Stellar Sunshine

EML4501 | SPRING 2022 | GROUP 3

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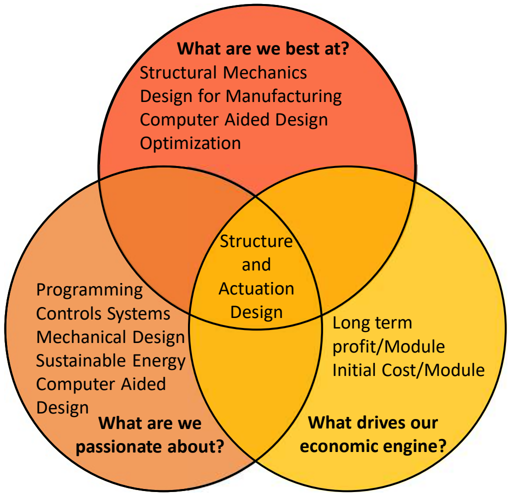
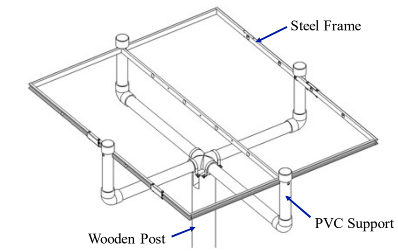
Hedgehog Concept



Abstract

Stellar Sunshine has implemented structural mechanics, design for manufacturing, and optimization all at a high-quality level for the heliostat design to succeed greatly in its desired job. The materials have been carefully selected based on many properties such as yield strength, stiffness, size, ease of purchasing, and cost effectiveness so that Stellar Sunshine is not only as light as possible, but it also has a substantial lifetime and generates low-cost energy. The entire module is secured using a 7-foot wooden post driven into the ground. This method of securing the module in place requires no fasteners and allows the cost for each module to be greatly reduced. This module has been designed with a reflective system that consists of four rectangular heliostats that are each mounted to individual rods therefore enabling easy replacement. A large reflective area to total area ratio is used to maximize the reflective area and bring down the cost of the reflective system. In addition, only two motors are required to move the four mirrors in the azimuth and altitude angles using a drive chain. What's more, the tracking error is minimized using a camera and motor system that result in accurate syncing between the sun and the module. Moreover, the heliostats are placed in a staggered pattern to minimize self-shading.

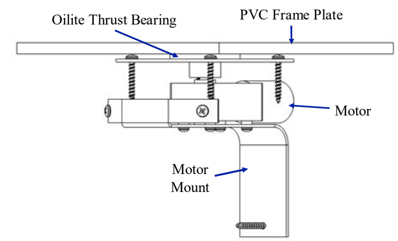
Structure System

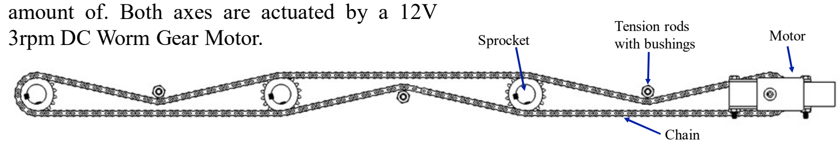


The structure subsystem is comprised of a central column with four L-shaped supports that uphold the mirror frame on all sides. The central column is driven almost completely into the ground to provide a fixed support against wind bending loads. The central column is made of pressure treated southern yellow pine and the L-shaped supports are made of PVC.

Maneuverability System

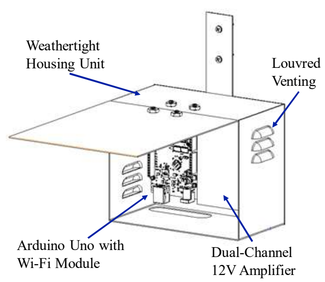
The maneuverability subsystem actuates each heliostat in the module simultaneously in the azimuth direction by rotating the frame supports where they join on top of the central column. Each heliostat is actuated in the altitude direction by one motor rotating a chain drive. This allows independent actuation of each heliostat in one direction while minimizing the amount of. Both axes are actuated by a 12V 3rpm DC Worm Gear Motor.



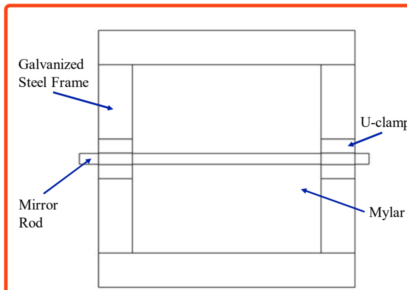


Tracking System

The tracking subsystem utilizes an Arduino Uno and a Wi-Fi module to track the sun throughout the day. A camera is then mounted to the tower to watch the module and determine its deviation from the sun using a high-resolution lens. The Arduino Uno and Wi-Fi module are attached and enclosed on the wooden post to ensure no debris harm them.



Reflective System



The reflective subsystem consists of four square mirrors made from Mylar polymer that are connected to a galvanized steel frame which is connected to an AISI 1020 steel rod using a U-clamp made from 20Ga 1023 carbon steel sheet. An AISI 1020 steel rod then connects each heliostat to the main frame. The frame design works to minimize self-shading.

