Design of a Low-Cost Sky Imager for Solar Forecasting

Brian Kiel, R. Jamie Asbach

Advisor: Dr. Tarunraj Singh, Mechanical and Aerospace Engineering

Overview/Abstract

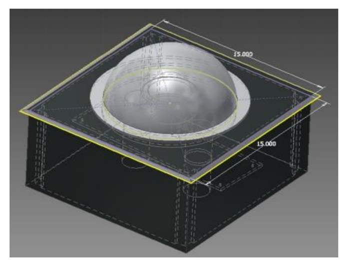
Sky imaging is an effective tool for gathering data used to analyze cloud cover, predict cloud motion, and estimate energy availability. With this technology, it is possible for solar power plants to estimate solar power availability and adapt to meet power demands accordingly.

A sky imager is a relatively small, weatherproof device equipped with a camera used outdoors in an area with few visual obstructions. In the most basic sense, a sky imager generally consists of three elements: a camera used to record a direct or reflected image of the sky, an arm or band used to block direct sunlight, and a digital video recorder coupled with image processing software [1].

This project is specifically being conducted to see if an inexpensive sky imager can be constructed and used to collect data necessary for forecasting the motion of clouds and amount of available sunlight. A prototype has been created and tested, and a redesign is currently in development to improve upon design flaws.

The Prototype

A prototype was constructed in the machine shop to test the performance of the design.



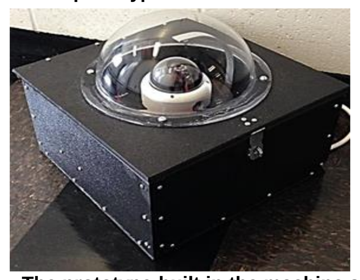
The prototype in CAD 3D software

Materials Used

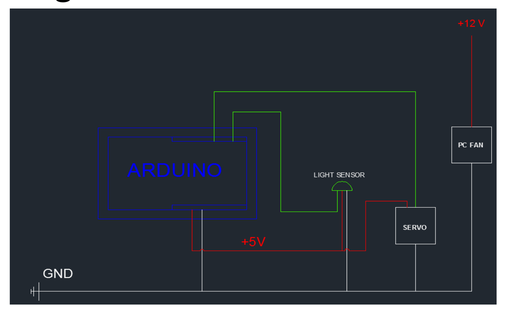
-ABS plastic, clear acrylic plastic, aluminum, steel

Internal Components

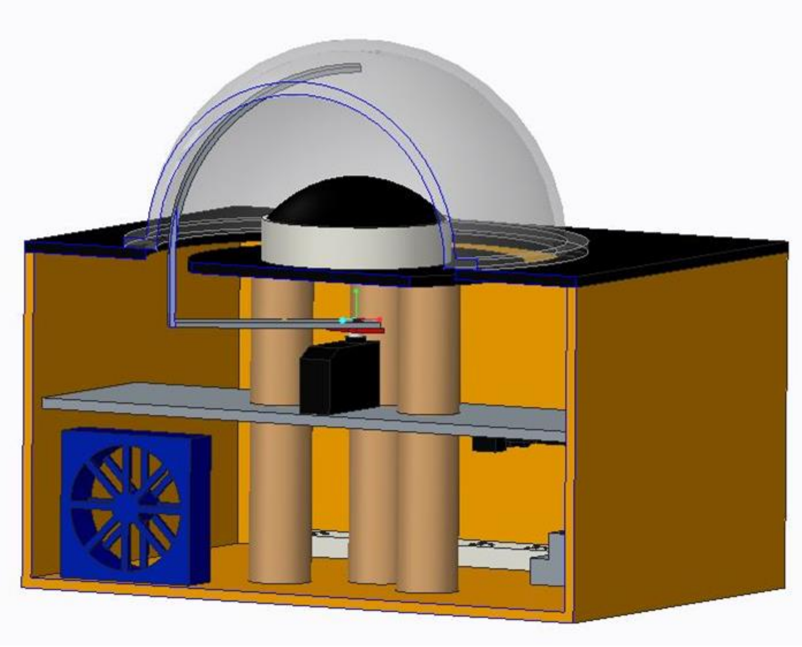
-Fisheye camera with attached light sensor
-Arduino microcontroller
-Servo motor
-Aluminum arm for sun-blocking (attached to servo)
-Computer fan
-12V, 2A power source



