Small Scale Irradiance Measuring Device

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Team 20

Mid-Point Review

Document

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1 Problem Statement

1.1 Introduction

The small-scale solar irradiance project aims to implement a device which may accurately model the irregularities of solar irradiance on COBar Ranch, outside of Flagstaff, AZ. The Institute for Sustainable Energy Solutions (ISES) and Dr. Tom Acker at NAU are working with Next Era Energy to evaluate the reliability of the solar resource on a square mile of area outside of Flagstaff, AZ in order to determine the viability of a large-scale energy generation project at COBar Ranch. The current evaluation method uses a large land area and many data collection devices to determine the reliability of irradiance. The project intent is to streamline data collection while minimizing cost, land area usage, and system assembly time.

1.2 Needs Identification

The current system is inefficient with its use of land, man hours, and produces poor data. The irradiance measuring system is large, semi-permanent, difficult to operate and maintain, and costly. Due to the large area of the current site, much time is required to set up the numerous pyranometers in the system and collect their data. This is an inconvenience for both the operators and land owners, as well as creates unnecessary expense. Our purpose is to design a more efficient system with respect to these issues. Overall, our Need Statement is: The current system is inefficient with its use of land, man hours, and produces poor data.

Presumably, we will be able to design a smaller scaled system which will collect data even more precisely. While striving to achieve our goal of designing a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area, we generated various unique designs.

1.3 Project Goal

Our goal is to design a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area that can help determine the viability of installing a solar PV plant.

1.4 Objectives

The following list describes the pertinent objectives as seen in Table 1 required to achieve this goal.

- Scales down site-required surface area for data collection is minimized.
- Location- each of the sensor locations needs to be known for representative data.
- Easy set up/operation- minimal set up time and error propagation.
- Longevity- the device needs to operate in an outside environment for the duration of the study.
- Transportable- the device should be deployed easily to the study site.
- Inexpensive- device should be cost effective.

1.5 Constraints

The constraints are identified in the list below.

- Does the data collected correlate with the larger site?
- The surface area must not exceed that of a 100 ft diameter circle.
- Does the system store data safely?
- The system must be properly set up in 16 man hours.
- Does the system autonomously function between data collection visits?
- Does the system measure an accurate location for each sensor?
- Are the sensors taking readings in synchronization?
- Is the system inexpensive?
- The system must be able to withstand 'typical' environment conditions for approximately 14 months.

2 Concept Selection

2.1 Concepts

The tripod concept uses simple tripods with telescoping legs and brackets on the feet to support individual pyranometers in addition to a wireless transfer device. The telescoping legs allow the assembly to be set up level on nearly any reasonable gradient. Brackets on the feet provide a way to anchor the tripod to the earth by using heavy duty stakes in sand and soil, or bolt anchors in compact rock. The tripod can be seen in Figure 1. A small solar panel would power a wireless data transfer device so that site data may be stored and collected on a single, centrally located data acquisition center.

The tripod concept would be a good solution to the problem because it would be simple to physically add or remove pyranometers, and can set up quickly and easily on nearly any site. Furthermore, the tripod concept has very few set-backs such as difficult hardware and software integration issues. Some of these simple issues include:

- Reliable power is required for each transmission station to ensure data acquisition center receives proper data.
- Enough open channels of wireless transfer for the number of pyranometers is required.
- Accurate time keeping across an array of pyranometers is required.

These were the main benefits and drawbacks to this concept, though many more were considered during its evaluation. The tripod is the best design to fulfill all the client's needs.

Figure 1. Tripod

2.2 Mount

The mounting system for the pyranometers consists of two main components: the leveling plate and the support platform as seen in Figure 2. The leveling plate is manufactured by Campbell Scientific with designation LI-2003S and will be supplied by the same contact that supplied the LI-200 pyranometers. The support platform was manufactured from common materials and was designed to support the LI-2003S.

