Project Title	**Adaptive Solar Tree**
Data Source URL	**-**
Project Members	Ahmed Syalabi Seet
Business Case and Objective	Design and demonstrate a solar panel robotic system that incorporates solar tracking and shadow tracking to reduce shadow loss thus maximizing power efficiency of solar panel modules
Proposed Architecture/Approach and its Novelty/Benefits	Use reinforcement learning to replace traditional solar tracking and shadow tracking. Current solar panel tracking systems use pure mathematical compute using solar tracking algorithms like SPA by NREL. Will be using microcontrollers as the compute and its dormant sleep mode to reduce power usage. The system will only periodically adjust the solar panel orientation.
Preliminary Results and Discussion	https://github.com/syalabi-seet/adaptive-solar-tree Completed designing and building the physical prototype using Lego parts. Used Studio 2.0 to design and Blender to convert to FBX model to import to Unity engine. Built C# scripts to make a geographical sun position within simulation environment using SPA formula Designed and tested on physical computing components like stepper motors, Raspberry Pi Pico, light sensors, and Pi Pico SDK to determine feasibility for use case. Mathematical proof of concept: On next page
Plans for the Remaining Duration	• Build simulation in Unity3D engine, • Train PPO agent using ML-Agents library • Build actual electronics using Raspberry Pi Pico • Incorporate agent model into electronics using Tensorflow Lite

Mathematical Proof of Concept

$$E_{elect} = \eta_{cell} E_{solar}$$

$$E_{solar} = HSA_{module}$$

$$H = \int_{t1}^{t2} I_{tot} dt = I_{tot} \Delta t$$

$$I_{tot} = I_D + I_S + I_R$$

$$I_D = I_{DN} \cos\theta$$

$$cos\theta = sin\beta_1 cos\beta_2 + \cos\ \beta_1 sin\beta_2 \cos\left(\alpha_1 - \alpha_2\right)$$

$$I_{DN} = Ae^{C}, where\ C = \left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)$$

E_{elect} is the electrical energy generated from the solar module.

η_{cell} is the electrical efficiency of the solar module.

E_{solar} is the solar energy generated from the solar module.

H is the solar irradiation or incident solar energy per unit surface area.

A_{module} is the surface area of the solar module.

I_{tot} is the total irradiance acting upon the solar module surface.

I_D is the direct irradiance.

I_S is the diffuse irradiance.

I_R is the reflected irradiance.

I_{DN} is the direct normal irradiance.

θ is the incidence angle between the normal of the solar module surface and the sun.

β_1 is the solar altitude angle.

β_2 is the solar module altitude angle or tilt angle.

α_1 is the solar azimuth angle.

α_2 is the solar module azimuth angle.

A is the apparent solar irradiation.

C is the ratio of diffuse radiation on a horizontal surface to direct normal irradiation.

$\frac{p}{p_o}$ is the relative atmospheric pressure.

B is the atmospheric extinction coefficient.

S is the ratio of unshaded surface area to total surface area of solar module.

Combining all equations:

$$E_{elect} = \eta_{cell} S A_{module} I_{tot} \Delta t$$

Ignoring I_S and I_R, thus $I_{tot} = I_D$;

$$I_{tot} = I_{DN} \cos\theta$$

$$E_{elect} = \eta_{cell} S A_{module} I_{DN} \cos\theta \Delta t$$

Assuming the same PV module used and a fixed time, $\eta_{cell} S A_{module} \Delta t = constant = c$.

$$E_{elect} = c I_{DN} \cos\theta$$

$$E_{elect} \propto \cos\theta$$

Similarly, assuming the same PV module, fixed time, and incident angle, $\eta_{cell} A_{module} cos\theta \Delta t = constant = c$,

$$E_{elect} = cS = c\frac{A_{unshaded}}{A_{module}}$$

$$E_{elect} \propto A_{unshaded}$$

The electrical energy generated from the solar module is directly proportional to the cosine of the incidence angle and the unshaded area of the solar module.

$$E_{elect} = c\left[Ae^{\left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)}[sin\beta_1 cos\beta_2 + \cos\ \beta_1 sin\beta_2 \cos\,(\alpha_1 - \alpha_2)]\right]$$

Obtaining optimal α_2 value,

$$\frac{d}{d\alpha_2} E_{elect} = \mathrm{c}\left[Ae^{\left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)}[\cos\ \beta_1 sin\beta_2 sin(\alpha_1 - \alpha_2)]\right] = 0$$

$$sin(\alpha_1 - \alpha_2) = 0$$

$$\alpha_2 = \alpha_1 - sin^{-1}(0)$$

$$\alpha_2 = \alpha_1$$

The optimal module azimuth angle should be always equal to the solar azimuth angle to maximize electrical energy of the module.

Obtaining optimal β_2 value with substituting $\alpha_2 = \alpha_1$,

$$E_{elect} = c\left[e^{\left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)}[sin\beta_1 cos\beta_2 + \cos\ \beta_1 sin\beta_2]\right]$$

Using trigonometric identity $\sin{(A+B)} = sinAcosB + \cos AsinB$,

$$E_{elect} = ce^{\left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)}[\sin{(\beta_1 + \beta_2)}]$$

$$\frac{d}{d\beta_2}E_{elect} = ce^{\left(-\frac{p}{p_o}\left(\frac{B}{sin\beta_1}\right)\right)}[\cos(\beta_1 + \beta_2)] = 0$$

$$\cos(\beta_1 + \beta_2) = 0$$

$$\beta_1 + \beta_2 = \cos^{-1}(0)$$

$$\beta_2 = 90 - \ \beta_1 = Solar\ zenith\ angle$$

The optimal module altitude angle should always be equal to the zenith angle of the sun which is 90 minus the solar altitude angle to maximize electrical energy of the module.

References

Matius, M.E.; Ismail, M.A.; Farm, Y.Y.; Amaludin, A.E.; Radzali, M.A.; Fazlizan, A.; Muzammil, W.K. On the Optimal Tilt Angle and Orientation of an On-Site Solar Photovoltaic Energy Generation System for Sabah's Rural Electrification. Sustainability 2021, 13, 5730. https://doi.org/10.3390/ su13105730