The prototype built in the machine shop



Circuit diagram



How it works:

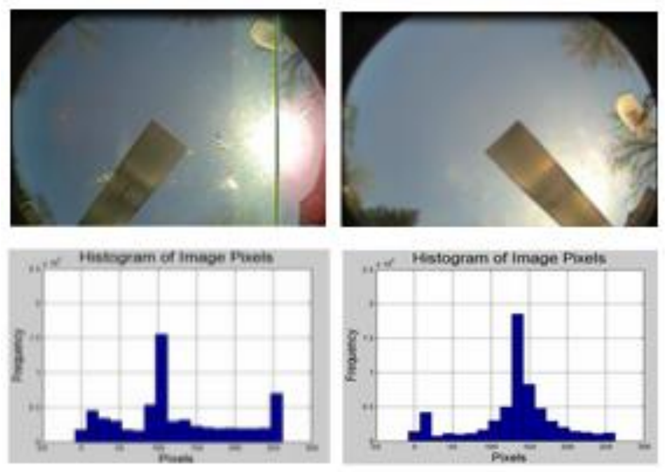
- Light sensor detects direct sunlight near camera lens.
- Command is sent to Arduino microcontroller to rotate servo with arm attached..
- Arduino validates that the lens is now covered from the sun via light sensor reading.
- If so, the arm stays in place.
- Otherwise, the arm moves to block the sun
- Fan circulates air at all times to help cool the system.
- Analog video signal is converted to digital and recorded off site.

Initial Testing

Sun Blocking	Light Sensor Sensitivity
- Arm tested to determine if sun is blocked effectively - Shaded images were compared to unshaded images	- Voltage readings read by Arduino to compare light intensity of a shaded and unshaded lens - Comparison used to set servo motion threshold
Temperature	**Moisture**
- Imager must not overheat to prevent electronic failure - Imager was exposed to sunlight and temperature was recorded	- Imager must remain waterproof to protect internal components - Imager was subjected to water from a hose for a period of time

Test Results

Sun Blocking Results - Success



As seen in the image to the right, the arm worked very well in improving the image. On a scale from 0-255, less pixels were maxing out the camera (250-255 range), which protects the camera from damage. Also by visual inspection, the covered image has less solar distortion.

Light Sensor Results - Failure

The light sensor readings (on a scale from 0-1023) were taken on a sunny, 60°F day. In the direct sunlight, the Arduino input measured an average value of 1015 bits from the light sensor. In the shade of the arm, an average value of 1006 bits was read. These readings are very close together and are nearly maxing the sensor. For these reasons, the threshold for moving the arm could not be set. A light sensor with a higher gain and resolution will be needed to differentiate the shade from direct sunlight.

Temperature Results - Failure

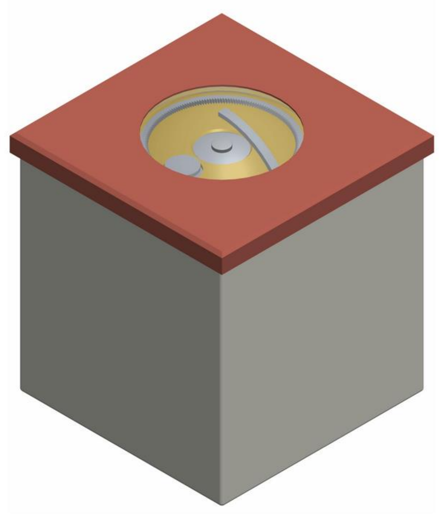
In testing, the box reached a temperature of 110°F in only 8 minutes in direct sunlight and ambient temperature of about 70°F. Any hotter, and the components inside would fail. The fan inside used to circulate air proved ineffective.

Moisture Results - Success

No moisture was detected inside the box after 1 min of water exposure..

