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Intelligent and Optimal System for Monitoring Environmental Variables and Solar Luminosity, with solar path tracker and telemetry

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Abstract. In this proposed research are analyzed general solutions and techniques to optimize the solar luminosity measurement by a designed smart system, as well as its usability by the solar energy conversion and its storing. However, many times, this kind of systems have not an optimal solar path tracker and as a consequence it can not be measured the full solar luminosity during all the day, therefore, in this work are designed optimal mathematical models and algorithms to enhance the solar path tracker according to measure solar luminosity and getting optimal solar energy conversion/storing, which is useful to study geographical conditions before to build solar energy conversion centers. As well as, in this research also is studied and suggested some techniques to get wireless data communication regarding the measured environmental variables, measured solar luminosity and stored electrical energy as a consequence of the solar energy conversion, which can be transmitted, so far away, to a central monitoring center by Radio Frequency (RF) waves.

Key words. Solar path tracker, transducers, nanostructures, Modulating Function (MF), wireless data transmission, smart sensors, energy-saving.

1. Introduction

In this proposed article is analyzed a general design of an intelligent system for the monitoring of physical variables of the environment conditions, as well as it is generalized a model to coordinate the dynamic of an automaton to follows the solar path in order to achieve solar light absorbance (from which also can be transformed to electrical energy), therefore, the automaton can use the stored electrical energy. Many times there are devices that try to give information of the solar light absorbance for specific places, however, these can not get right values even though them are used from the sky, such as for example satellites.

The disadvantage to use satellites is given in the necessity to proportionate information to the user regarding the solar energy (correlated by the light absorbance) when it is not practical to get intricate areas such as for example when suddenly appear clouds covering the sky. Hence, it is proposed a mechatronic system, which is depicted by the figure 1, in which is represented the small solar panel to measure the light absorbance (that also proportionate energy to be stored in small rechargeable batteries) that is quite necessary for the system movement. Furthermore, there is an antenna to solve the task of the wireless communication through RF between the control monitoring place with the proposed system.

Therefore, it is depicted on the figure 1, a proposed model of a solar path tracker, in which it is represented the solar path, the solar panel and the tracker.

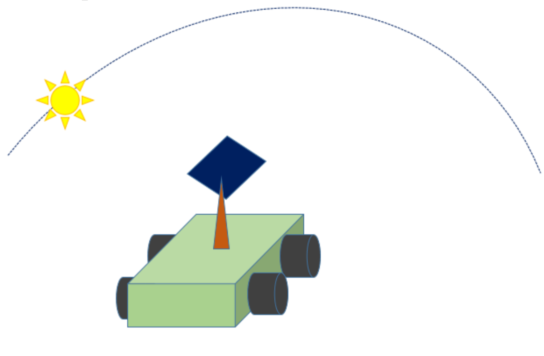

Figure 1: Scheme representation of the proposed system

The main idea of this research is given in the analytical tracker achieved by the designed system, for which, the tracker measures (by sensors based on nanostructures) the solar luminosity/radiation (correlated by the absorbance), as well as some environment variables, such as temperature, pressure and humidity of the studied area.

The path tracker analyzes the optimal place to suggest to users where needs to be stored solar panels according to achieve optimal sun energy transformation. Consequently, it can be useful to optimize the uses of solar panels around the world due to most of them are not recyclable and it is necessary to work with them but knowing where could be good places to obtain better quantity of electrical energy as a result of the sun energy conversion.

2. Methodology

The dynamic of the proposed system needs a model, which could proportionate parameters with the information of its movement as a response of the correlation with other important variables consequently to the integration of the light absorbance analysis, moreover the internal and external data communication. Hence, it must be designed an adaptive mathematical model and integrating with everyone of the subsystems of the proposed mechatronic system, especially to interpret own orders for its autonomous behavior programed as main objectives for the designer.

