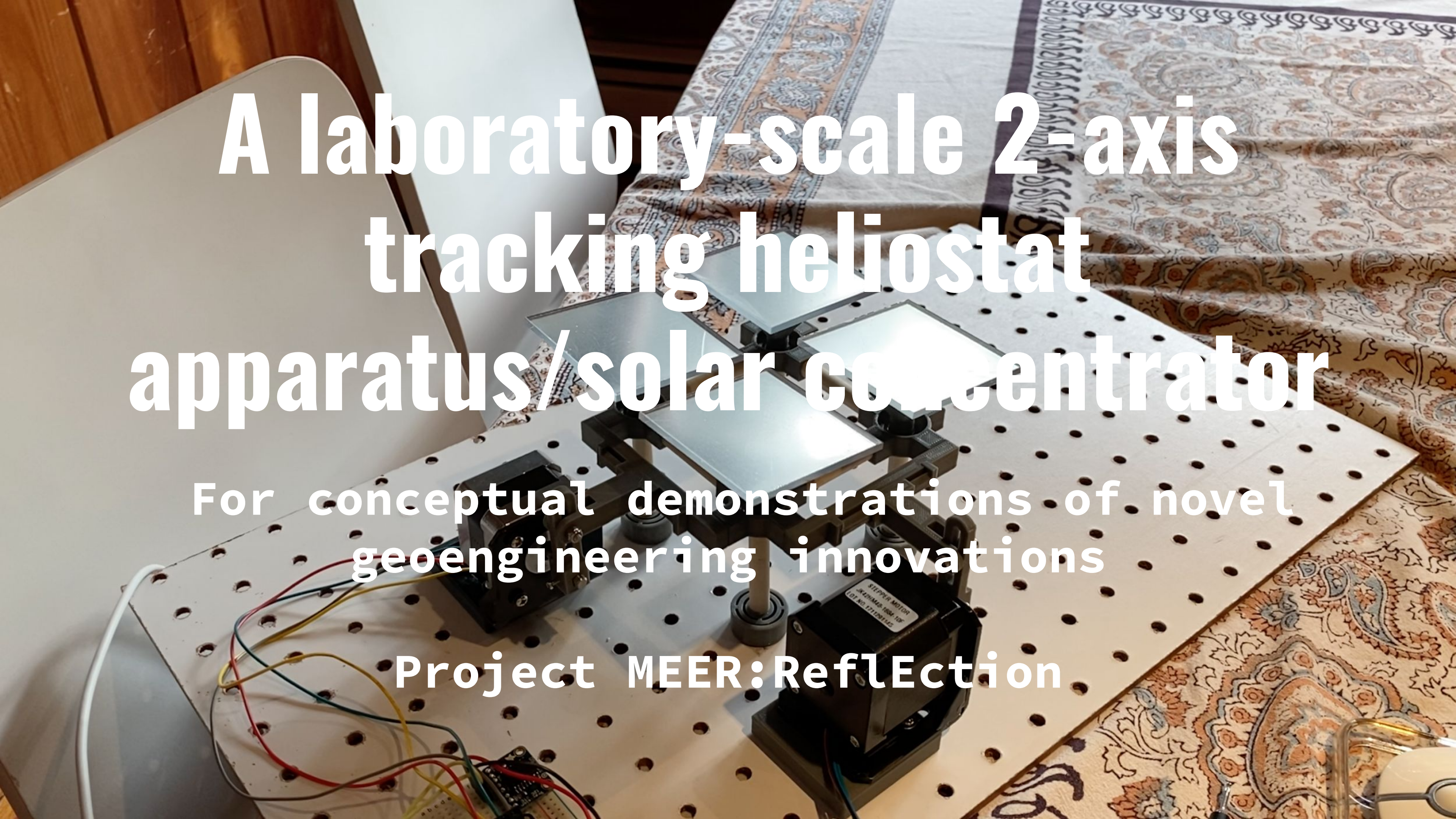

A laboratory-scale 2-axis tracking heliostat apparatus/solar concentrator
For conceptual demonstrations of novel geoengineering innovations
Project MEER:ReflEction

Who We Are

Mohan Hathi

- Junior at the Cambridge Rindge and Latin School, in Cambridge, MA

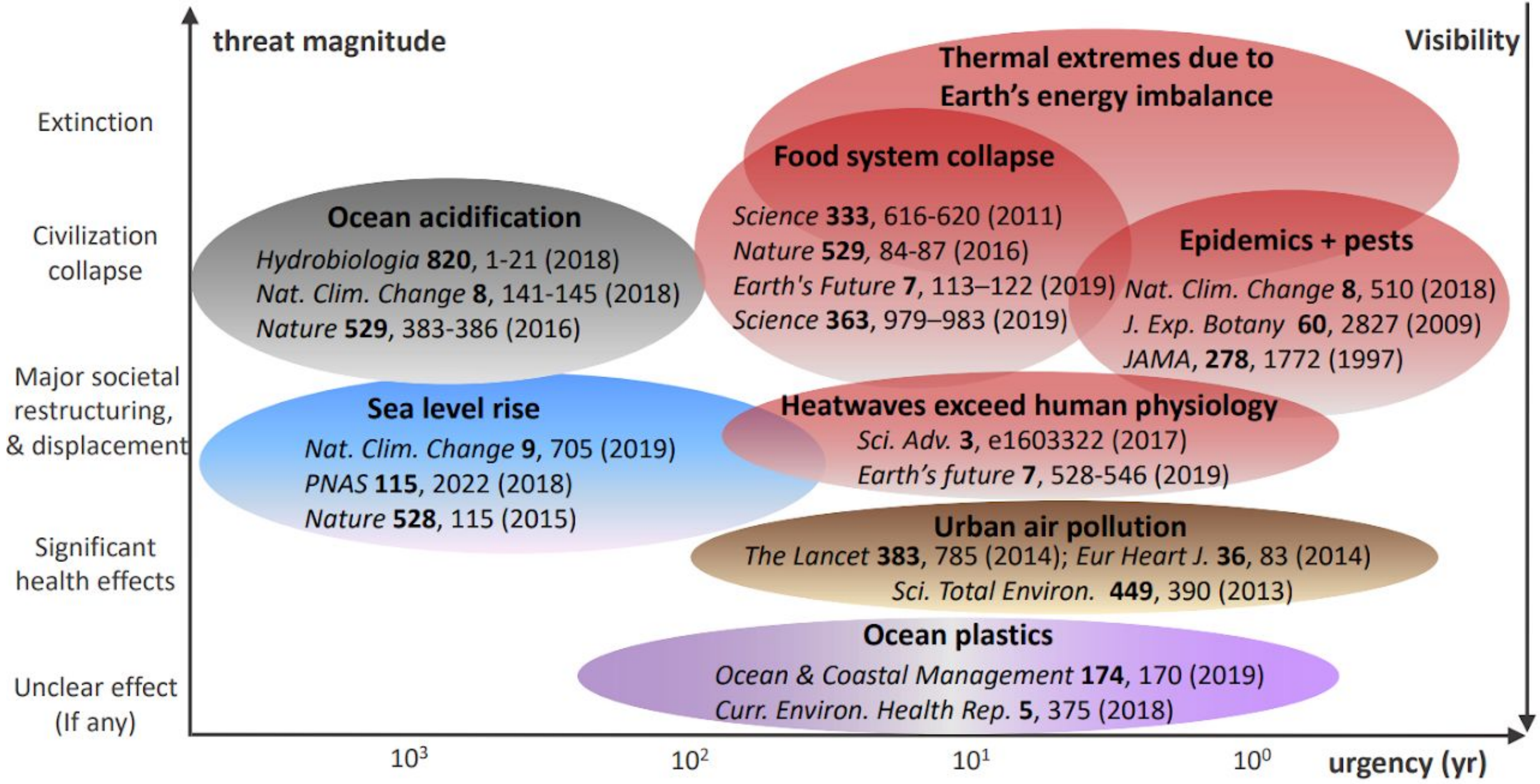
Chris Stokes

- Laboratory engineer at the Rowland Institute in Cambridge, MA.