Functionality

The Stellar Sunshine heliostat system utilizes four reflective surfaces that are attached to a metal frame that is supported by a PVC support system. The reflective surfaces actuate along the altitude angle within the metal frame using a chain and sprocket mechanism. The PVC support system can be broken into the vertical support and the part that articulates along the azimuth angle. A central thrust bearing allows the upper PVC support to rotate around the vertical support. The vertical support is driven into the ground to support the weight and external loads on the heliostat. Movement is made possible by two 12V 5RPM DC worm gear motors. The motors are controlled by an Arduino Uno and Wi-Fi module that is programmed to follow the sun based on the GPS location. A closed loop system using a camera to track the sun is also utilized to minimize tracking error throughout the day. The number of motors is minimized to two in order to maintain cost efficiency for each module.

Cost Breakdown

OTS Parts:	$219.21
Raw Materials:	$182.83
Manufacturing Labor:	$31.12
Assembly Labor:	$45.00
Energy Consumption:	$0.95
Total:	**$479.11**

Customer Needs Maps

Customer Need	Engineering Requirement	Subsystem	Result
Total module collection size $\leq 1\ m^2$	Total collection size $\leq 1\ m^2$	Reflective	4 Mirrors with a total collection area of $0.81m^2$
Each module must be composed of 4-16 heliostats	Each module must be composed of 4-16 heliostats	Reflective	4 Heliostats per module
Cannot shade other heliostats in that module 60 minutes after sunrise or 60 minutes before sunset	Minimize self-shading to not exceed 90% within the allotted time.	Reflective	Approximately 90% self shading occurs during this time
The reflecting surface of each heliostat must be washable using conventional cleaning techniques to remove dust and residue.	Can withstand high pressure spray of 10,000 psi	Reflective	PET film reflective surface has yield strength of $\sigma_y = 14kpsi$
Concentrated focal thermal input power of 1 MW	Concentrated focal thermal input power of 1 MW	Reflective	1885 Modules with a flux of $163.8\ W/m^2$
Solar concentration ratio greater than 1000 suns at all time 60 minutes after sunrise and 60 minutes before sunset	Delivered Flux = 174,300 W/m^2	Reflective	266 Modules at 94% optical efficiency with a flux of $163.8\ W/m^2$
The distance of heliostat units furthest from the collector target tower must account for dispersion of reflected light from the heliostats relative to the size of the absorbing aperture of the solar receiver target	90% of the light contacting the heliostat reflective surface makes direct contact with the tower.	Reflective	The reflective surface has an optical efficiency of 94%

Customer Need	Engineering Requirement	Subsystem	Result
Each module must mitigate optical losses due to tracking errors not to exceed 40%	Each module must mitigate optical losses due to tracking errors not to exceed 40%	Tracking	Tracking error minimized by camera feedback system
Sun Tracking via onboard controller	1 controller per module	Tracking	Arduino Uno Controller

Customer Need	Engineering Requirement	Subsystem	Result
Each module must be capable of tracking the sun throughout the day.	Elevation Rotation: 90°/ Azimuth Rotation: 180°	Maneuverability	360 degrees of freedom in the azimuth direction and 360 degrees of freedom in the altitude direction
Modules must redirect sunlight to a receiver target mounted on a central tower up to 100 m tall.	Receiver mounted at height of $0 < h \leq 100m$	Maneuverability	Receiver mounted at a height of $h = 100m$
Each mirror (heliostat unit) in a module must move independently of all other mirrors in its module in at least one axis. (Multiple mirrors actuated together min both axes count as one mirror).	Each mirror moves independently in 1 or 2 axes.	Maneuverability	Chain drive moves mirrors independently in the altitude direction

Customer Need	Engineering Requirement	Subsystem	Result
Small Heliostat Size	Structure height cannot exceed a height of $h = 0.6\ m$	Structure	Structure height $h = 0.31\ m$
Total module area relative to the reflective surface must be small	Surface is 85% reflective (mirrors) - 15% supporting material	Structure	Surface has a reflective area percentage of approximately 95%
Factor of Safety must exceed N=2	$N \geq 2$	Structure	Buckling factor of safety of $N = 1005$
Las Vegas	Max Wind Speed: 90 mph	Structure	Bending factor of safety of $N = 6.83$

Customer Need	Engineering Requirement	Subsystem	Result
Small Heliostat Size	Overall module heliostat volume cannot exceed of $V = 1m^3$	All Subsystems	Module volume of $V = 0.251m^3$
Aggregate cost of an individual module is below $100/$m^2$	Aggregate cost of an individual module is below $100/$m^2$	All Subsystems	Individual module is below $479.11/$m^2$
Individual parts must be equal in price or less expensive than the closest available OTS part	Custom parts must cost $\leq$ 100% of the total OTS price	All Subsystems	Custom parts cost $219.21
20-year lifetime	Lifespan = 20 years	All Subsystems	Replacement of motors once every 10 years