In the described context above, it was looked for an adaptive polynomial model based on modulating functions, thus the equation (1) gives information of the changeable response of a system in front an input signal "*u(t)*" on the time domain "t", the changeable response is given by "*y(t)*" but in simple response dynamic that can be considered as first order system, which also can be understood by its first derivative. Moreover, solving the equation (1) can be achieved the parameters "a_1" and "b_1" [8], [11].

$$\frac{dy(t)}{dt} + a_1 y(t) = b_1 u(t) \qquad (1)$$

Moreover, by the equation (2), it was expanded the previous equation (1) according to increase a derivative, due to obtain a usual second order system.

$$\frac{d^2y(t)}{dt^2} + a_1\frac{dy(t)}{dt} + a_2 y(t) = b_1\frac{du(t)}{dt} + b_2 u(t) \qquad (2)$$

As well as the generalized model is given by the equation (3), owing to expanding the derivatives on the equation (2) in the order "n" and error "e".

$$\frac{d^ny(t)}{dt^n} + \sum_{j=1}^{n-j} a_j \frac{d^{n-j}y(t)}{dt^{n-j}} - \sum_{j=1}^{n-j} b_j \frac{d^{n-j}u(t)}{dt^{n-j}} = e \qquad (3)$$

Therefore from the equation (2), it is generalized a second order proposed by the equation (4), depending on an input excitation signal *"u"* without derivatives.

$$\frac{d^2y(t)}{dt^2} + a_1\frac{dy(t)}{dt} + a_2 y(t) = b_2 u(t) \qquad (4)$$

In dependence on the modulating function "$\phi(t)$", by Modulating Functions technique, it was achieved the equation (5). The integration is given in the range from null to "T".

$$\int_0^T y(t)\frac{d^2\phi(t)}{dt^2}dt - a_1\int_0^T y(t)\frac{d\phi(t)}{dt}dt + a_2\int_0^T y(t)\,\phi(t)dt - b_2\int_0^T u(t)\phi(t)dt = e \qquad (5)$$

The equations (6), (7), (8) and (9) can organize the solution searching of the previous equation (5).

$$I = \int_0^T y(t)\frac{d^2\phi(t)}{dt^2}dt \qquad (6)$$

$$II = \int_0^T y(t)\frac{d\phi(t)}{dt}dt \qquad (7)$$

$$III = \int_0^T y(t)\phi(t)dt \qquad (8)$$

$$IV = \int_0^T u(t)\phi(t)dt \qquad (9)$$

Hence, for this context, it was proposed a Modulating Function "$\phi(t)$" given by the equation (10), in which the amplitude is "*A*", frequency "*w*" on the time domain *"t"*, as well as the complex field *"j"* that helps to find more expanded solution and stability analysis for the main system.

$$\phi(t) = Ae^{-jwt} \qquad (10)$$

Furthermore, the input excitation signal "$u(t)$" is given by the equation (11) with amplitude "u_0" and frequency "w_0".

$$u(t) = u_0 e^{-w_0 t} \qquad (11)$$

Moreover, it is proposed a first model for the response system "y" by the equation (12), in which the amplitude is "y_0" and the frequency "w_1".

$$y(t) = y_0 e^{-w_1 t} \qquad (12)$$

From the equations (10), (11) and (12) in the equation (6) is obtained the equation (13).

$$I = \int_0^T (y_0 e^{-w_1 t}) \frac{d^2 A e^{-jwt}}{dt^2} dt \qquad (13)$$

The reduction of the previous equation (13) is given by the equation (14).

$$I = \frac{w^2 A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} \cos\left(\frac{\pi}{2} - \arctan\left(\frac{w_1}{w}\right) + wT\right) - j \frac{w^2 A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} \sin\left(\frac{\pi}{2} - \arctan\left(\frac{w_1}{w}\right) + wT\right) \qquad (14)$$

According to organize the equation (14), there were proposed the equations (15) and (16).

$$X_1 = \frac{w^2 A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} \qquad (15)$$

$$V_1 = \frac{\pi}{2} - \arctan\left(\frac{w_1}{w}\right) + wT \qquad (16)$$

Hence, it was organized the equation (14) in the equation (17).

$$I = X_1 e^{-jV_1} \qquad (17)$$

As well as from the equation (7), it was reduced till to achieve the equation (18)

$$II = \int_0^T y_0 e^{-w_1 t} \frac{d(A e^{-jwt})}{dt} dt \qquad (18)$$

Therefore, the equation (19) generalize the equation (18)

$$II = \frac{w A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} e^{-j(wT - \arctan\left(\frac{w_1}{w}\right))} \qquad (19)$$