Dr. Ye Tao

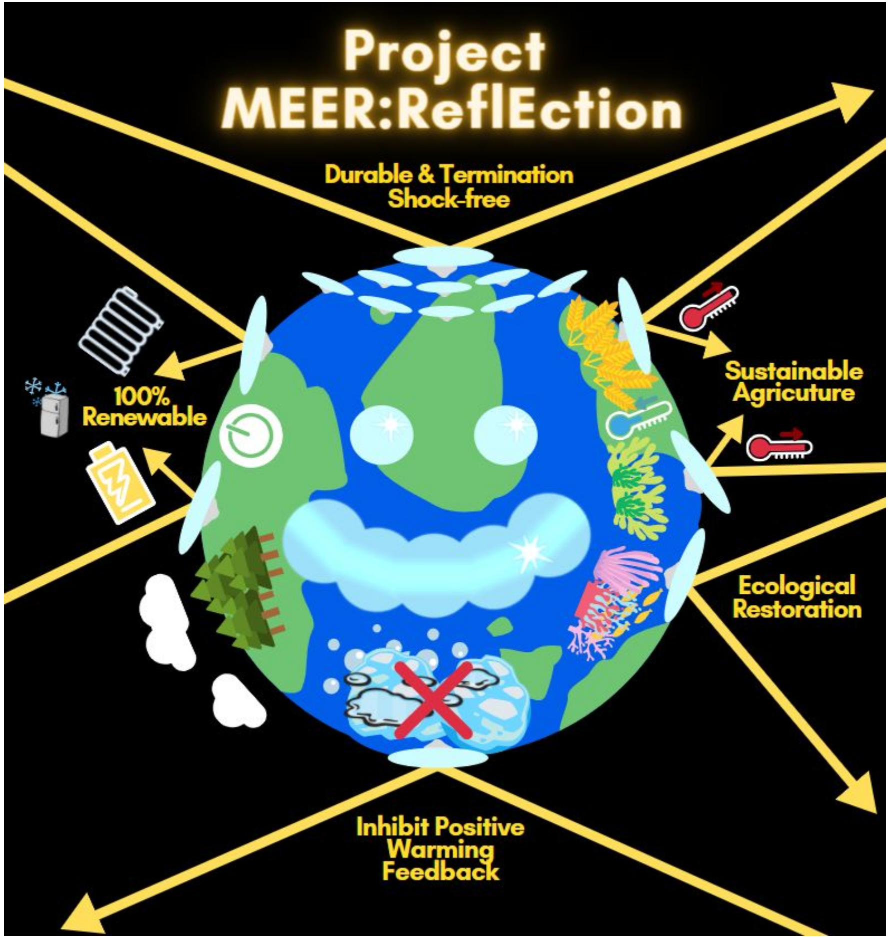
- Principal Investigator at the Rowland Institute at Harvard.
- Founder of Project MEER:ReflEction

Project Background



Project Background

Project MEER:ReflEction is a new **geoengineering** framework which seeks to create versatile **mirror**-based infrastructures to **mitigate temperature extremes** (stabilize temperatures) and enable a **recovery of biodiversity and biomass** affected by climate change.



- Ye Tao (2019, Nov. 19th). Mirrors for Earth's Energy Rebalancing (MEER:ReflEction) [Invited talk]. NanoScientific Symposium 2019, SUNY Polytechnic Institute Albany, NY, USA. https://www.youtube.com/watch?v=fwvPJnPP9KI&t

Overall Idea/Context

Overall Idea

- **Small-scale heliostat apparatus** with **active sun-tracking capabilities**

Image: Font-Romeu Via, France via Wikimedia Commons

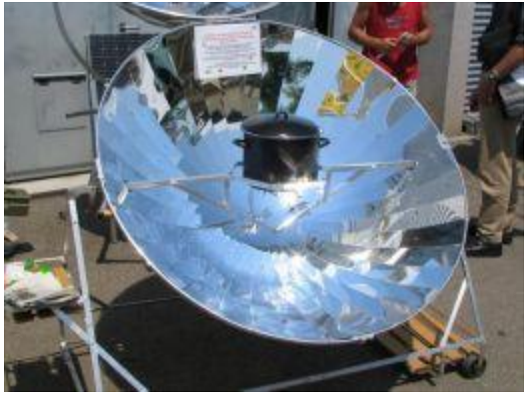


Image: Planetary Engineering Group Earth

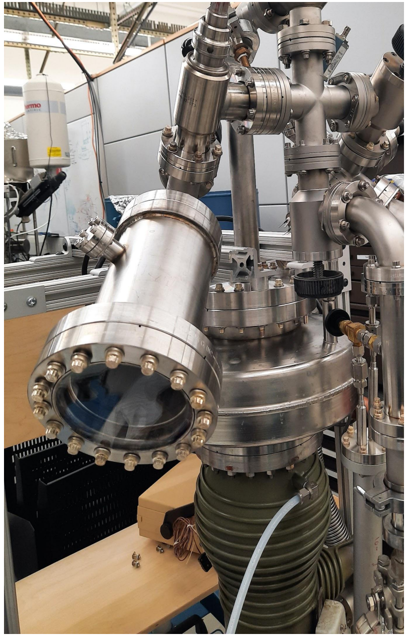
Image: Heliostat in Thémis, France, David66 via Wikimedia Commons

Image: United States Department of Energy, National Renewable Energy Laboratory

Concentrating solar power (solar thermal power plant), generating electricity, solar cooking, heating water

Goals/Uses

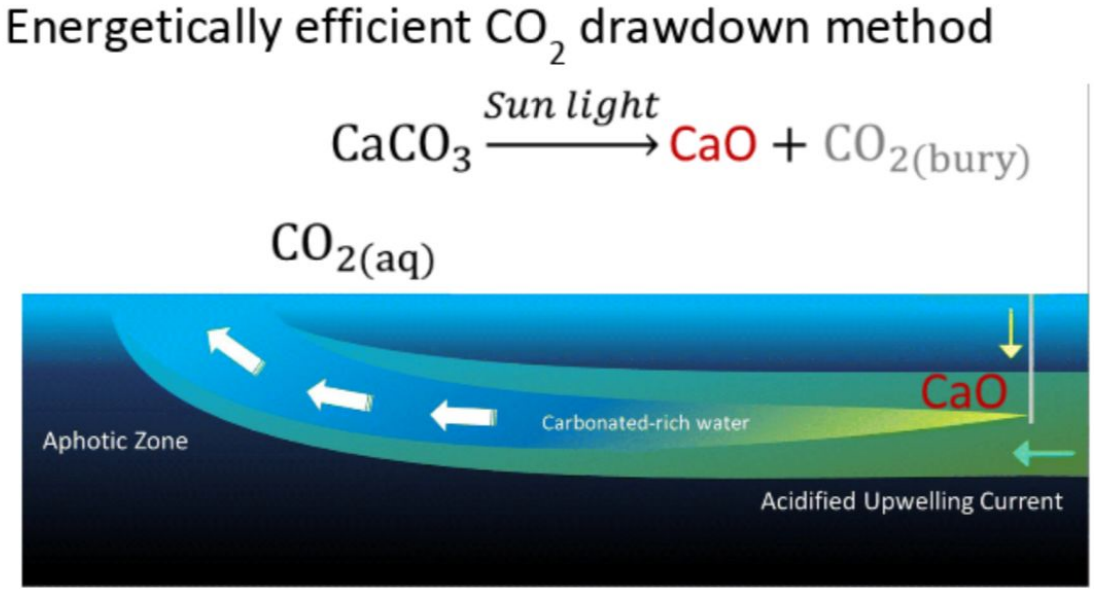
- Focus light into a reaction vacuum chamber to calcinate calcium carbonate in clamshells -- capture of a pure CO_2 offgas stream
- Model for larger-scale heliostat apparatuses.
- Open-source, modular, and affordable