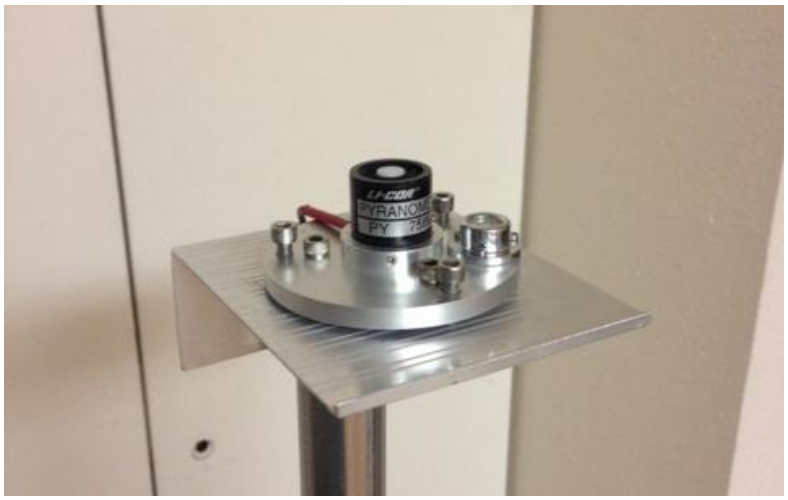


Figure 2. Fully Assembled Mounting System

Leveling Plate

The leveling plate is machined from a block of aluminum and includes two sets of bolt holes, a bubble level and a place for the pyranometer to be attached as seen in Figure 3. The raised perimeter for the pyranometer includes a set screw to secure the device and a recess to give the wire an unobstructed path to the datalogger. The inner bolt holes are for bolts that firmly secure the LI-2003S to the base plate and are smooth bore. The outer bolt holes are threaded to allow the leveling screws to be adjusted before tightening the inner bolts.

Figure 3. Close-up View of the LI-2003S Leveling Plate

Support Platform

The support platform is made of common components and materials so any repairs, modifications, or supplementations could be made by field teams setting up the system. It was decided that an L-shaped, extruded aluminum segment, normally used on houses as a weather guard, was suitable for our purposes because of its resistance to the elements and the ease with which it could be manipulated. The segment was cut into five 4” lengths to form a broad base for the leveling plate and U-bolt bracket. Each platform was then filed to remove any rough edges that could cause injury. A part drawing, supplied by Campbell Scientific, was used to lay out bolt holes that would match the LI-2003S. Finally, all bolt holes, including those for the U-bolt bracket, were drilled.

Difficulties

At the time the platforms were manufactured, the LI-2003S plates were not physically available, so part drawings had to be obtained from Campbell Scientific. The drawings included tolerances for the diameter of the circle on which the holes were positioned. When the leveling plates arrived it was discovered that, according to ideal measurements, only two bolts could be inserted at a time, so the design was modified by elongating one hole to allow for the tolerance.

3 Engineering Analysis

3.1 Natural Variance of Irradiance

To begin an analysis of the data (one second irradiance data from 6 pyranometers between 10:00am and 2:00pm for September 22, 2012) provided from the Next Era site, irradiance was plotted versus time for each of the pyranometers. The configuration of the pyranometers can be seen in Figure 4, and the plot of irradiance versus time can be seen in Figure 5.

