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MINIMUM HELIOS ORBITAL MODELING WITH ARDUINO®NANO CHIPS FOR DRIVING SOLAR ENERGY SYSTEM

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ABSTRACT

Recently, it has become important to bind the most use of the green technology as the power saving strategy. Several applications of the solar energy with specifically designed storage and conducting component for providing the solar illuminating system is being proposed. Yet, just a few of the designs that considers the working with the micro-controller unit (MCU) for the conduction of the solar light into the environmental illuminating. To complete this task, construction an appropriate sunlight illuminating model with the relative movement of the sun respect to the earth for the MCU is recorded. With ray tracing and scattering model, variations in the energy flux of the moving Helios can be calculated, which shows the feasibility of present methodology.

KEYWORDS: Sunlight model, natural light system (NLS), micro-controller unit (MCU), Arduino®Nano

INTRODUCTION

It is critical to determine the optimized angular direction for solar energy apparatus and the natural light system (NLS) that rival the best usage of the solar rays **[1-2]**.Hence, to model the Helios orbit by the MCU for minimum control of the active solar energy system becomes an important task. The central elements for such optimization and control are to obtain the detailed data of the solar orbit and transform this information as the empirical formulae inside the MCU for the device operating at specific longitude and latitude location. In order to complete such optimization task, a good model for simulating the solar rays with the orbital information is needed. A straightforward plan of attack is to handle the sun rays as a set of emitting rays in a round aperture that come from the calculated spherical coordinate of the celestial orbit. However, such simplification did not look at the fact that the sunlight is an object with finite angular in the celestial coordinate.A modified approach is to provide the finite angular effects by the scatter model, hence one can simulate scattering of the sun beam into a specified circular cone, which is concentrated in the specular direction**[3]**. By taking this approach, the simulated rays, which surrounding the ecliptic, can illuminate toward directly to the solar energy system. After integrating the energy from the sunlight carefully, the construction parameters of the active solar energy system can be optimized with appropriate iterative procedures, under the given location and Julian-time.Based on **[4]**, following paragraph give the plot of the present investigation with the realization strategies.

METHODS

To develop the MCU program, one need to give a detailed calculation of the Helios orbit and found out the characteristic of these orbital parameters, such that the programming procedures can be proceed.The movement of the sun can be obtained by using the ephemeris calculated by software from Meade© **[5]** or SkyMap® **[6]**.For example, **Figure**

1demonstrates the southern view of the Helios position at Sapporo (Hokkaido, E141.348100, N43.054260) on **2016.7.20** from the SkyMap®. SkyMap®[5].

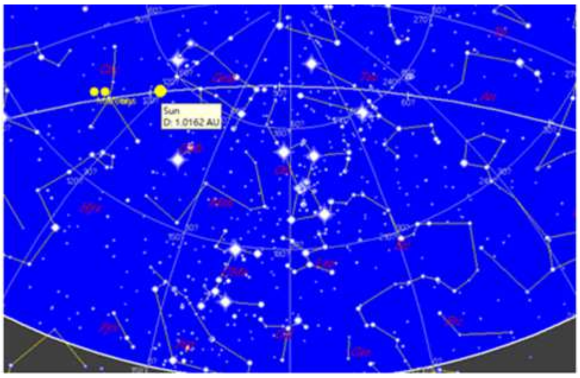

Figure 1: Helios orbits at Sapporo@Hokkaido on 2016.7.20

The conventional usage of the zenith distance ϕ(t), altitude *AL*(t) and the azimuthal angle *AZ*(t)=θ(t)for the Helios in this article are according to the definition of the International Organization for Standardization (ISO), which can be referred to **figure 2**. Nevertheless, one needs to notice that the procedure required the transformation of the altitude and azimuth coordinate between the geographical references to the global spherical coordinates. Rotations by 90° for altitude and 180° for azimuth will be performed to make the measurement between these two system consistent. The celestial coordinates can be listed in high resolutions between two Julian times, such that the time average for solar energy optimization can be completed. **Figure 3** gives the four views scenario of the solar orbit on Gregorian's calendar at **2016.7.20** at Taiwan near the landmark Taipei-101 (E121.564101, N25.033493), which indicates the possible shadowing effects that cause by the movement of the Helios. Notice that due to the stable movement of the celestial, the similar figure can be found in **[7]**.

