Aiming Strategy for Linear Fresnel Reflectors

In this project investigating the soiling effect on the efficiency of a linear Fresnel reflector (LFR) plant, it is important to specify the coordinate system used to calculate the optimal tilt angle, β. This must be found from the sun's position at any given time, given by its azimuth and zenith.

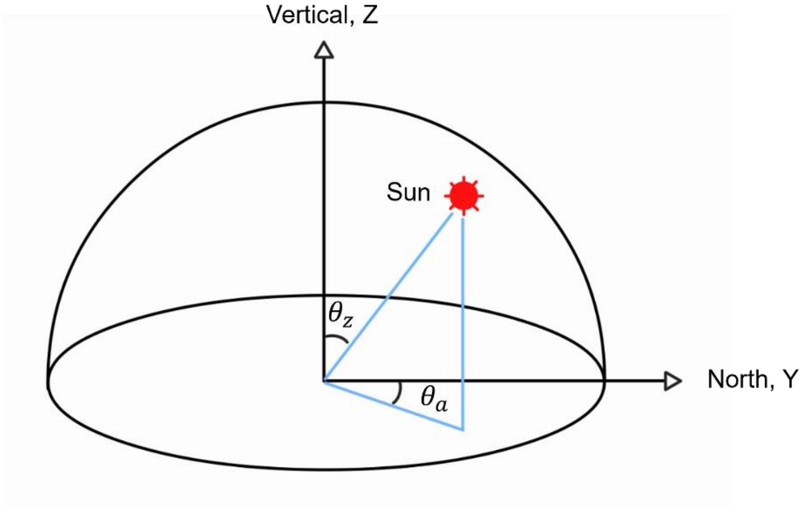

Figure 1: Diagram showing the sun's position using the azimuth and zenith angle.

The azimuth, θ_a, is the sun's clockwise horizontal position from North (Y) and the zenith, θ_z, is the sun's vertical position starting from vertical (Z). Therefore, Eastward is X.

The tilt angle is defined as shown below.

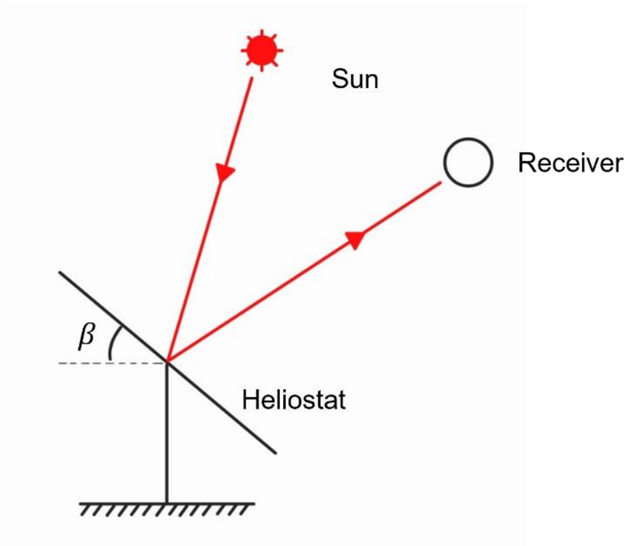

Figure 2: Diagram showing the tilt angle taken by the heliostat to effectively reflect the sun's energy to the receiver.

The sun vector, $\bar{S}$, can be fully described using θ_a and θ_z, but to then use the aiming equations, two other angles θ_T (transversal) and θ_L (longitudinal) must be defined.