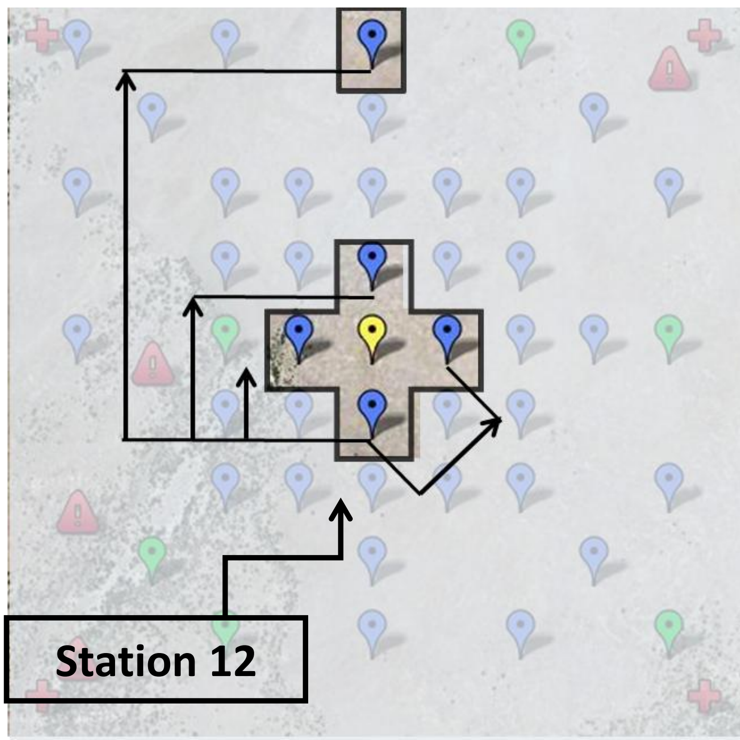


Figure 4**.** Configuration of Sensor from which Data was Received

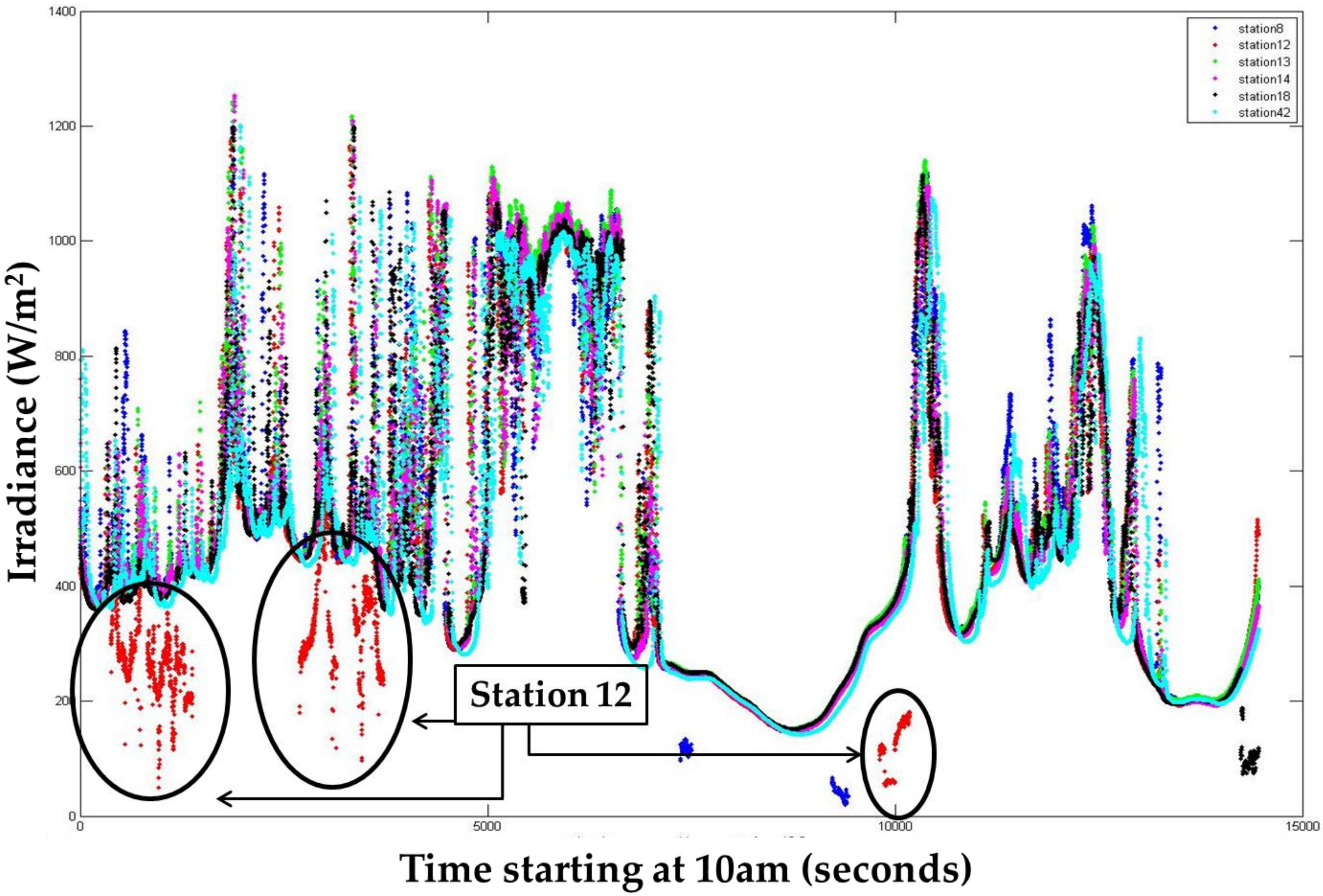


Figure 5. Irradiance versus Time for all Sensors

In looking at the plot in Figure 5, it was noted that all of the sensors are showing the same trend in irradiance observed. The one station that exhibits a significant amount of outlying points is Station 12. This is significant because when looking at the positioning of Station 12 in Figure 4, data was not received for stations South, East, or West of Station 12 so it cannot be determined with 100% certainty if Station 12 was seeing localized cloud cover, or if Station 12 was malfunctioning and recording bad data.