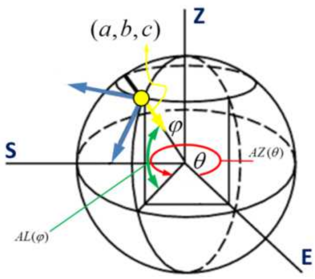

Figure 2: Conversion between Spherical Coordinate and Helios Direction Vector (a,b,c)

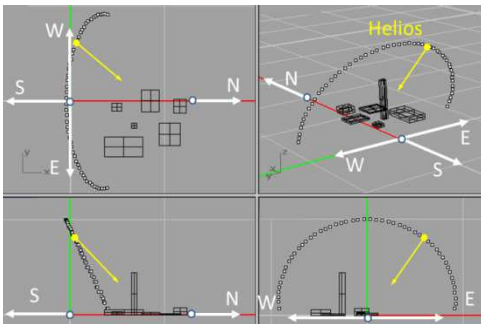

Figure 3: Helios Movements Demonstrate in (X,Y,Z) Coordinate at Taiwan on 2016.7.20

Once the celestial coordinate is listed, the direction cosines (*a*, *b*, *b*) of the sun's ray that towards the horizontal plane then can be obtained by using **equation (1)**. Again ϕ and θ are the zenith distance and the azimuth of the celestial sphere, in which stands for *AL*(t)= π/2-ϕ(t) and *AZ*(t)= θ(t).

$$a = -\cos(\theta(t))\sin(\phi(t))$$
$$b = -\sin(\theta(t))\sin(\phi(t)) \quad \textbf{(1)}$$
$$c = -\cos(\phi(t))$$

Equation (1) is the Cartesian-Spherical transformation with a minus sign.This implied that the solar rays is emitting towards directly to the center of the object where the observers or the targeting solar apparatus is located.The size of the celestial sphere should be adjusted to represent as a far field light source, such that one can get around of the dimension problem during the sunlight simulation. To go further, a demonstrated Helios coordinates are constructed in**2016.7.20** at Dali district (E120.714194, N24.095472), Taichung (Taiwan). **Figure 4** is made for every 15 mins started from 6 am to 6 pm, such that there are total 12□4=48 data points, with the abscissa is the time t (minutes) and the vertical axis indicate the angles (degree).

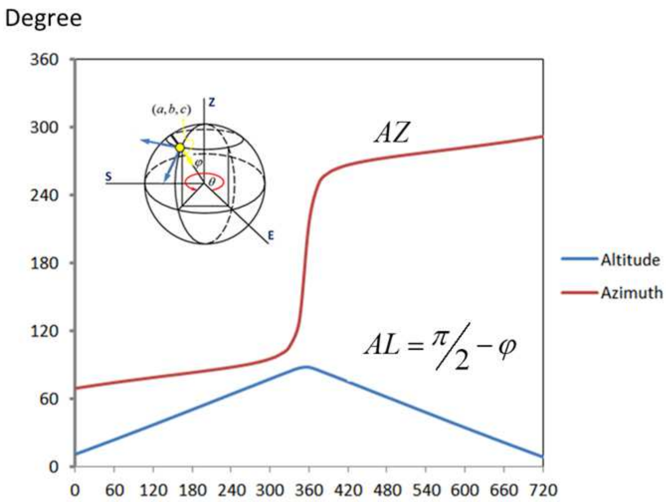

Figure 4: Azmithual and Altitude Angle of Helios at Dali District on 2016.7.20

Need to mention that due to the $PM_{2.5}$(Particulate Matter 2.5) and related factors, it is necessary to discuss the possible scattering model for the ray tracing. After constructing the rays emitting towards in the direction cosine vector (*a*, *b*, *c*), the two surfaces are suggested to be made to model this phenomena.The first one is the surface which is built to represent the fact that the solar rays will absorb by the target object. Another plane is built a little bit higher than the target plane with appropriate scattering model, which is designed to simulate the finite angular size (include the scattering effects) of the sun. Isotropic scattering model (**equation 2**) has already been suggested to mimic the sunlight during the ray tracing [3,7], where Ω(θ,ϕ) is the solar half angular size in radians.

