Staggered Tracking Actuated Reflectors

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Abstract

When renewable energy first needed a solution, humanity looked to our star. When it comes to advancing the solution, group 5 looks to our STAR. Group 5 is dedicated to creating innovative and long-lasting solutions that help solve expensive problems. This mindset led to meticulous research into the use of unordinary materials and innovative ideas to create the Staggered Tracking Actuated Reflector, or STAR. The primary feature of the assembly is the reflectors' unique arrangement. The narrow mirrors and 30-degree tilt minimize the shading distance between reflectors and promote a compact module while maintaining the proposed reflective area of 1m^2. The module is composed of an array of steel rods stemming from a central hub, which rotates about a rod secured in a concrete base beneath the ground. The steel structure provides a cost-effective, rigid structure for mounting while increasing the lifespan and safety of the system. Additionally, the STAR is driven by five stepper motor pulleys that allow each mirror to track the sun and utilizes an ESP32 microcontroller with online access to solar position data. All modules would efficiently perform in a field to reflect over 1 MW of solar radiation onto a central receiving tower. The STAR system is a compact, robust, highly efficient system that will reflect vast amounts of renewable energy, making large heliostats a technology of the past.

Product Functionality

A heliostat is a structure consisting of a reflective surface that is able to track the Sun. When placed in a field of numerous heliostats, they reflect sunlight onto a central receiving tower, up to 100 m away and 100 m tall. The STAR design tracks the Sun using an online database, communicating via a Wifi enabled ESP32 microcontroller. The stepper motor provides a cheap, but accurate, method to actuate the reflectors while the pulley-belt system ensures the strength needed to operate in average Las Vegas wind gusts of 9 m/s. With a steel and concrete structure, the STAR heliostat design has been engineered with safety in mind to withstand the harsh desert climate, including maximum forces from 90 mph wind gusts and temperatures of 117°F.

Cost Breakdown

OTS Parts	$52.83
Modified OTS Parts	$14.20
Raw Materials	$122.83
Manufacturing Labor	$78.71/hr
Assembly Labor	$36.30/hr
Energy Consumption	$0.01/hr
Total	$304.85

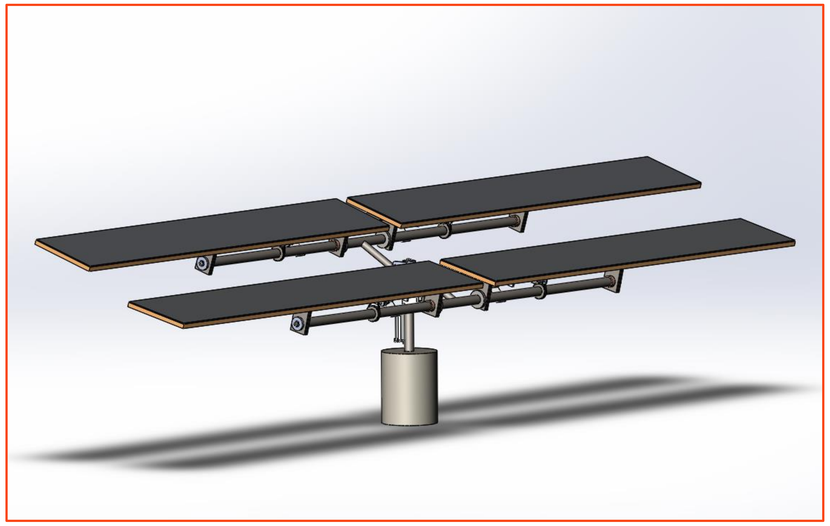


Figure 1. Full assembly CAD model of STAR heliostat

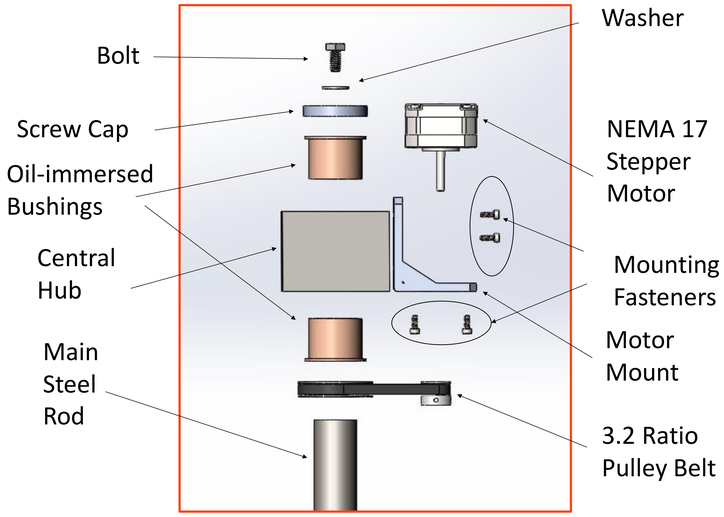


Figure 2. Exploded view of central hub driver system to rotate in the azimuth angle