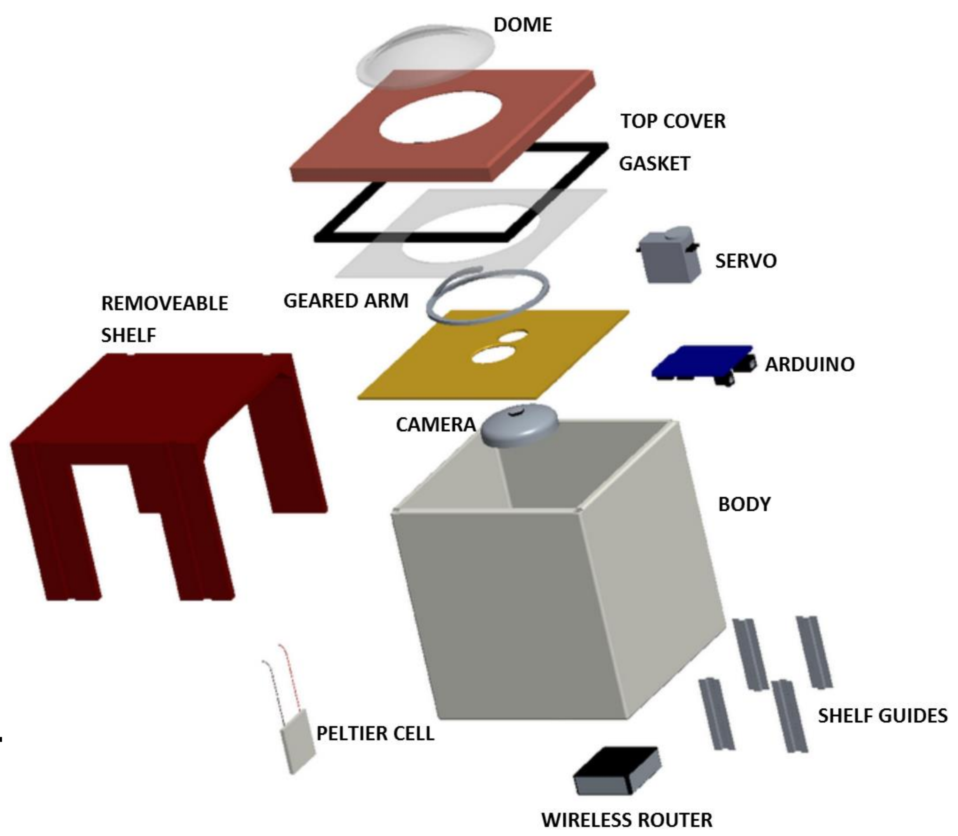
Redesign: Modeling and Circuitry

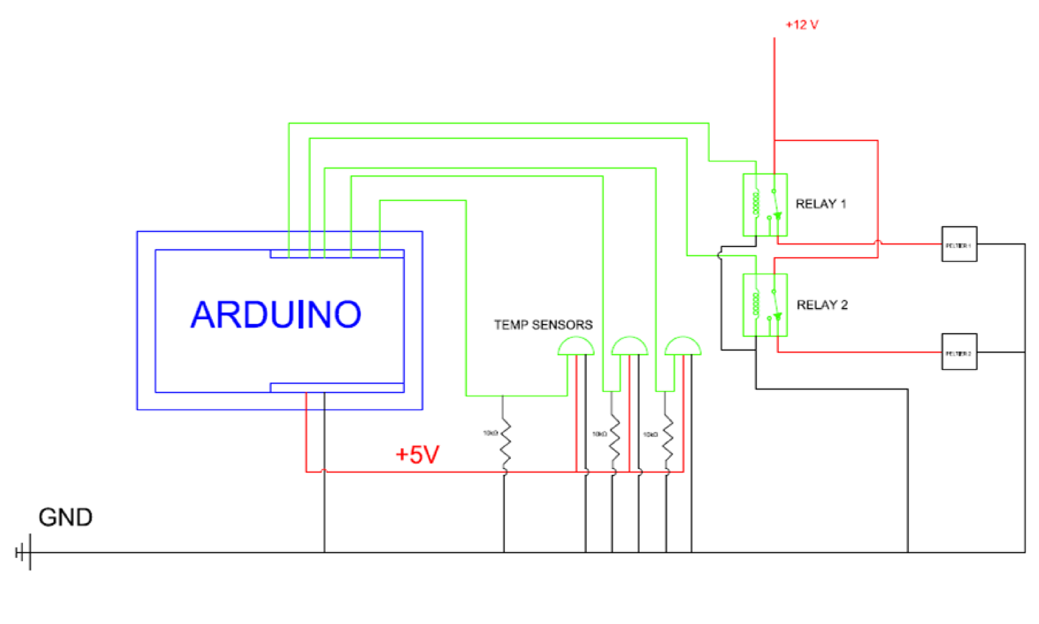
Taking into account the test results and recognizing obvious design flaws, the sky imager was redesigned to improve performance and robustness. Additional funding will allow for a more reliable, effective design. Below is a 3D rendering and exploded view of the the imager along with a basic electrical schematic for the new heating and cooling system.