$$BSDF \propto \frac{1}{\pi\Omega(\theta,\phi)^2} \quad \textbf{(2)}$$

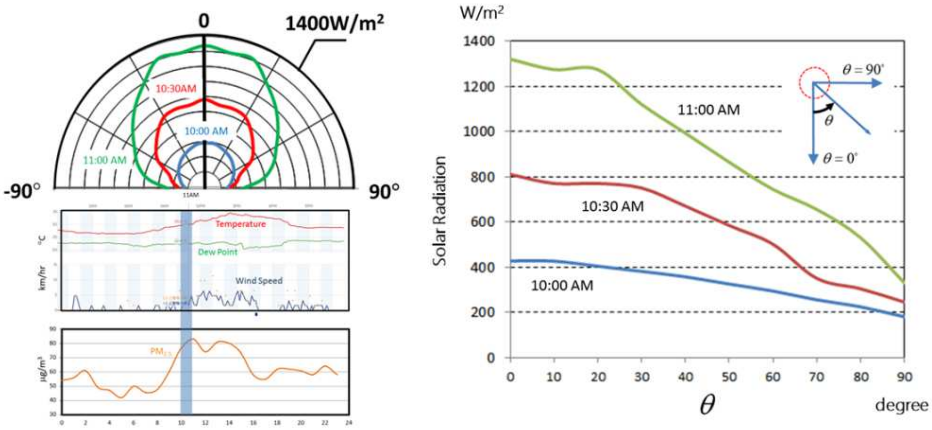

Figure 5: Scattering Effects in the Cloudy Sky with Variations on Temperature, Dew Point and $PM_{2.5}$ on 2016.10.20

Figure 5 gives a sample measurement on **2016.10.20** for the scattering phenomena, located at the same Dali district. One can see that due to cloudy and the $PM_{2.5}$, the apodization of the solar radiations is changing dramatically within 1 hours. Based on this, normalization procedure is proceeding on the *BSDF* to simulate the desired effect, and the ray tracing is take place from the scattering surface to the ground plane.This approach is to assign the scattering rays towards to the ground plane or the device target, and then the rays can be traced again, but in the reverse directions, to find the directional spot that projected on the celestial sphere – which is the location of the sun under specific solar angular size **[7]**.Through this methodology, one can give the lower limit and upper limits of the solar radiation during the Helios movement under different atmospheres scattering conditions. After complete the initial ray tracing, the rays can be saved or keep tracing in the same direction that heading for any kind of solar energy system, such as the green building, solar electricities facilities, TiO_2 based visible light hydrogen generating or the natural light display system **[8]**. It is important that if one need to estimate the solar tracking mechanism for lower altitude orbit, then the distance between the two pseudo surfaces should be larger, such that the reverse ray tracing procedures can be implemented for the solar energy calculation in low altitude conditions. As for the modelling of the Helios orbit, the altitude and azimuthal curve can represent by the polynomial with minimum coefficients that coding into the MCU chip, such as Arduino® Nano chip. **Figure 6** gives the example for the altitude *AL*(t) of Helios on **2016.10.15** (results close to **2016.10.20**) at Dali district. One can see that the altitude can be approximated by the sinusoidal function or the polynomial form.The comparison between the two will be revealed in**[9]**. Here the polynomial form is being taken, and **equation (3a and 3b)** gives the example on two formulae to calculate the altitudes of the sun at specific time *t* on October, with 6^{th}order and 4^{th} order polynomial approximation.Note that the coefficients for each term is varied for different months. The publishing on the relationship between the coefficients for different months is also scheduled in **[9]**. Based on these strategies, now one can demonstrate the implement of these theories for the activation of the solar energy facilities:

$$AL(t)=-0.000000000000010786t^6+0.000000000022217887t^5-0.000000015224381423t^4+0.000003479773515294t^3-0.000330716036253342t^2+0.221171954520855000t+0.86336608903639 \quad \textbf{(3a)}$$

$$AL(t)=0.000000001690446315t^4-0.00000232913050922t^3+0.000539344201410247t^2+0.176926164099086t+1.12279763172228 \quad \textbf{(3b)}$$

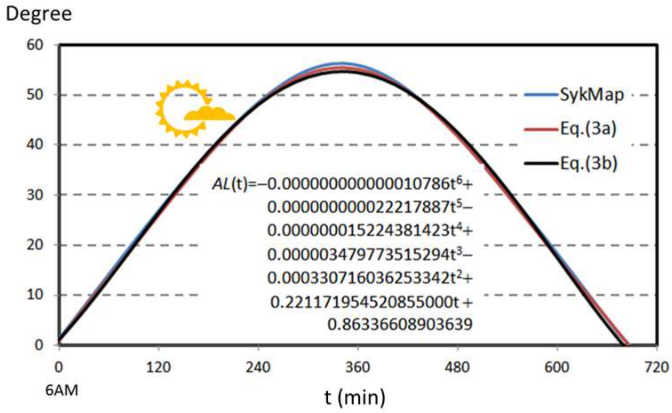

Figure6: Comparison of Calculated Altitude AL(T) of Helios on 2016.10.15 at Dali District

RESULTS AND DISCUSSIONS

Arduino®Nano with *ATmega168* core is recommended as the MCU for this application. According to the methodologies for **figure 6** and**equation (3a or 3b)**, the approximate polynomial for each month can be obtained. **Figure 7** gives the complete results for the altitude *AL*(t) of the Helios orbit at Kuala-Lumpur of Malaysia (E102.003055, N3.141200), in which the author had completed a demonstration of solar rays guiding windows core driving device **[10]** to improve the brightness and the contrast ratio under the energy saving guidelines.