[6] Shiying Lin, Takashi Kiga, Yin Wang, and Katsuhiro Nakayama, 2011, "Energy analysis of CaCO3 calcination with CO2 capture," Energy Procedia, 4, pp. 356-361.

Goals/Uses

Also can be used for ocean deacidification; calcium oxide product (from burning of CaCO3 - clamshells) can be scattered in the ocean to neutralize dissolved CO2.



Approach/Why This is Unique

Traditional Approaches:

Dish-Sterling Research Project,
Font Romeu Odeillo, France

Cerebralmeltdown.com blog

Our Approach:

National Renewable Energy Laboratory, concentrating solar power

- Our design ==> flat-plane concentrator (fresnel lens-style approach)

- Array of **eighty 2.5’’ mirrors** in a **1 m^2 rectangular grid**, mounted on **universally-articulated individually-angled 3d-printed blocks**. The system uses a **microcontroller** and two **stepper motors** to **angle the mirror system on two axes**, **maintaining a desired stationary focal point as the sun moves across the sky.**

Design Basis/Deliverables

- “Heliostat Apparatus” patent by Jesse Bunch [1]
- “Power From the Sun” report by William Stine [2]

- **~1 kW** peak power under optimal conditions.
- **900 degrees C** maximum operating temperature.
- **3” round focal point.**

[1] Jesse C. Bunch, 1980, “Heliostat Apparatus,” U.S. Patent, 892,960.
[2] William B. Stine, 1988, “Power From The Sun,” SERI/SP-273-3054, Solar Energy Research Institute - U.S. Department of Energy, Colorado.

United States Patent [19] [11] **4,218,114**
Bunch [45] **Aug. 19, 1980**

[54] **HELIOSTAT APPARATUS**

[76] Inventor: **Jesse C. Bunch,** 1008 Kerwin Rd., Silver Spring, Md. 20901

[21] Appl. No.: **892,960**

[22] Filed: **Apr. 3, 1978**

Related U.S. Application Data

[62] Division of Ser. No. 642,473, Dec. 19, 1975, Pat. No. 4,110,009.

[51] **Int. Cl.**[3] **G02B 5/08**
[52] **U.S. Cl.** **350/292;** 126/438; 350/299; 353/3
[58] **Field of Search** 126/438, 439, 440; 350/288, 292, 299; 353/3

[56] **References Cited**

U.S. PATENT DOCUMENTS

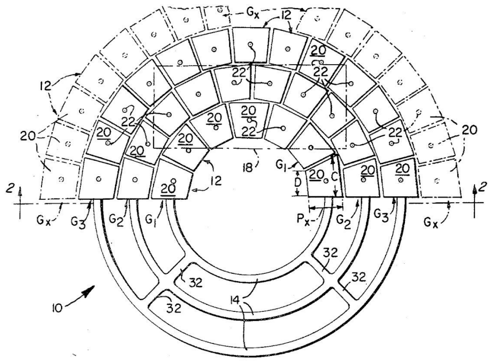
509,390	11/1892	Paine	126/438 X
1,367,472	2/1921	Harvey	350/292
1,386,781	8/1921	Harvey	350/292 UX
2,471,954	5/1949	Harvey	126/438 X
3,466,119	9/1969	Francio	350/299
3,872,854	3/1975	Raser	126/438 X
3,905,352	9/1975	Jahn	350/299 X
3,924,604	12/1975	Anderson	126/438 X
3,985,118	10/1976	Bard	126/440 X
4,110,009	8/1979	Bunch	350/299 X

Primary Examiner—F. L. Evans
Attorney, Agent, or Firm—Morton J. Rosenberg

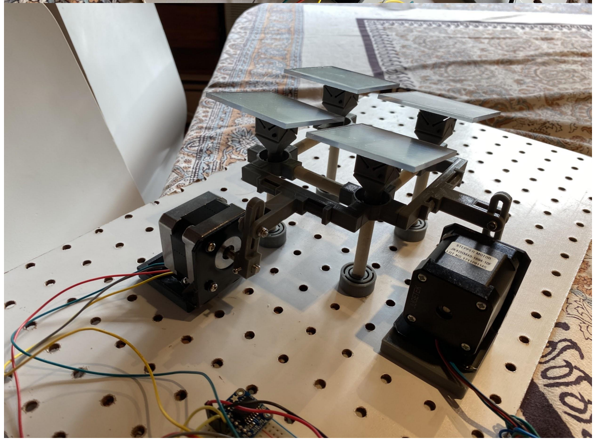
[57] **ABSTRACT**

Heliostat apparatus for concentrating solar energy comprising support structure disposed in a first plane and supporting a plurality of mirror units having freedom of substantial universal articulation thereon, each of the plurality of mirror units carrying at an upper portion thereof reflective element trained to receive incident rays of the sun and to focus reflection thereof to a desired focal point, adjustment structure operatively connected to the plurality of mirror units and disposed in a plane generally parallel to the first plane in which the support structure is disposed, the adjustment structure being shiftable to additional planes adjacent and generally parallel thereto to effect conjoint articulation of each of the mirror units at the support structure and thereby conjointly retrain the reflective element of each of the mirror units to receive incident rays of the sun and maintain reflection thereof on the focal point over the course of any day.

