Solar Power Capture Using Movable Mirrors for Heating Applications in Manufacturing

Nima Amirdastmalchi, Irvine Valley College

Mentor: Professor Lan Pham

Introduction

Solar thermal power plants collect and concentrate sunlight using mirrors to produce extreme power and temperature at a receiver. A computer program is created in this research to model and visualize solar thermal power plants and the mirrors with calculated angles relative to the sun. The aim of this research is to facilitate the prediction of the power output of these plants before they are constructed. Hence, the modeling will shed light on the feasibility of adaptive methods to maximize heat collection.

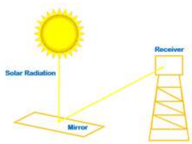


Figure 1- The capture of solar energy at a receiver equivalent to 1,000 suns

Methods

- Using the Stefan-Boltzmann's law for black bodies, the solar flux (W/m^2) onto earth's surface can be represented by the equation $F = \sigma T^4 (\mathrm{R}/\mathrm{d})^2 cos(z)$, where σ is the Stefan-Boltzmann constant and T, R, d, and z are sun's surface temperature, radius, distance to earth, and zenith angle respectively.
- The power at a mirror is, hence, determined by the equation: $P_m = Facos(\alpha)$, where a is the mirror's area visible to the sun and α is the angle between the mirror's normal and a direction vector pointing to the sun.
- The total power at the receiver would approximately be determined by adding the power at each mirror and multiplying by the fraction f_R of rays that hit the receiver from those that hit a mirror.
- The power reflected to the receiver would be:

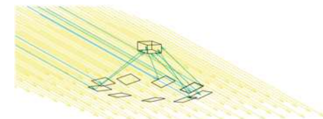
$$P_R = \sigma T^4 \left(\frac{\mathrm{R}}{\mathrm{d}}\right)^2 cos(z) \sum_{i=1}^{N} a_i\, cos(\alpha_i)\ \times f_R$$

- Using a Ray Tracer program (C++), a predetermined number of rays are generated from the sun to the panels. Each ray is traced and determined whether it hits a mirror or the receiver.
- A subroutine in the program is used to determine the power at the receiver throughout the day.

Results

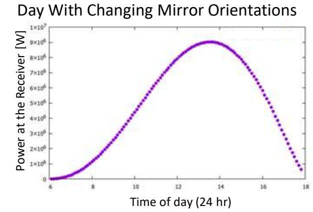
Using the Ray Tracer program, the information about the rays generated is stored into a file and plotted on a graphing software (Gnuplot) as shown in Figure 2. In the figure, yellow rays miss the panels and green rays hit a panel and hit the receiver after being reflected. Note that only 120 rays are generated for visualization purposes.

Figure 2- The Solar Thermal Power Plant Visualized



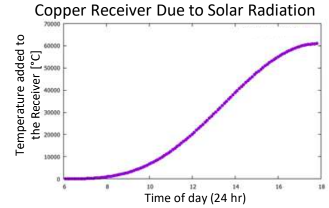
Next, the Ray Tracer program uses the equation in the Methods section and stores the power at the receiver from solar radiation throughout the day. The plot of the data is shown in Figure 3. In the figure, the orientation of the mirrors is changed every time a data point is collected (every second).

Figure 3- Power on Receiver Throughout the Day With Changing Mirror Orientations



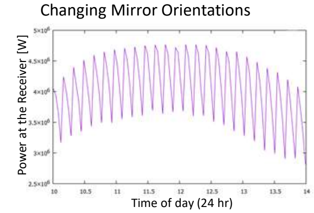
Furthermore, By using the equation $\mathrm{q} = \mathrm{mc}\Delta\mathrm{T}$, the change of temperature $\Delta\mathrm{T}$ of a material with mass m and specific heat c used as the receiver can be calculated based on the total energy q it receives. For example, if a copper receiver is used, the total temperature added due to solar radiation throughout the day is represented in Figure 4. Note that much of the temperature in the figure is not maintained and the receiver cools down over time.

Figure 4- Total Temperature Added to a Copper Receiver Due to Solar Radiation



To make the data more realistic, Figure 5 is a plot of the power radiated from the sun onto the receiver from 10AM to 2PM with mirrors that change orientation every 10 minutes instead of every second. The power at the receiver decreases during the 10-minute interval until the mirrors are adjusted to the changed location of the sun in the sky again.

Figure 5- Power on Receiver With Changing Mirror Orientations



Significance

- Although much of the solar radiation is lost in space, the earth still receives millions of times more power than needed. Hence, modeling a solar thermal power plant that collects sun radiations with mirrors is necessary.
- With the use of the Ray Tracer program, a solar thermal power plant is modeled. Using this model, the data such as power and temperature can be collected and analyzed for optimization.
- For example, Figure 3 is a graph of the data generated by the Ray Tracer program for the mirrors visualized in Figure 2. From the graph, the power at the receiver is maximized at 1:30PM. This result makes sense because the power at the receiver P_R depends on two angles, as discussed in the methods section. Thus, the max power does not necessarily happen at noon.

Limitations

- The actual power at the receiver depends on many other factors, such as the location where the plant is set up, the inclination of the earth's axis, and the day in the year.
- However, the focus of this study is the optimization of solar thermal systems. Therefore, the above factors are not considered.

References

Freedman, Roger A., and Hugh D. Young. *University Physics with Modern Physics.* Pearson Education, 2012. pp 1080-1213.

Peatross, Justin, and Michael Ware. *Physics of Light and Optics.* Brigham Young University, 2008. pp 323-333.