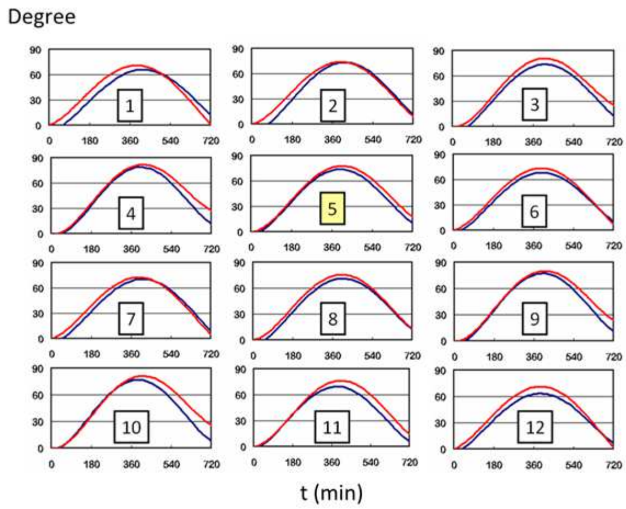

Figure7: Comparison of Calculated AL(T) between Skymap® (Blue) and the Arduino®Nano (Red), At Kuala-Lumpur

In the above **figure 7** one can see that the variations of the Helios altitudes *AL*(t) from January to the December. Note that for the changing of the altitudes, each curve can represent by a 4^{th} order polynomial with minimum digits coefficients that coding into the MCU. At the same time, for each month there are 5 coefficients (C_4=0.000000001690446315, C_3=0.00000232913050922, C_2=0.000539344201410247, C_1=0.176926164099086 and C_0=1.12279763172228) to fit the *AL*(t), such that it is supposed to have total 12*5=60 coefficients that required to store in the MCU registers.However, if one plots the coefficients C_1 to C_4 as the function of month, then a similarity between the four coefficients after appropriate scaling, shifting and reversing can be observed in **figure 8**.

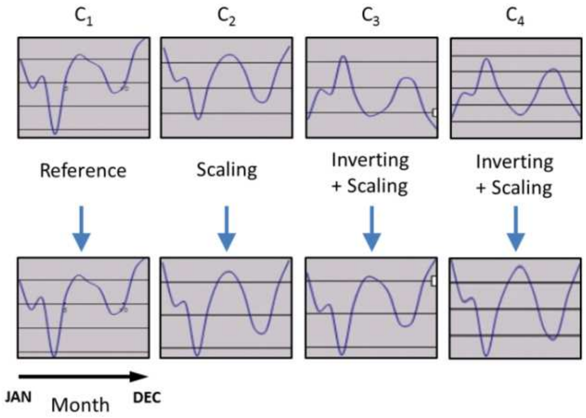

Figure.8: Reduction of Polynomial Coefficients through the Similarities

After the reduction shown in **figure 8**, now the numbers of coefficients that required to upload into the MCU is estimated as below:

- **12** C_0 coefficients for 12 months;
- **7** new coefficients that can simulate the entire profiles of C_1 to C_4 for 12 months;
- **4** scaling and **4** shifting coefficients for 4 coefficients curves C_1 to C_4

Now that there are only **27** coefficients (12+7+4+4=27) that can generate the complete *AL*(t) in the whole year, that are required to save into the MCU resisters (recall that there are 48×12=576 raw data for the *AL*(t)).Due to the minimum Helios orbital modeling with Arduino®Nano now is achieved (scattering effects like **figure 5** can be adjust by the scaling and shifting coefficients), then it is appropriate to demonstrate the possible application for this MCU - the solar window with Natural Lighting System (NLS) **[10,11]**. **Figure 9** is the scenario for the NLS window that conduct the solar energy. Such device can be helpful to provide appropriate light into a house environment with the best usages of the sunshine. Such scenarios that can also be reckoned as the targeting markets for various system with a specific function (the "panel" can be a window, an LCD display, a solar panel or a TiO_2 based electrolysis Hydrogen generating device).Founded on these requirements, to provide a very detailed understanding of the solar light source for that location with shadowing effects is extremely important and of practicality. In this figure, particular optomechanical design (two conjugate-movement mirrors) along with the MCU algorithm and reflector are designed to guide the illuminating light in this panel. Since the seasoning variations of the Helios orbit within a day, it is necessary to estimate and stick in the MCU to manipulate the angle of the optical system driving scheme.Appropriate illuminating region of the panel is designed, such that one can reduce the energy consumption of the NLS system.