23 Claims, 20 Drawing Figures



Overall Design



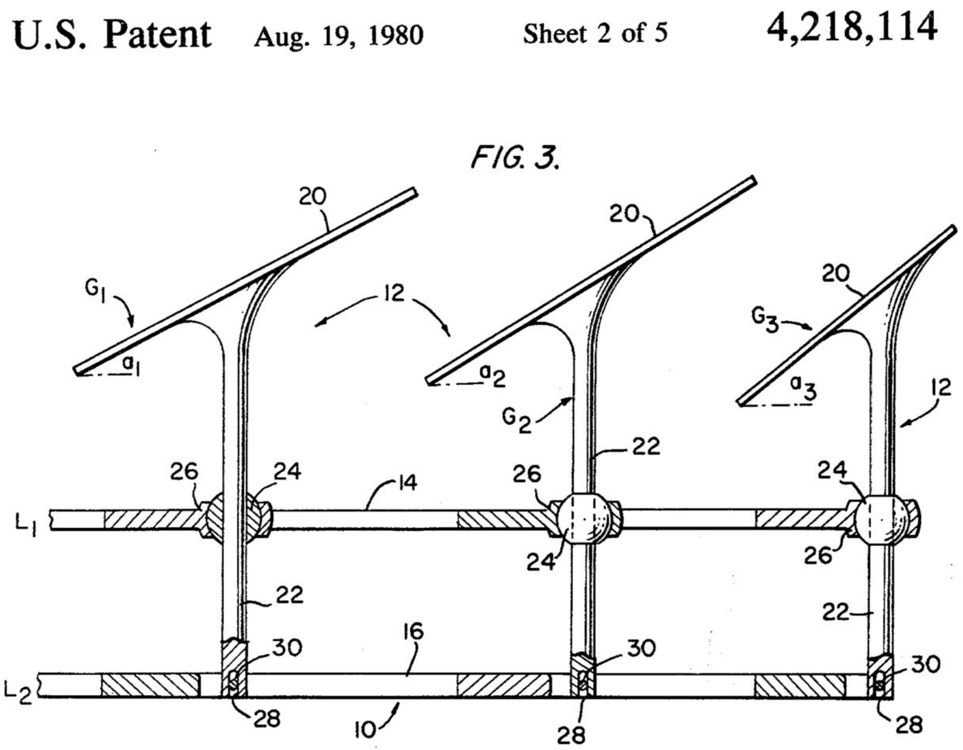
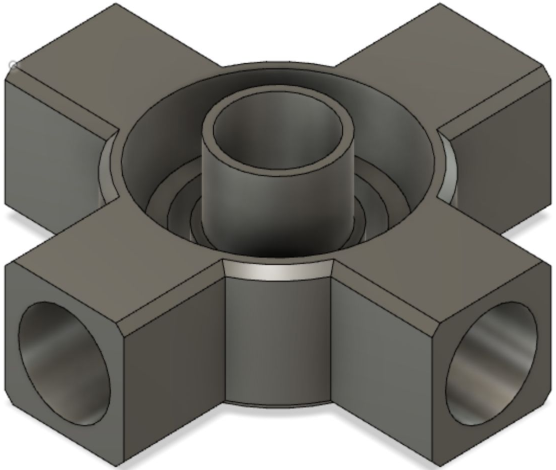
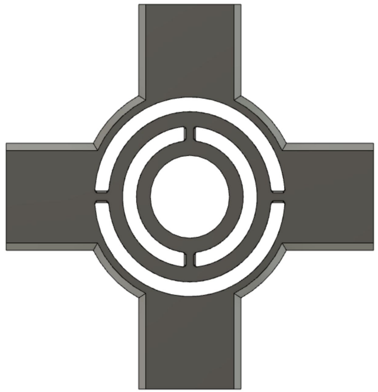


Image: Jesse C. Bunch, 1980, “Heliostat Apparatus,” U.S. Patent, 892,960.

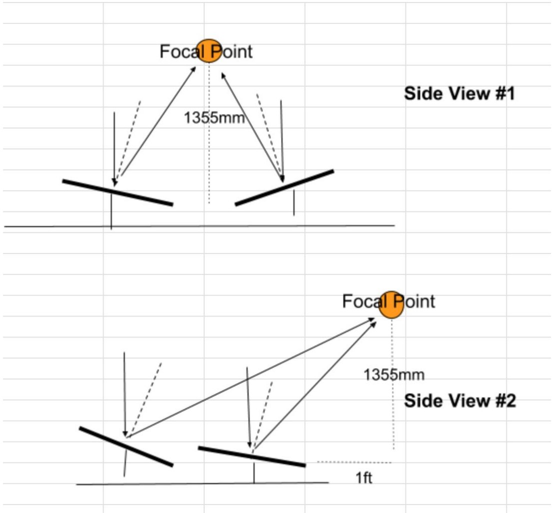
Universal Joints

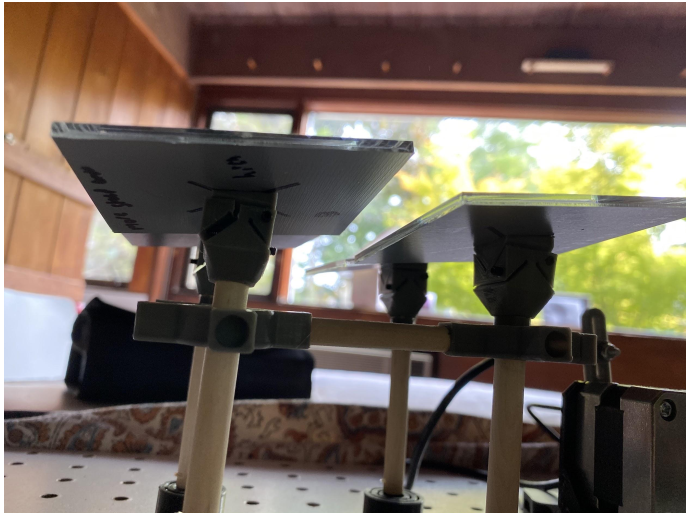


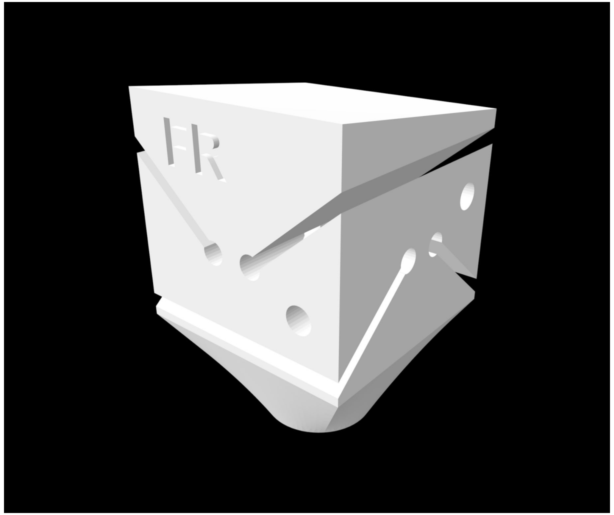


Focal Point and Angled Mirror Mounts

- Mirrors are attached to individually angled mounting blocks, calibrated such that the **focal point is 1 ft in front of the mirror array, and ~5ft (1355mm) high.**