3D Rendering of the Imager - Above

Exploded View of the Imager - Right

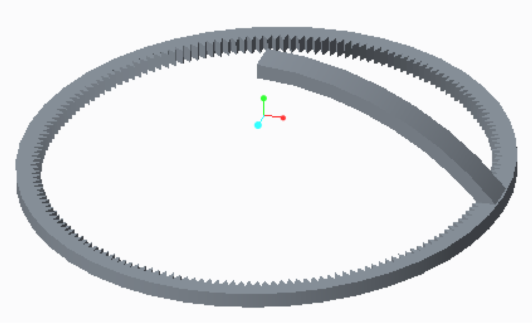




Electrical Schematic of the Heating and Cooling System

Design Improvements Include:

- Addition of a heating and cooling system using thermoelectric coolers (Peltier cells)
- Removeable shelf for component access
- Improved circuitry and sensors for more accurate temperature and light readings
- A redesigned arm mechanism that will allow for 360° rotation
- A higher resolution digital camera with wireless networking capabilities
- Aluminum body for waterproofing and protection from sun damage



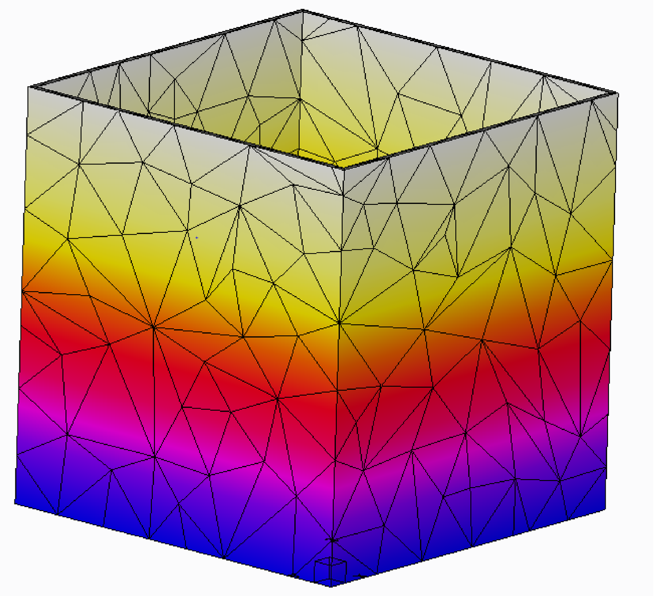
Arm Mechanism

Future Work/Considerations

After the design is finalized and subsystem components are recognized and validated, modeling and testing will be performed. These tests will include:

Heat Transfer Finite-Element Analysis:

- Estimate maximum or minimum heat transfer rates from the sun, ambient temperature, etc. and size the heating/cooling system accordingly



Rain and Moisture Test:

- Validate that the imager is water-proof.
- Determine whether there is excessive moisture from condensation on dome, which can hinder image quality. Here, humidity sensors will be used

Sun Exposure

- Determine effectiveness of sun-blocking arm
- Measure radiation heat transfer from the sun to determine effectiveness of the heating/cooling system
- Test improved light sensor technology

References

1.) "TSI-880 Automatic Total Sky Imager." *Yankee Environmental Systems, Inc.* N.p., n.d. Web. 3 Apr. 2014.