In **figure 9**, the reflecting mirror A with length *L* and angle rotating angle β can reflect the solar rays, which incident with altitude angle *AL*(t), into the panel 6 at specific high *H*. One can define an Γ ratio that equal to *H*/*L* such that after some algebraic calculation, the following **equation (4)** can be obtained. Note that the rotation angles α and β of the device are controlled by the MCU.

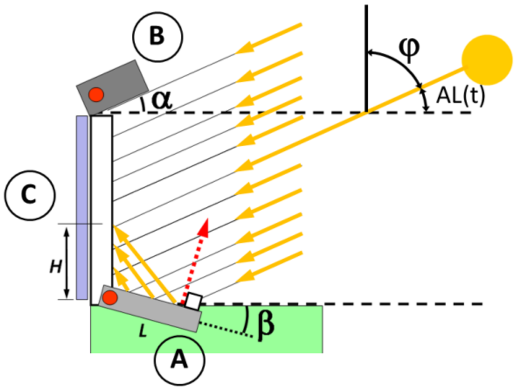

Figure9: NLS System with Two Mirrors Type that Using MCU to Control α and β Under Specific *AL*(T)

$$\begin{cases} \tan(AL(t)) = \left(\dfrac{2\Gamma\cos^2\beta - \sin\beta - \Gamma}{\cos\beta\cdot(1+2\Gamma\cdot\sin\beta)}\right) \\ \Gamma = H/L \end{cases} \quad \textbf{(4)}$$

If Γ=1, then the following exact solution in degree, **equation (5)** stands

$$\beta = -\frac{2}{3}\cdot AL(t) + 30 \quad \textbf{(5)}$$

In general, it is difficult to find the exact solution for **equation (4)** with arbitrary Γ, and even there is the exact one for particular Γ, it is also hard to be implemented into the MCU directly. However an inverted numerical method can achieve the purposed for the MCU algorithm. For example, if Γ=2, one can obtain the following **equation (6)**. Solutions for the complicated **equation (4)** now turn into the linear form, such as **equation (5,6)**, make it easy to be implemented into the MCU to drive the servo-motor for responding to the effects caused by Helios movement.

$$\beta = -0.5656\cdot AL(t) + 36.369 \quad \textbf{(6)}$$

As a summary, the procedures for the present investigation includes the analysis the orbit of the Helios, speculate the scattering phenomena, the radiation patterns, the reduce the tracing parameters for efficient tracing and the embedded algorithm for the MCU with minimum usages of registers. Throughout these procedures, one can calculate the overall efficiency of the system. Moreover, the weather conditions can be carried out by using the scattering model between the ground plane and the solar positions mentioned above. Pay attention that the difficulties will be occurring on the determinations of the scattering coefficients. Once the values of altitude *AL*(t) and the azimuth *AZ*(t) within 720 min is given during the tracking process, the normalized flux of the solar then can be estimated by exam the energy along the earth plane – which is the energy without any shadowing or the scattering effects, such that any variations the cause by the other factors can be estimate through this *baseline*.

CONCLUSIONS

Grounded along the above formulations, an algorithm is trained and the comparison between the MCU (Arduino®nano) with the original data from SkyMap® are complete. The minimum Helios orbital modeling for MCU to drive solar energy system is achieved, and results indicate that the MCU can generate the acceptable results compare to the

SkyMap®, with only limited memories stored in the MCU.Moreover, in this report, the model on the solar rays and the method to trace it is discussed.Grids of parallel rays are initially created from the target plane, toward to the center of the earth, then trace back to the celestial to locate the position of the Helios.The solar position is estimated through a finite angle by using isotropic scattering model. This model is successful in designing solar energy system setups, and one can use it to complete the key procedure on the fabrication of the solar illuminating NLS. The orbital issues are revealed, and the working status, the operating requirement on the MCU is explained.

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