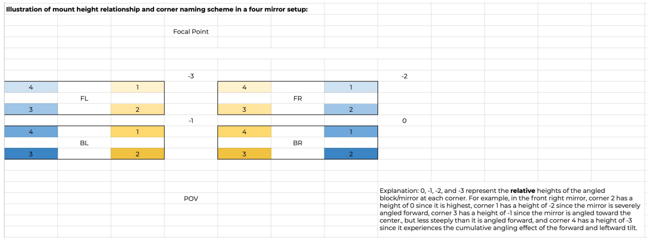


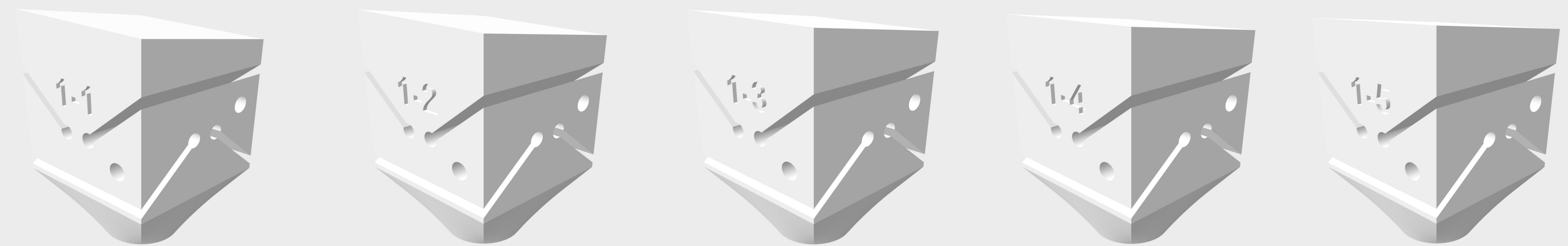




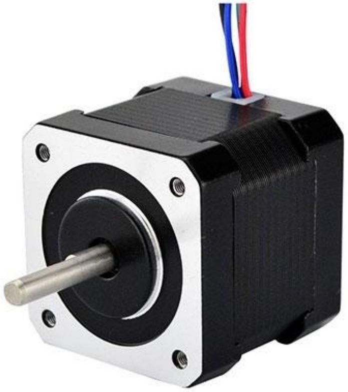
Focal Point and Angled Mirror Mounts

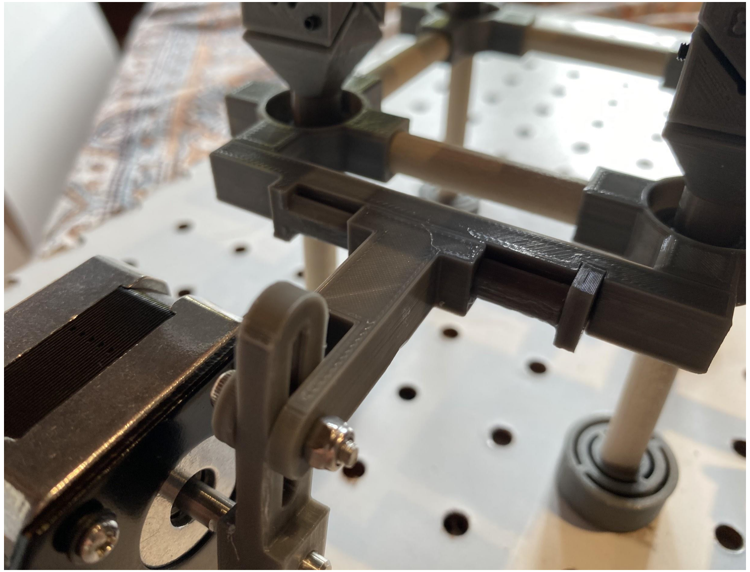
- Spreadsheet, python script to calculate the angle of the mirrors on two axis.
  - Calculations take into account the dimensions of mirrors, array size, center heights, and focal point.
- Fusion 360 parametric model
- Angle can be fined tuned with set screws - projector system.

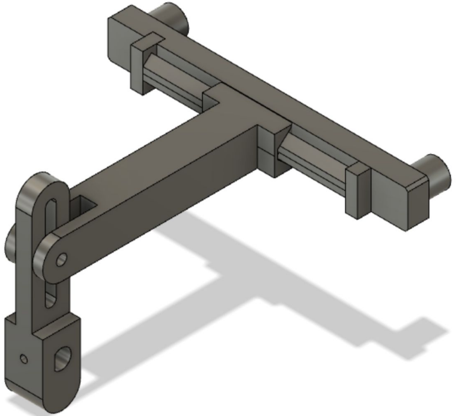




Stepper Motor Control and 2 Axis Movement

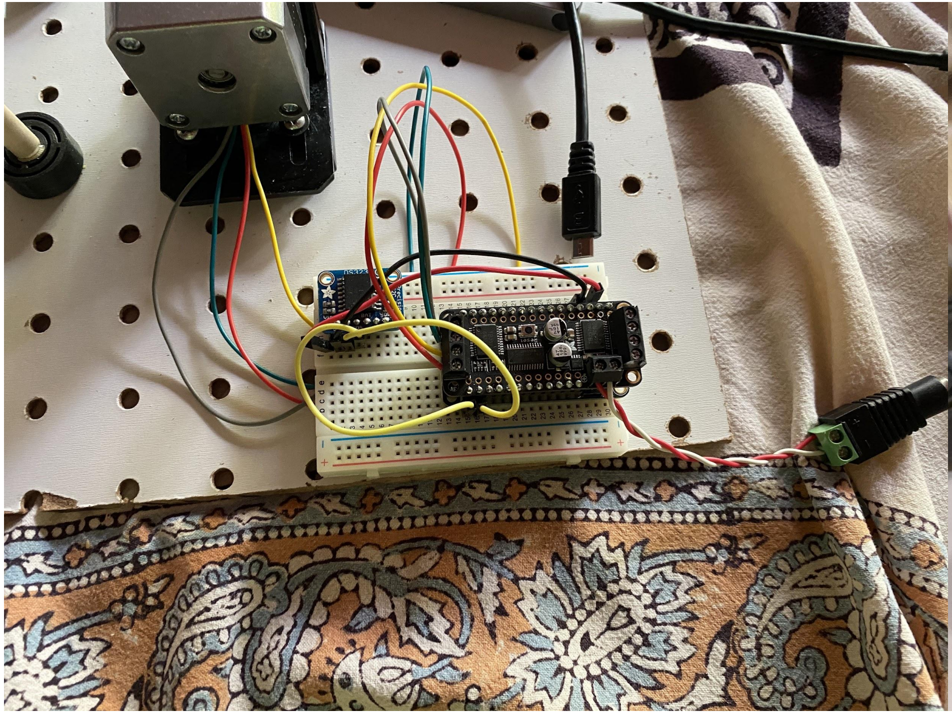


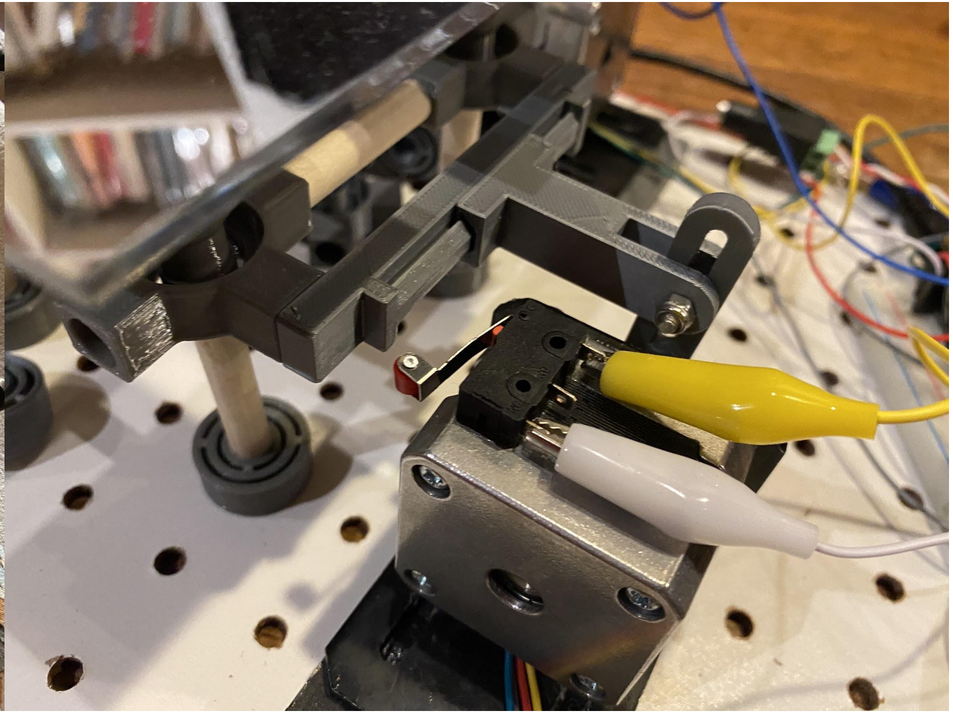




Electronics

Stepper motors, Microcontroller, Real time clock, Endstops, 12V power supply





Sun Movement and Code

- Sun moves in an arc across the sky, defined by azimuth and elevation.