For which, the equations (20) and (21) help to organize the equation (19)

$$X_2 = \frac{w A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} \qquad (20)$$

$$V_2 = wT - \arctan\left(\frac{w_1}{w}\right) \qquad (21)$$

Thus, it was obtained the equation (22)

$$II = X_2 e^{-jV_2} \qquad (22)$$

As well as for equation (8), it was obtained the equation (23).

$$III = \int_0^T y_0 e^{-w_1 t} A e^{-jwt} dt \qquad (23)$$

Then, expanding the equation (23), it was obtained the equation (24).

$$III = -\frac{A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} e^{-j(\frac{\pi}{2} - \arctan\left(\frac{w_1}{w}\right) + wT)} \qquad (24)$$

The equations (25) and (26) helped to organize the equation (24).

$$X_3 = -\frac{A y_0}{\sqrt{w_1^2 + w^2}} e^{-w_1 T} \qquad (25)$$

$$V_3 = V_1 \qquad (26)$$

Hence, it was obtained the equation (27)

$$III = X_3 e^{-jV_3} \qquad (27)$$

In similar context, the equation (28) is consequently to the equation (9)

$$IV = \int_0^T u_0 e^{-w_0 t} A e^{-jwt} dt \qquad (28)$$

Thus, observing the equation (25), the solution for the equation (28) is achieved comparing the equation (24).

$$IV = -\frac{A u_0}{\sqrt{w_0^2 + w^2}} e^{-w_0 T} e^{-j(\frac{\pi}{2} - \arctan\left(\frac{w_0}{w}\right) + wT)} \qquad (29)$$

Then, by the equations (30) and (31), it was organized the equation (29).

$$X_4 = -\frac{A u_0}{\sqrt{w_0^2 + w^2}} e^{-w_0 T} \qquad (30)$$

$$V_4 = \frac{\pi}{2} - \arctan\left(\frac{w_0}{w}\right) + wT \qquad (31)$$

Therefore, it was achieved the equation (32).

$$IV = X_4 e^{-jV_4} \qquad (32)$$

Hence, in equation (5), by I, II, III and IV, analyzing their components real and imaginary helped to obtain the equation (33)

$$I - a_1 II + a_2 III - b_2 IV = \sqrt{E_{Re}^2 + E_{Img}^2}\, e^{-j\arctan\left(\frac{E_{Img}}{E_{Re}}\right)} \qquad (33)$$

Thus, it was achieved the equation (34).

$$X_1\, e^{-jV_1} - a_1 X_2\, e^{-jV_2} + a_2 X_3\, e^{-jV_3} - b_2 X_4\, e^{-jV_4} = \sqrt{E_{Re}^2 + E_{Img}^2}\, e^{-j\arctan\left(\frac{E_{Img}}{E_{Re}}\right)} \qquad (34)$$

From the previous equation (34), it was recognized its real component, which is given by the equation (35).

$$X_1 \cos(V_1) - a_1 X_2 \cos(V_2) + a_2 X_3 \cos(V_3) - b_2 X_4 \cos(V_4) = E_{Re} \qquad (35)$$

In similar context, in the equation (34), it was obtained its imaginary component, which is given by the equation (36).

$$X_1 \sin(V_1) - a_1 X_2 \sin(V_2) + a_2 X_3 \sin(V_3) - b_2 X_4 \sin(V_4) = E_{Img} \qquad (36)$$

Therefore, the equation (37) takes the equations (35) and (36) according to find the parameters "a_1" and "a_2".

$$\begin{pmatrix} -X_2 \cos(V_2) & X_3 \cos(V_3) \\ -X_2 \sin(V_2) & X_3 \sin(V_3) \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} E_{Re} + b_2 X_4 \cos(V_4) - X_1 \cos(V_1) \\ E_{Img} + b_2 X_4 \sin(V_4) - X_1 \sin(V_1) \end{pmatrix} \qquad (37)$$

The equation (38) is the solution to achieve "a_1".

$$a_1 = \frac{X_3 \sin(V_3)}{X_2\, X_3\, Sin(V_2 - V_3)} (E_{Re} + b_2 X_4 \cos(V_4) - X_1 \cos(V_1)) - \frac{X_3 \cos(V_3)}{X_2\, X_3\, Sin(V_2 - V_3)} (E_{Img} + b_2 X_4 \sin(V_4) - X_1 \sin(V_1)) \qquad (38)$$