To try to determine if Station 12 was malfunctioning during the time period of the received data set, the maximum and minimum change in irradiance between each data point was found for Station 12 and compared to the maximum and minimum change in irradiance for the other stations from which data was received. These maximum and minimum values can be viewed in Table 1.

Table 1**.** Changes in Irradiance

Station	Maximum Change in Irradiance (W/m^2)	Minimum Change in Irradiance (W/m^2)
8	99	-107
12	333	-336
13	100	-123
14	101	-143
18	99	-107
42	99	-107

Viewing the changes in irradiance, it was observed that Station 12 had significantly greater changes than any other station. Based on the trends seen at the other stations, it is thought that Station 12 was malfunctioning; however, more data and input from technical advisors are required before it can be said that Station 12 was in fact malfunctioning.

The next step that was completed in the data analysis was to calculate the Natural Variance in Irradiation (NVI) for the data sight. NVI is a tool that compares the change in irradiance to the average irradiance seen at a point over a time set and is calculated using equation 1.

$$NVI = \frac{\sigma_{\Delta G}}{\overline{G}} \qquad \text{Eqn. 1}$$

NVI was calculated for each station over the course of the 4 hour period, over an average at each hour, and over an average every 10 minutes which can be seen in Table 2, Figure 6, and Figure 7 respectively, noting that the bold lines in Figures 6 and 7 are the average NVI for all station.

Table 2. NVI Over the Four Hour Period

Station	NVI
8	0.02369
12	0.03642
13	0.02054
14	0.02093
18	0.02174
42	0.02213
Average	0.02424