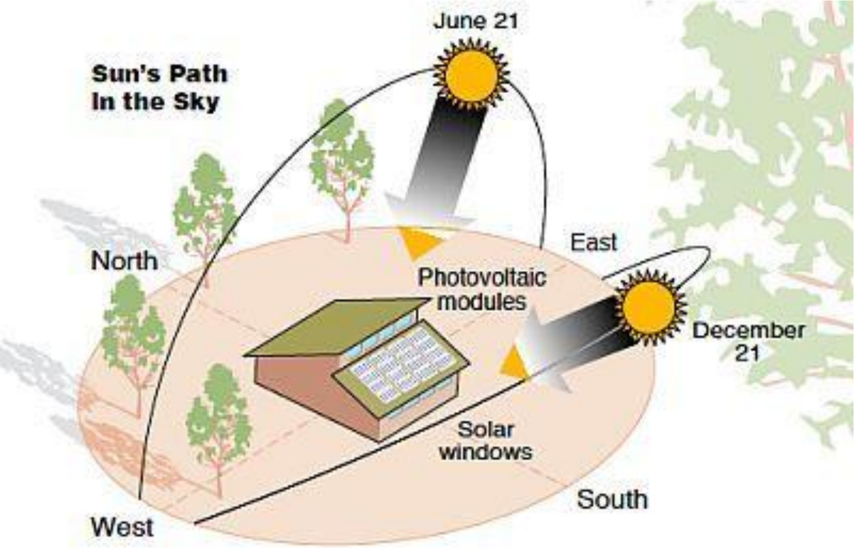


Image: Green Passive Solar Magazine

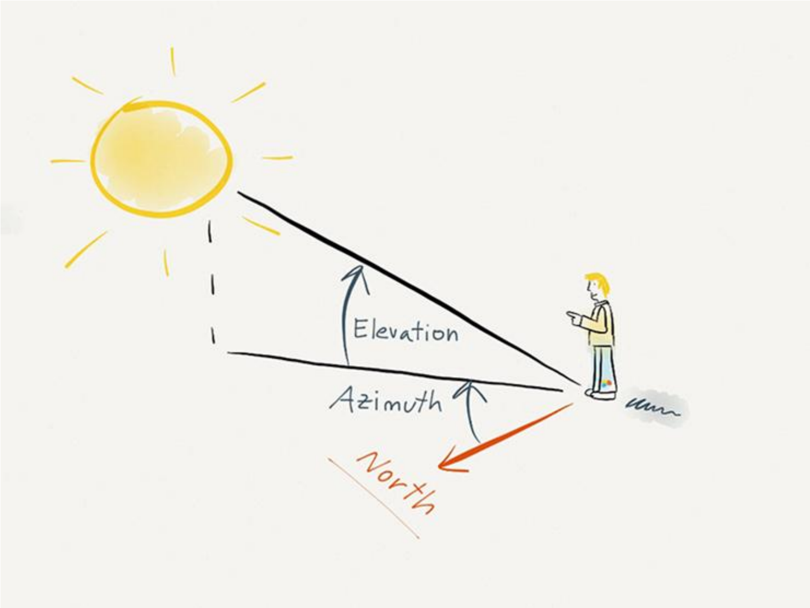


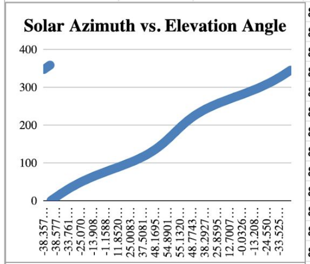
Image: Rafael Pons, PhotoPills

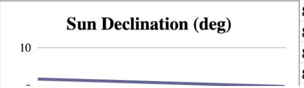
CircuitPython Code

NOAA Sunrise/Sunset and Solar Position Calculator - based on equations from Astronomical Algorithms, by Jean Meeus

NOAA Solar Calculations - Change any of the highlighted cells to get solar position data for that location and date.

Latitude (+ to N)	42.3825
Longitude (+ to E)	-71.12082
Time Zone (+ to E)	-4
Date	8/31/2020



