Nevertheless, by error analysis as the dependence on weights, it was possible to enhance the estimation as it is given through Eq. (8), furthermore, it was used Least Mean Square (LMS) error analysis.

$$W(n+1) = W(n) + \mu \hat{X}(n) E(n) \quad (8)$$

Resulting is in

$$\bar{Y} = W_i^T X_i \quad (9)$$

Which should provide the optimal solution by finding W. Moreover, according to make practical calculations, it is possible to reduce the equation before by two and three vector points, such as it is described by the following equations.

For X it was composed by two components X_1 *and* X_2.

$$X = (X_1 X_2) \quad (10)$$

Furthermore,

$$Y = (Y_1 Y_2) \tag{11}$$

As it was explained by Eq. (4)

$$Y_e = X\beta \tag{12}$$

Therefore, by algorithmic analysis and design it is reduced to the following equation, in which a, b, c, d are the coefficients of the matrix X.

$$\begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} = \frac{1}{(ad-bc)^2} \begin{pmatrix} ((ad-bc)^2 + abcd)Y_1 \\ ((ad-bc)^2 + abcd)Y_2 \end{pmatrix}_{2X1} \tag{13}$$

It means that the estimation is the response variable for to components and by the other side, the result is showed in the following equation:

$$\begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \end{pmatrix}_{3x1} = \begin{pmatrix} a_1\beta_1 + b_1\beta_2 + c_1\beta_3 \\ a_2\beta_1 + b_2\beta_2 + c_2\beta_3 \\ a_3\beta_1 + b_3\beta_2 + c_3\beta_3 \end{pmatrix}_{3x1} \tag{14}$$

Therefore, when it is stored in the input matrix a reference variable that causes the estimated response tends to be to the reference variable. In last equation β_3 tends to be 1 and β_1 with β_2 tend to be 0.

3. MODELING

Nanostructure systems are structures as the dependence on their geometry and composition, which are elaborated in nanoscales, such as electrical conductivity, electrical resistance and capacitance, inductance also thermal and optical properties and for which many changes of these properties are given by geometrical characteristics of them. Therefore, this new technology started to be applied in different engineering tasks, which needed correlation between sensors and actuators. However, the development of this technology needed complex procedures by chemistry or atomic knowledge as for example, Atomic Load Deposition (ALD), Physical Vapor Deposition (PVD) or sputtering process.

Samples that are based in Anodic Aluminum Oxide (AAO) were also elaborated at PUCP, such as it is described in figure 4, in which "A" shows the setup for "electropolishing and anodization", "B" shows sample after electropolishing, "C" and "D" - after the first and the second anodization process. Finally, "E" is an extension of "D" in order to show the sample in nanoscale.

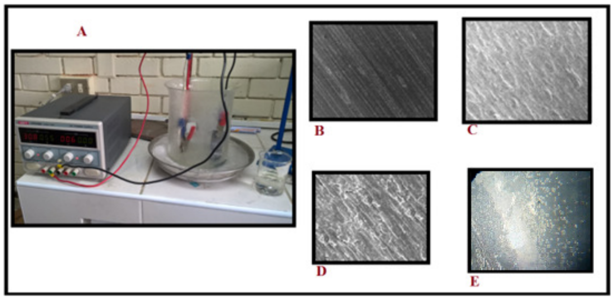

Figure 4. Setup and process to elaborate AAO samples.

It was evaluated "humidity and temperature" by sensors from the ARDUINO company. However, in order to get adapted and adjusted fixation of sensors over plants, it was designed sensors based in nanostructures that means to find connection with theory and experimental analysis.

The figure 5 represents heat transmission that is very important to analyze temperature measurement through the designed sensor prototypes. Therefore, in this figure is depicted the heating transmission Q as the dependence on time t from the focus to the sensor, when there is temperature change Tf as high value to Ts as low value, and the geometrical parameters K and db with material parameter K keeps the thermal resistivity of the sensor.

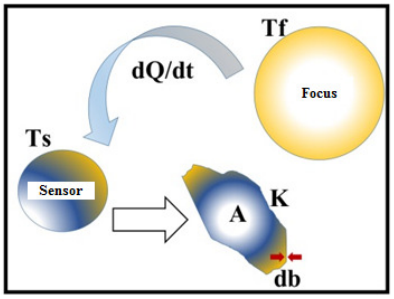

Figure 5. Heat transmission representation from high temperature to low temperature changes.