The equation (39) is the solution to achieve "a_2".

$$a_2 = \frac{X_2 \sin(V_2)}{X_2\, X_3\, Sin(V_2 - V_3)} (E_{Re} + b_2 X_4 \cos(V_4) - X_1 \cos(V_1)) - \frac{X_2 \cos(V_2)}{X_2\, X_3\, Sin(V_2 - V_3)} (E_{Img} + b_2 X_4 \sin(V_4) - X_1 \sin(V_1)) \qquad (39)$$

For this reason, the obtaining of the parameters "a_1" and "a_2" was quite important owing to achieve the correlation between the transducers parameters with the path tracker dynamic, as well as, it was possible to verify its stability by Lyapunov based on the polynomial model designed. Consequently, it was designed the main algorithm for the simulations and experiments to get the evaluation of the performance for the designed path tracker. Furthermore, the achieved solution helped to organize the measured data from the sensors based on nanostructures (designed for this research) according to enhance the main control system of the path tracker.

The short response time of the sensors helped to execute an intricate main algorithm of the control/monitoring path tracker because of getting an optimal suggestion (for an external user) regarding the decision of the appropriated place where to fix and use sun panels. Hence, for the wireless data transmission to the external user, it was generalized the solution for an electromagnetic wave (information carrier), it is proposed the model in dependence on "relativity factor β" given by the equation (40). For which, "c" is the speed of light and "v" is mobile speed.

$$\beta = \sqrt{1 - \left(\frac{v}{c}\right)^2} \qquad (40)$$

Therefore, by the wavelength of the studied signal, it can be proposed a solution for the wave equation "y" given by the equation (41), "A" is the amplitude, "f" is the frequency, and "α" is the phase.

$$y(t) = A \sin(2\pi f\, t \pm \alpha) \qquad (41)$$

While it is known the equation (42), where "α" is the wavelength.

$$f = \frac{C}{\lambda} \qquad (42)$$

Moreover, because of relativity theory and Lorentz analysis, it was obtained the equation (43).

$$f = f_0 \sqrt{1 - \left(\frac{v}{c}\right)^2} \qquad (43)$$

Therefore, it was obtained the equation (44) as a general model for the wave equation solution, which takes the data transmitted from the path tracker sensors and sent to the external user, of course, the path track speed "v" is absolutely less than "c" and consequently the equation (44) tends to the equation (41). Nevertheless, the proposed generalization can be used for the similar systems under interplanetary tasks.

$$y(t) = A \sin(2\pi f_0 \sqrt{1 - \left(\frac{v}{c}\right)^2}\; t \pm \alpha) \qquad (44)$$

Even though, it is necessary to analyze the context of the equation (45) [9], [10]

$$C_0 = C\,(1 + \left(\frac{v_e}{c}\right)^2) \qquad (45)$$

Because of it can be studied as the limit speed to leave from a system, it just could happen in comparison with the initial value of the speed of light "C_0", from which can be supported by the equation (46).

$$-C^2 + C_0 C = v_e^2 \qquad (46)$$

The equation (45) is based on the equation (47), as well as it must be correlated with the gravitation effect, in which "m" is the mass of the scape particle, "M" is the mass of the body that cause the gravitational attraction under constant "G" for the distance "r".

$$\frac{1}{2} m v_e^2 = \frac{GMm}{r} \qquad (47)$$

Hence, the scape speed is given by the equation (48)

$$v_e^2 = 2\frac{GM}{r} \qquad (48)$$

It means that in equation (45) can be reduced to the equation (49). [9], [10]

$$C = \frac{C_0}{1+2\frac{GM}{rC^2}} \qquad (49)$$

Then, the general model for the electromagnetic wave equation, which has the information from the sensors of the path tracker can be reduced by the equation (50)

$$y(t) = A\sin\left(2\pi\frac{\left(\frac{C_0}{1+2\frac{GM}{rC^2}}\right)}{\lambda}\,t \pm \alpha\right) \qquad (50)$$

It means the equation (51), which also tends to the classic equation (41) because of the path tacker speed is quite less than "c". However, also this model can help for interplanetary tasks that could use a model as it is proposed in this research, because of the searching of optimal places where to fix and use solar panels.