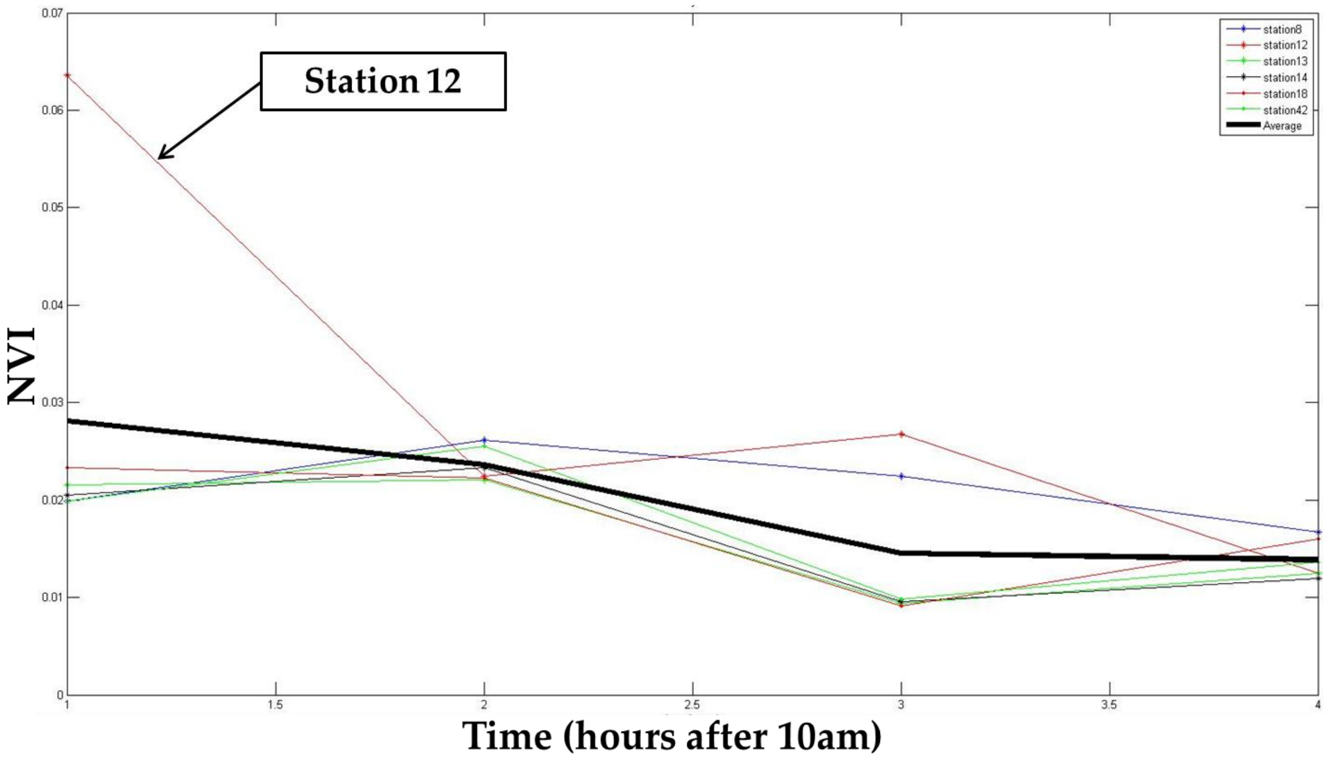


Figure 6. Hourly NVI

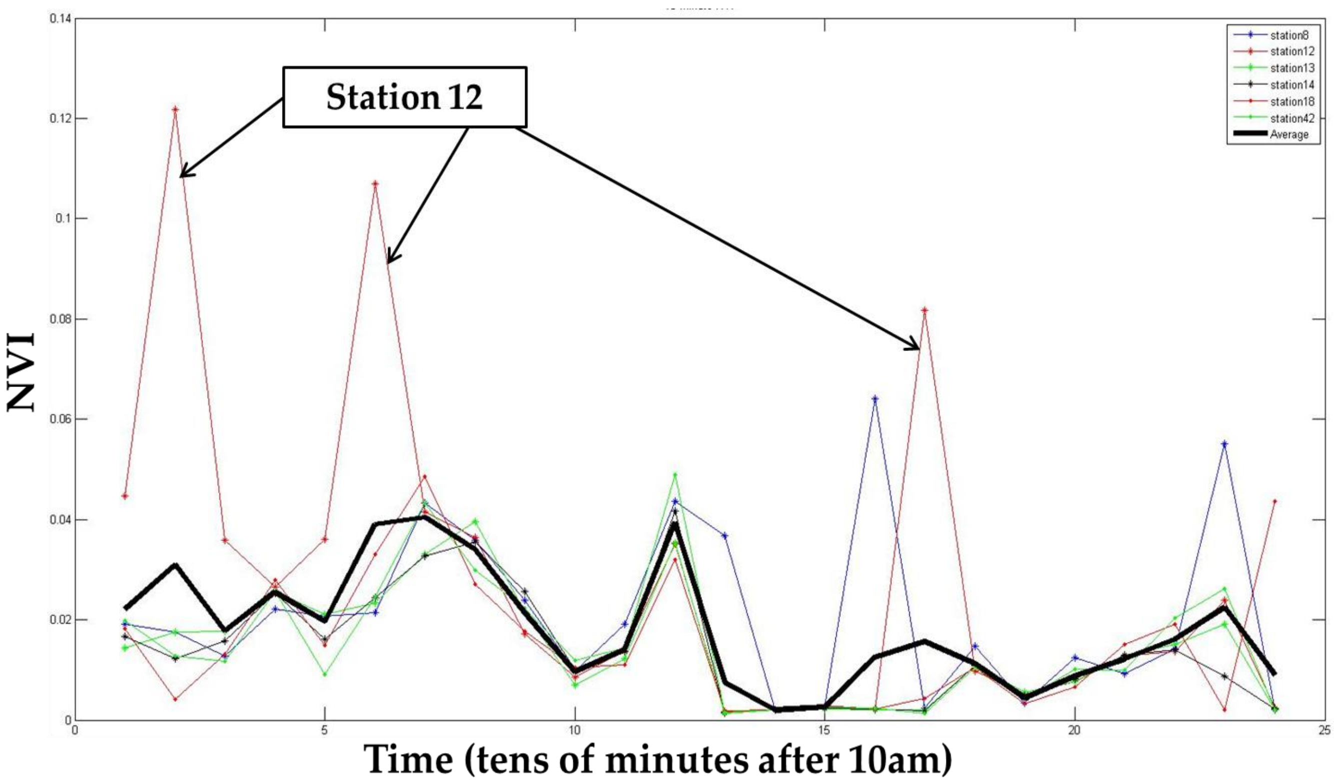


Figure 7. 10 Minute NVI

3.2 Calculating Needed Sample Rate

To calculate the needed sample rate for pyranometers placed 40 feet apart, one second data from Stations 17, 18, and 22 was used. The Matlab Correlation function (corr2) was used to relate data from Stations 18 and 22 to Station 17. This correlation was run through iterations, each iteration removing one data point from the end of the Station 17 data set and one data point from the beginning of both the Station 18 and 22 data sets. Removing these data points allowed for looking at the relationship between Stations 17, 18, and 22 through time while keeping the lengths of the data set. The iteration that provided the highest correlation value was assumed to be the average amount of time in seconds that it took for Stations 18 and 22 to see the same irradiance values that Station 17 saw. Since changes in irradiance values are caused by cloud movement, this method is used to track the movement of the clouds.