The sensor equation is given by the Eq.(15), in which the scale is near the atomic scale (nanoscale). Therefore, the transduction after internal electromagnetic response has very short response time and robustness.

$$\Theta(t) = \Theta_f(1 - e^{-\frac{t}{RC}}) \tag{15}$$

For the measurements were used (as dependence on the experimental context) thermocouples, the ARDUINO temperature sensor and humidity sensor. Material characteristics of sensors are stored in R and C, due to heating transfer for that equation model. Hence, by correlating Eq. (9) and Eq. (15), it was possible to prepare the algorithm to estimate temperature and humidity measurements (psychrometric chart), which were enhanced by achieved experimental data from the designed sensor, which procedure is explained by the following flowchart.

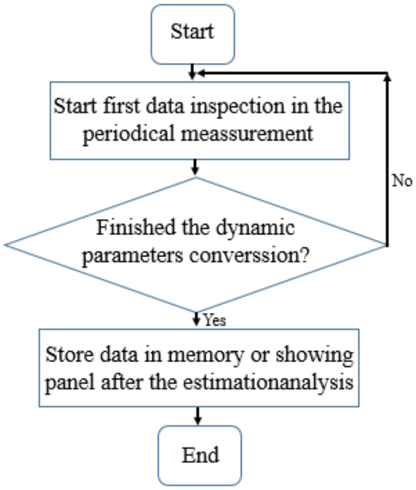

Figure 6. Flowchart of the main algorithm.

It is improved the curve, which is waiting to estimate by optimal adaptation by a dynamical response that is given by Eq. (16). Nevertheless, according to get correlation with more variables of the process, it is analyzed the following equation the costing function, in which is looking for the parameters that were obtained after deriving as the dependence on "Γ".

$$\hat{Y} = \Gamma(\Gamma^T W^{-1} \Gamma)^{-1} \Gamma^T W^{-1} Y \qquad (16)$$

Hence, it was possible to design a concurrent algorithm that increased informatics calculation of stored data from sensors, faster response from the designed sensors and it helped to achieve the algorithm as it is described in the following block diagram.

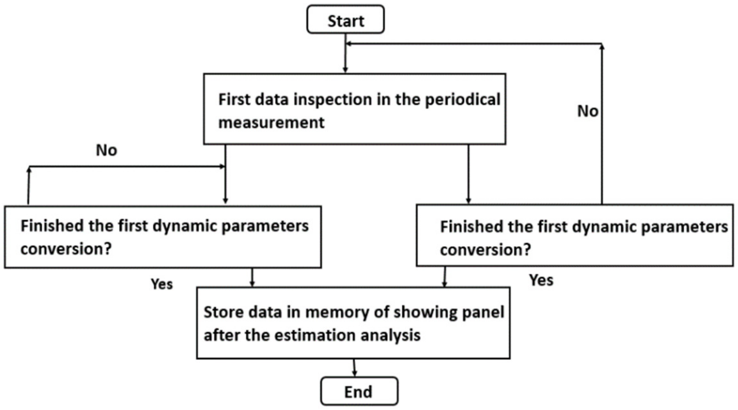

Figure 7. Algorithm proposed by concurrence analysis.

Furthermore, in figure 8 is described the dynamical behavior of the sensor prototype that was designed for temperature measurement, for which in curve "A" is obtained the temperature measurement by an integrated circuit (LM35) in electrical equivalence. Moreover, in curve "B" is showed the temperature measurement that was achieved by the designed sensor after the execution of the polynomial model of the algorithm that correlates the geometrical and thermal parameters of the sensor, because of its AAO composition based in nanostructures. The designed sensor achieved the error of 0.9% in comparison of LM35 sensor that obtained the error of 1.4%.