Structure Subsystem

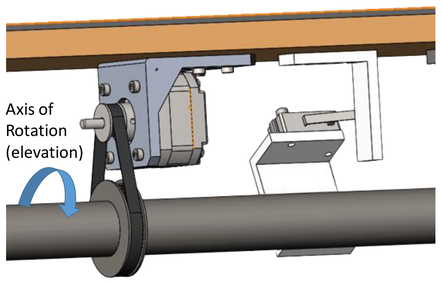
- Underground concrete base for added support and rigidity
- Steel rods welded in place for long-lasting support
- Custom manufactured central hub that rotates in the azimuth direction around oil-immersed bushings
- Metal plates bolted in at the end of steel rods to resist axial movement of angled brackets
- Staggered structure to avoid shading on other reflectors

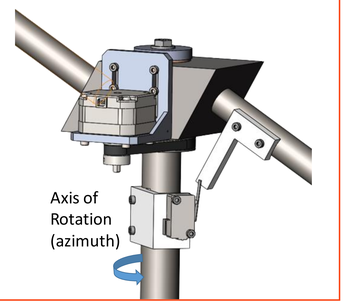
Reflection Subsystem

- Four 1.25 m x 0.2 m silver backed borosilicate glass mirrors with a thickness of 3 mm
- Reflectivity of 97%
- Total reflective area of 1m^2 per module
- Reflectors are adhered to and supported by ½ in thick panel of southern yellow pine wood
- The wood is coated in a protective sealant to last several years

Driver Subsystem

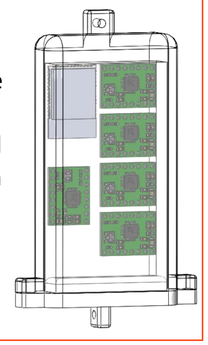
- A central hub is actuated in the azimuth angle by a single NEMA 17 stepper motor, combined with a 3.2 ratio pulley system
- Each reflector moves in the elevation angle using a NEMA 17 stepper motor with the same 3.2 ratio pulley belt assembly
- Each rotation axis includes a limit switch so the stepper motors can recalibrate their positions when needed
- Large pulley mount is welded to support rod in order to induce a rotation about it





Controller Subsystem

- The motors and motor drivers are controlled by an ESP32 microcontroller with Wi-Fi connectivity
- Each motor uses an A4988 driver
- The microcontroller and motor drivers are protected within a custom designed housing unit
- Housing unit is made of injection molded polycarbonate to meet the electronics protection standards of a NEMA 3 enclosure



N1) Small, innovative heliostat designs	M1) Mass of heliostat < 50 kg	Reflection Subsystem	F1) Mass = 1.875 kg
N2) Collection Area ≤ 1m^2	M2) Collection Area ≤ 1m^2		F2) Collection Area = 1m^2
N3) Each module: 4-16 heliostats	M3) $4 \leq$ Number of Heliostats ≤ 16		F3) Number of heliostats = 4
N4) Optical losses less than 40%	M4) Tracking error $\leq \pm 0.25°$		F4) Tracking error = 0.0879°
N5) Track sun throughout day	M5) $\theta_{range} = \theta\text{max} - \theta_{\text{min}} = 180°$		F5) $\theta_{range} = 180°$
N6) Cannot shade other heliostats	M6) Dist. $X > L(\sin(27.5°) + \frac{\cos(27.5°)}{\tan(10°)})$		F6) X = 1.098m
N7) Redirect sunlight to central tower	M7) Reflectivity $\rho > 0.6$		F7) Reflectivity = 0.95
N8) Overall cost below \$100/m^2	M8) Cost < \$100/m^2 Reflective Area	Structure Subsystem	F8) Total cost is \$121.22
N9) Automated/computer-controlled tracking	M9) Autonomous Score > 2		F9) Autonomous Score = 4
N10) Ratio of module area to Reflective Area should be small	M10) $A_{module}/A_{reflect} < 3$		F10) $A_{module}/A_{reflect}$=0.005
N11) Individual parts cost less or equal to OTS parts	M11) Part Price – OTS Price ≤ 0	Drive Subsystem	F11) Total part prices were all less than the OTS part prices
N12) Reflecting surface can be cleaned	M12) Cleaning Score ≥ 2		F12) Cleaning score of 2
N13) Factor of safety for any mechanical function is great than 2	M13) Factor of safety $n \geq 2$		F13) Factor of safety $n = 44.08$
N14) One heliostat unit moves independently from other units	M14) $N_{actuator} > N_{heliostats}$	Controller Subsystem	F14) Five actuators in total with four heliostats
N15) Operational lifetime more than 20 years	M15) $Life_{lowestFOS} \geq 20\ years$		F15) Lifetime is 2737.9 years
N16) Operates in Las Vegas	M16) Thermal Factor of Safety ≥ 2		F16) n_{therm} =13.76
N17) Thermal input power of 1 MW	M17) $P_{tower} \geq 1\ MW$		F17) Delivers 1.05 MW of power
N18) Solar concentration ratio greater than 1000 suns	M18) Solar Concentration Ratio $q''_{\text{actual}}/q''_{sun} \geq 1000$		F18) Solar Concentration Ratio equal 1000
N19) Heliostat units account for dispersion of reflected light	M19) Max Heliostat Module Distance = 100 m		F19) The furthest heliostat module is placed 100 m from the central tower