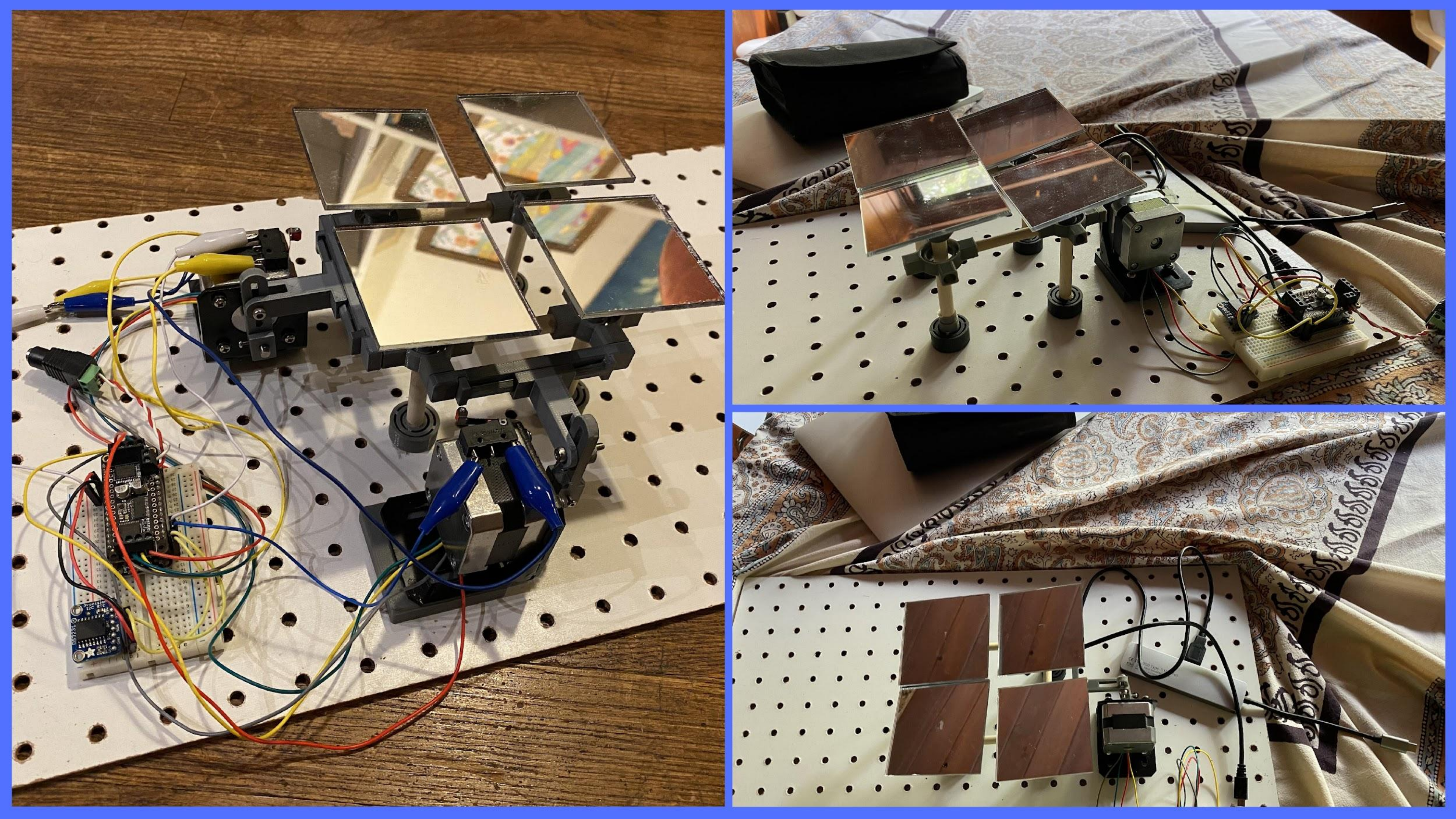


Date	Time (past local midnight)	Julian Day	Julian Century	Geom Mean Long Sun (deg)	Geom Mean Anom Sun (deg)	Eccent Earth Orbit	Sun Eq of Ctr	Sun True Long (deg)	Sun True Anom (deg)	Sun Rad Vector (AUs)	Sun App Long (deg)	Mean Obliq Ecliptic (deg)	Obliq Corr (deg)	Sun Rt Ascen (deg)	Sun Declin (deg)	var y	Eq Tin (m
8/31/2020	0:06:00	2459092.67	0.20664397	159.808	7796.51	0.01669	-1.57768	158.230	7794.93	1.00940	158.220	23.4366	23.4368	159.867	8.48653	0.04302	-0.
8/31/2020	0:12:00	2459092.68	0.20664408	159.812	7796.51	0.01669	-1.57776	158.234	7794.94	1.00940	158.224	23.4366	23.4368	159.870	8.48502	0.04302	-0.
8/31/2020	0:18:00	2459092.68	0.20664419	159.816	7796.52	0.01669	-1.57784	158.238	7794.94	1.00940	158.228	23.4366	23.4368	159.874	8.48352	0.04302	-0.
8/31/2020	0:24:00	2459092.68	0.20664431	159.820	7796.52	0.01669	-1.57791	158.242	7794.95	1.00940	158.232	23.4366	23.4368	159.878	8.48201	0.04302	-0.
8/31/2020	0:30:00	2459092.69	0.20664442	159.824	7796.53	0.01669	-1.57799	158.246	7794.95	1.00940	158.236	23.4366	23.4368	159.882	8.48051	0.04302	-0.
8/31/2020	0:36:00	2459092.69	0.20664454	159.828	7796.53	0.01669	-1.57807	158.250	7794.95	1.00940	158.240	23.4366	23.4368	159.886	8.47900	0.04302	-0.
8/31/2020	0:42:00	2459092.70	0.20664465	159.832	7796.54	0.01669	-1.57814	158.254	7794.96	1.00939	158.244	23.4366	23.4368	159.889	8.47750	0.04302	-0.
8/31/2020	0:48:00	2459092.70	0.20664476	159.837	7796.54	0.01669	-1.57822	158.258	7794.96	1.00939	158.248	23.4366	23.4368	159.893	8.47599	0.04302	-0.
8/31/2020	0:54:00	2459092.70	0.20664488	159.841	7796.54	0.01669	-1.57830	158.262	7794.97	1.00939	158.252	23.4366	23.4368	159.897	8.47449	0.04302	-0.
8/31/2020	1:00:00	2459092.71	0.20664499	159.845	7796.55	0.01669	-1.57837	158.266	7794.97	1.00939	158.256	23.4366	23.4368	159.901	8.47298	0.04302	-0.
8/31/2020	1:06:00	2459092.71	0.20664511	159.849	7796.55	0.01669	-1.57845	158.270	7794.97	1.00939	158.260	23.4366	23.4368	159.904	8.47148	0.04302	-0.
8/31/2020	1:12:00	2459092.72	0.20664522	159.853	7796.56	0.01669	-1.57853	158.274	7794.98	1.00939	158.264	23.4366	23.4368	159.908	8.46997	0.04302	-0.
8/31/2020	1:18:00	2459092.72	0.20664533	159.857	7796.56	0.01669	-1.57860	158.278	7794.98	1.00939	158.268	23.4366	23.4368	159.912	8.46846	0.04302	-0.
8/31/2020	1:24:00	2459092.73	0.20664545	159.861	7796.56	0.01669	-1.57868	158.283	7794.99	1.00939	158.272	23.4366	23.4368	159.916	8.46696	0.04302	-0.
8/31/2020	1:30:00	2459092.73	0.20664556	159.865	7796.57	0.01669	-1.57876	158.287	7794.99	1.00939	158.276	23.4366	23.4368	159.920	8.46545	0.04302	-0.
8/31/2020	1:36:00	2459092.73	0.20664568	159.869	7796.57	0.01669	-1.57883	158.291	7794.99	1.00939	158.280	23.4366	23.4368	159.923	8.46395	0.04302	-0.
8/31/2020	1:42:00	2459092.74	0.20664579	159.874	7796.58	0.01669	-1.57891	158.295	7795.00	1.00939	158.284	23.4366	23.4368	159.927	8.46244	0.04302	-0.
8/31/2020	1:48:00	2459092.74	0.20664590	159.878	7796.58	0.01669	-1.57899	158.299	7795.00	1.00938	158.288	23.4366	23.4368	159.931	8.46094	0.04302	-0.
8/31/2020	1:54:00	2459092.75	0.20664602	159.882	7796.58	0.01669	-1.57906	158.303	7795.01	1.00938	158.292	23.4366	23.4368	159.935	8.45943	0.04302	-0.
8/31/2020	2:00:00	2459092.75	0.20664613	159.886	7796.59	0.01669	-1.57914	158.307	7795.01	1.00938	158.296	23.4366	23.4368	159.938	8.45793	0.04302	-0.
8/31/2020	2:06:00	2459092.75	0.20664625	159.890	7796.59	0.01669	-1.57922	158.311	7795.01	1.00938	158.300	23.4366	23.4368	159.942	8.45642	0.04302	-0.
8/31/2020	2:12:00	2459092.76	0.20664636	159.894	7796.60	0.01669	-1.57929	158.315	7795.02	1.00938	158.304	23.4366	23.4368	159.946	8.45491	0.04302	-0.
8/31/2020	2:18:00	2459092.76	0.20664648	159.898	7796.60	0.01669	-1.57937	158.319	7795.02	1.00938	158.308	23.4366	23.4368	159.950	8.45341	0.04302	-0.
8/31/2020	2:24:00	2459092.77	0.20664659	159.902	7796.61	0.01669	-1.57945	158.323	7795.03	1.00938	158.312	23.4366	23.4368	159.954	8.45190	0.04302	-0.