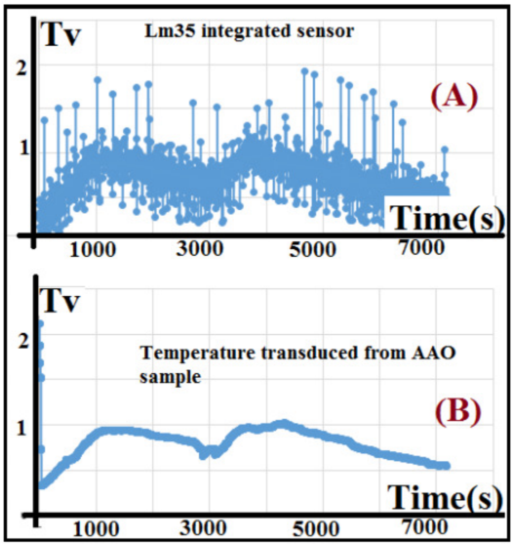

Figure 8. Dynamical behavior of sensor prototype for temperature measurement

Finally, in figure 9 is described the dynamical behavior of the sensor prototype that was designed for humidity measurement (relative humidity), in which red colour curve is obtained by the psychrometric chart (such as a good reference of the measurements, the green colour curve is obtained from the ARDUINO humidity sensor and blue colour curve is obtained from the designed sensor that is the correlation consequence on dynamic temperature and psychrometric chart values during its calibration. The designed sensor achieved the error of 1.2% in comparison of the ARDUINO sensor that obtained the error of 2.1%.

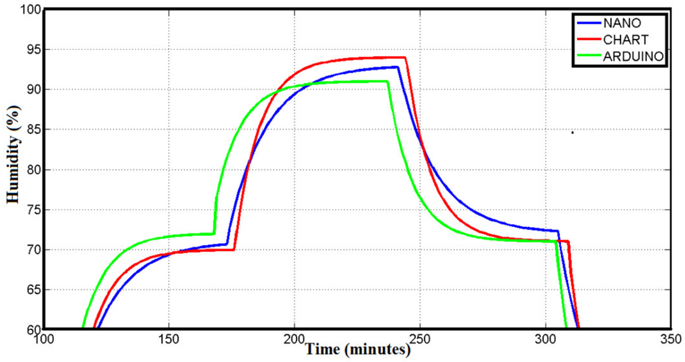

Figure 9. Dynamical behavior of sensor prototype for humidity measurement.

4. RESULTS

In order to evaluate the performance, avocado plants were studied as it is shown in figure 10. The archived procedure was giving by obtaining the measurement data from the designed sensor (temperature and humidity) positioning the sensor around the avocado plant and over the ground.

The data was stored during the avocado growth and the achieved information was executed by the optimization designed algorithm in order to find the optimal relation of temperature and humidity, due to get the optimal length of every avocado plant.

The correlation of the measured temperature and humidity helped to proportionate water to every avocado plant during their growth.

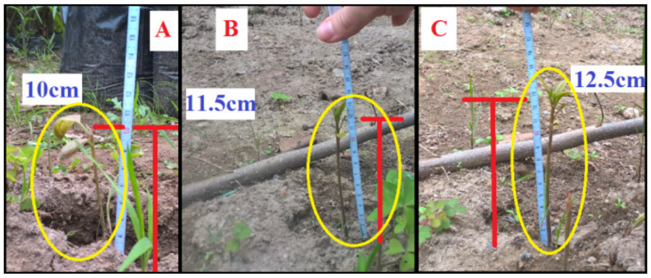

Figure 10. Avocado plants.

Every group of avocado plants (“Persea Americana”) was evaluated under sequence of steps of the designed algorithm and as a consequence it was possible to get uniform plants growth. Hence, the figure 11 shows one of the avocado plant in maximal growth length.

Figure 11. Obtained result.

The figure 12 shows the result of the algorithm execution. The ideal situation is given, when every avocado plant achieves the size of 30 cm (this variable is considered as a requirement) for which the surface with border in color brown is a flat surface. By other side, the surface composed by color blue points is the real sizes of every avocado plant (without optimal correlation of temperature and humidity).

Therefore, according to compare with the designed algorithm, the surface from color red points is the optimal. The execution of the algorithm by the data that was measured with the designed sensor that helped to repeat the experiments in the optimal trajectory of temperature and humidity and as a consequence to obtain the yellow surface (red points of avocado plants length).