$$y(t) = A\sin\left(2\pi\frac{f_0}{1+\left(\frac{v}{c}\right)^2}\,t \pm \alpha\right) \qquad (51)$$

3. Results

After to analyse every equation to describe the correlation between the transducer data (sun radiation absorbance, temperature, pressure and humidity) with the path tracker dynamic, it was designed the algorithm to be executed for the evaluation of the performance of the designed system by the simulations and experiments. Notwithstanding, a quite important task was the design of the solar light absorbance, which was based on nanostructures of Anodic Aluminium Oxide (AAO), such as it is showed on the figure 2. In which it is showed an image achieved by a microscope Litz in maximal scale 1000 nm (1 um) as well as, it is depicted the hexagon cylinders with diameters "Dp" and "Db" obtained as consequence of the anodization, in which were stored particles to design transducers of TiO2 for the transducers of the designed path tracker.

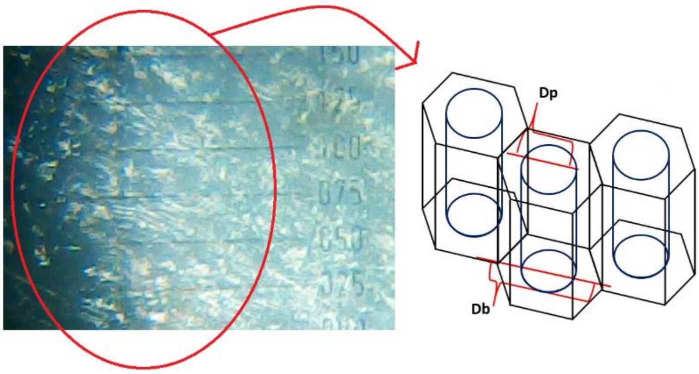

Fig. 2. Transducer samples design

The figure 3 shows the electrical energy absorbed (W/m^2) by the solar panel designed for the path tracker during operation (data quantity per second), based on the execution of the main algorithm selection of the path tracker in order to find an optimal suggestion to the user where to fix and use solar panels.

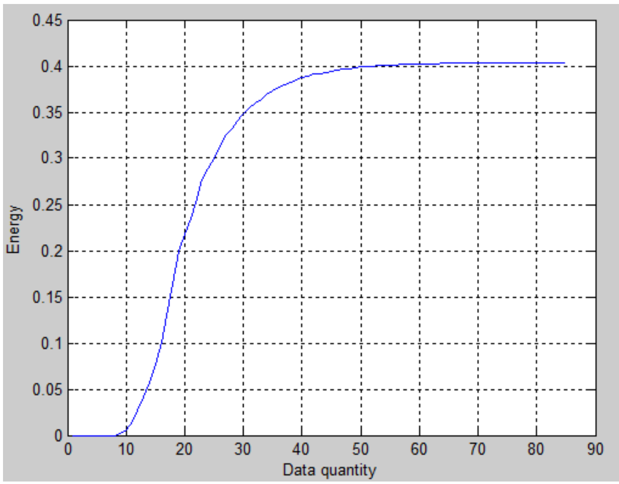

Fig. 3. : Dynamic response of the energy absorbed by the designed path tracker.

4. Conclusion

It was designed a general polynomial model according to correlate the transduction effect of sun radiation by transducers based on nanostructures, with the dynamic of a solar path tracker. Therefore, the analytical solutions through Modulating Functions by adaptive criterion were good strategies to design a sophisticated algorithm, which also was used by the simulations and experiments to evaluate the performance of the proposed designed system.

As well as, also it was analyzed the telemetric effect among the transduction (sun radiation and environment variables), the path tracker dynamic and the telemetry (data communication from the path tracker with the external user). Furthermore, it was analyzed the consequence of the proposed system under relativity theory that could be a support for interplanetary communications, such as for example to deal with the trouble of the delay reduction from the data communication between our planet and mars.

Hence, the proposed research can be a support to improve the uses of sun panels, because of the designed solar path tracker can give information regarding optimal places to store solar panels, which can be used to develop optimal tasks, such as for example pumping water, which is taken from lakes to far communities based on the energy conversion from solar panels to the pump.

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