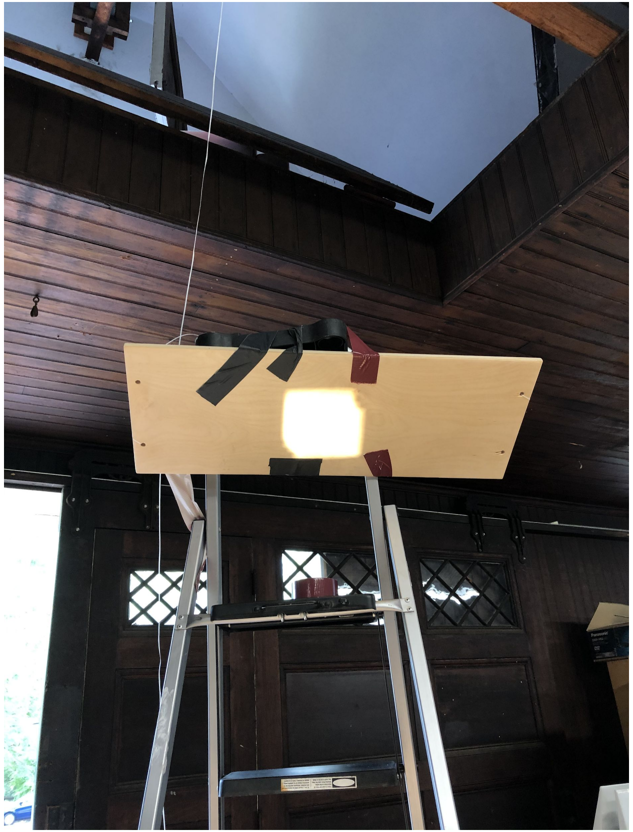
CircuitPython Code

1. Take current time and location and calculate the sun elevation and azimuth angles.
2. Convert spherical coordinates to cartesian coordinates to calculate the x & y axis angle.
3. Calculate desired mirror angle on both axes (front-back and right-left).
4. Translate the desired mirror angle to the angle of the stepper motor on each axis, and to steps/microsteps.
5. Move motors to desired position and repeat to adjust the mirror angle and maintain a constant focal point as the sun moves across the sky.

```
while True:
    rightleftangle, frontbackangle = solar_calculations(my_lat, my_lng, my_time_zone, my_currentdatetime)  # Call t
    print("called fxn")
    print(math.fabs(rightleftposition - rightleftangle))
    print(math.fabs(frontbackposition - frontbackangle))
    if math.fabs(rightleftposition - rightleftangle) > 0.9:  # If the angle is changed appreciably enough that move
        # Right - left movement
        if rightleftangle < 30 and rightleftangle > -30:  # Prevent motor from moving too far
            # Moving right
            while rightleftposition < rightleftangle:  # If current position is less than (more negative/left) than
                kit.stepper1.onestep(direction=stepper.BACKWARD, style=stepper.INTERLEAVE)
                rightleftposition += 0.9 # Increment the position by the degrees of one interleaved step
                time.sleep(0.02)  # Delay for proper motor movement
                # print("moving right")
            # Moving left
            while rightleftposition > rightleftangle:  # If current position is greater than (more positive/right)
                kit.stepper1.onestep(direction=stepper.FORWARD, style=stepper.INTERLEAVE)
                rightleftposition -= 0.9  # Increment the position by the degrees of one interleaved step
                time.sleep(0.02)  # Delay for proper motor movement
                # print("moving left")
    if math.fabs(frontbackposition - frontbackangle) > 0.9:
        # Front - back movement
        if frontbackangle < 30 and frontbackangle > -30:  # Prevent motor from moving too far
            # Moving forward
            while frontbackposition < frontbackangle:  # If current position is less (more negative/backward) than
                kit.stepper2.onestep(direction=stepper.FORWARD, style=stepper.INTERLEAVE)
                frontbackposition += 0.9  # Increment the position by the degrees of one interleaved step
                time.sleep(0.02)  # Delay for proper motor movement
            # Moving backward
            while frontbackposition > frontbackangle:  # If the current positon is greater (for positive/forward) t
                kit.stepper2.onestep(direction=stepper.BACKWARD, style=stepper.INTERLEAVE)
                frontbackposition -= 0.9 # Increment the position by the degrees of one interleaved step
                time.sleep(0.02)  # Delay for proper motor movement
    time.sleep(60)  # Code loops/checks again every 1 minute
```

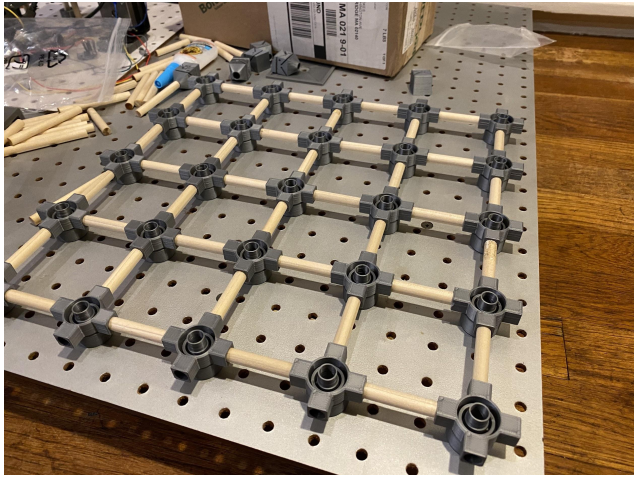


Testing So Far



Going Forward

- Scale up to more mirrors. (5x5 and 9x9 for 1 m^2 area)
- Testing with the vacuum chamber/reactor
- Collect data on power output, temperature, and CO_2 capture.
- Experiment with other optimizations (e.g. shapes/arrangements for the mirrors.)



Thank You!

Questions/Feedback?

Rich Oettinger: Type in your questions here in the chat

lcarmon3@eafit.edu.co: Thank you so much! Beautiful presentation and talk

KLee: Excellent! Great presentation. Interesting project!

IbrahimKandil: Very well

byong@parksystems.com: Look like an exciting project. Keep up the excellent work, and good luck with the project going forward.

MohanHathi: Thank you all! If anyone wants more information about the project, please go to meerreflection.com

Rich Oettinger: Thanks for presenting, Mohan!

47 Speakers 0 Viewers

Type a message...

From pattiM to Everyone: 3:35 PM
Good to use python!
Are those sealed-bearing U joints?
OK, they're called "flex pivots"
...not bearings

From Alan Weisman to Everyone: 3:37 PM
These will br both ground-and ocean-mounted?

From pattiM to Everyone: 3:37 PM
What's the fatigue-resistence of the 3D printed material?

From Shaun Fitzgerald to Everyone: 3:37 PM
Mohan, v nice presentation thank you. In terms of scale up deployment, what do you think about the maintenance issue of moving parts versus the reduced energy if you used a stationary set up?

From pattiM to Everyone: 3:38 PM
Flrx-pivots are very environmentally resistent
Flex
Plastics?

From pattiM to Everyone: 3:38 PM
Need info on millions of cycles for ocean deployment

From jaggeralexander to Everyone: 3:39 PM
The next presentation will be on material science and discuss potential materials for large-scale implementation

From pattiM to Everyone: 3:39 PM
Possible to 3D print metals

From Nathaniel Cira to Me: (Privately) 3:39 PM
Very cool. Great work!

From Ellie Flint to Everyone: 3:40 PM
hard to hear you