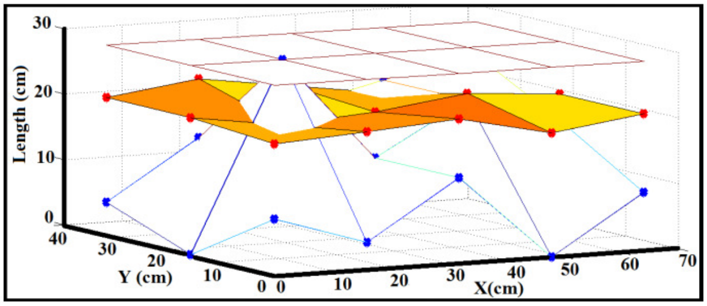

Figure 12. Optimized result for the growth up of avocado.

5. CONCLUSIONS

It was designed and evaluated an estimated/predictive algorithm in order to measure physical parameters during growth of plants (avocado for this research).

Commercial sensors such as from ARDUINO company and sensors based in nanostructures due to achieve physical parameters information as “temperature, humidity, length” of plants were evaluated in this research.

Traditional techniques for plants growth used by older civilizations, which lived in coast of Peru, were revisited. Nevertheless, it is suggested to analyze new cases, such as for example, to study the same family of seeds, homogeneity of the ground and position of the seeds that are stored in the ground.

6. FUTURE WORK

It is suggested to enhance the research through wireless sensors, of course that can be designed by joining controllers, sensors and infrared (IR) receiver/transmitter. However, it is heavy and can damage the plant growth. That is the reason, why it is suggested to prepare wireless sensors based in nanostructures due to not heavy, but simple, accurate, robust and faster ever it is necessary to warrant that IR range of work can not damage the growth of plants.

7. ACKNOLEDGEMENT

It is expressed deep warm gratefulness to Aleksandra Ulianova de Calderón due to her total support for the development of this research, moreover, to get the understanding of the compromise of natural science with cares of nature and agriculture traditions during the process of measurements and investigation time.

It is expressed gratefulness to Eng. Hugo Lozano, because of his knowledge and experience that was shared to the development of this article, according to get better understanding of the traditional agriculture in the Andes Mountains.

There is expressed special thankful to the Mechatronic Engineering Master Degree Program of PUCP (Pontificia Universidad Católica del Perú), The Energy Laboratory LABEN PUCP and DGI (Dirección de Gestión de la Investigación) researching office from PUCP, because of financial support for this research through the financing of FONCAI.

8. REFERENCES

[1] Attorre, F., Sciubba, E., & Vitale, M. (2019). **A thermodynamic model for plant growth, validated with Pinus sylvestris data.** Ecological Modelling, 391, 53–62. doi: 10.1016/j.ecolmodel.2018.10.022

[2] Chepstow-Lusty, A. & Jonsson, P. (2000). **Inca agroforestry: Lessons from the past.** AMBIO: A Journal of the Human Environment, 29(6): 322-328. doi: 10.1579/0044-7447-29.6.322

[3] Jones, H. G., & Rotenberg, E. (2001). **Energy, Radiation and Temperature Regulation in Plants.** ELS, 1–7. doi: 10.1038/npg.els.0003199.

[4] Ministerio de Ambiente (2014).

Perú: Mountain Country. Facing the challenge of climate change. Lima COP20 CMP10, Conferencia de las Naciones Unidas sobre el cambio climático 2014.

[5] Proulx, D.A. (1999).
The Nasca Culture: An Introduction. J. Rickenbach (Ed.), Nasca: Geheimnisvolle Zeichen im Alten Peru, Museum Rietberg, Zürich (1999). 59-77.

[6] Roddier, F. (2017).
The Thermodynamics of evolution An essay of thermo-bio-sociology.

[7] Sauerheber, R.D. (2018).
Thermodynamics and entropy in natural and artificial systems. American Research Journal of Chemistry, 2(1):1-26.

[8] Yong Lei, Weiping Cai, Gerhard Wilde (2007).
Highly ordered nanostructures with tunable size, shape and properties: A new way to surface nano-patterning using ultra-thin alumina masks. Progress in Materials Science 52 (2007)465 A ¸S539.

[8] Wang, L. (2009).
Model predictive control system design and implementation using MATLAB. Springer-Verlag London. doi: 10.1007/978-1-84882-331-0