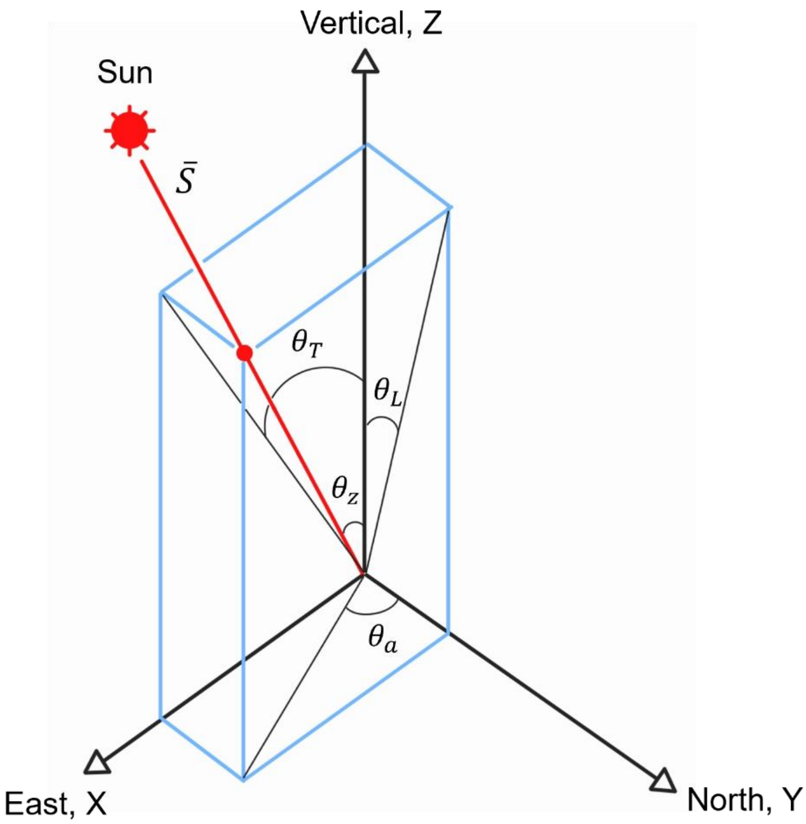

Figure 3: Diagram showing how θ_a, θ_z, θ_T and θ_L relate to the sun vector $\bar{S}$.

Therefore $\bar{S}$ can be defined as:

$$\bar{S} = (S_x, S_y, S_z) \tag{1}$$

$$S_x = \sin(\theta_z) \sin(\theta_a) \tag{2}$$

$$S_y = \sin(\theta_z) \cos(\theta_a) \tag{3}$$

$$S_z = \cos(\theta_z) \tag{4}$$

To find θ_T and θ_L we then normalise the $\bar{S}$ to $\hat{S}$, so that only direction is considered when calculating the transversal and longitudinal angles.

$$\theta_T = \arctan\left(\frac{\widehat{S_x}}{\widehat{S_z}}\right) \tag{5}$$

$$\theta_L = \arctan\left(\frac{\widehat{S_y}}{\widehat{S_z}}\right) \tag{6}$$

From “Development of an analytical optical method for linear Fresnel collectors” by G.Zhu et al. [1] we obtain equations that give us the tilt angle required.

Firstly, an angle known as θ_{aim} is found via:

$$\theta_{aim} = \frac{\left(\overrightarrow{I_z} \times \overrightarrow{v_{aim}}\right)}{\left|\left(\overrightarrow{I_z} \times \overrightarrow{v_{aim}}\right)_y\right|} \cdot \arccos\left(\frac{\overrightarrow{I_z} \cdot \overrightarrow{v_{aim}}}{\left|\overrightarrow{I_z}\right| \cdot \left|\overrightarrow{v_{aim}}\right|}\right) \tag{7}$$

$$\overrightarrow{I_z} = \begin{Bmatrix} 0 \\ 0 \\ 1 \end{Bmatrix}; \quad \overrightarrow{v_{aim}} = \begin{Bmatrix} x_{aim} - x_0 \\ 0 \\ z_{aim} - z_0 \end{Bmatrix} \tag{8}$$

where x_{aim} and z_{aim} are the X,Z coordinates of the receiver, and x_0 and z_0 are the X,Z coordinates of the pivot point of the heliostat.

The tilt angle can therefore be found as

$$\beta = \frac{\theta_{aim} + \theta_T}{2} \tag{9}$$

However, the PySolTrace API used to simulate all the raytracing requires the normal vector of the panel to know how to orientate it. As all the panels only rotate about the Y axis, we can apply the rotation matrix R_y on the normal vector of a horizontal panel facing upwards.

$$\overrightarrow{n_s} = \begin{bmatrix} \cos(\beta) & 0 & \sin(\beta) \\ 0 & 1 & 0 \\ -\sin(\beta) & 0 & \cos(\beta) \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{10}$$

$$\overrightarrow{n_s} = \begin{bmatrix} \sin(\beta) \\ 0 \\ \cos(\beta) \end{bmatrix} \tag{11}$$

From this, for any position of the sun in the hemisphere above the heliostat, the optimal tilt angle can be found to reflect the sunlight onto the receiver.

References

[1] G. Zhu, "Development of an analytical optical method for linear Fresnel collectors," Solar Energy, vol. 94, pp. 240–252, Aug. 2013, doi: 10.1016/j.solener.2013.05.003.