Knowing the distance between the stations and the time it took for a cloud to move between stations, x and y components of cloud velocity were found by comparing Station 22 to Station 17 and Station 18 to Station 17 respectively. Knowing an x and y component allowed for finding the actual cloud velocity vector. The magnitude of this vector was then assumed to be the average magnitude of cloud vectors.

This average cloud speed was found to be about 25.5 m/s. A Weibull distribution was applied to the data set and a cumulative density function was found which can be seen in Figure 8.

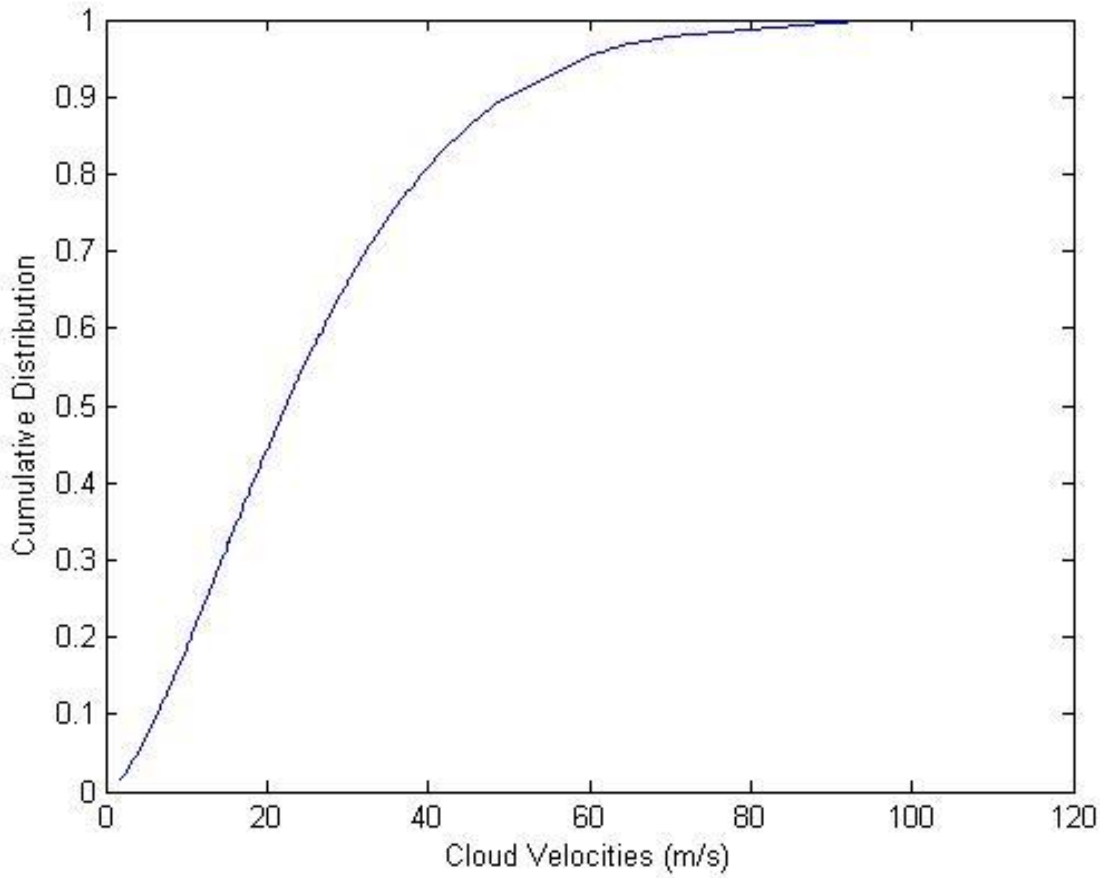


Figure 8. Cumulative Density Function

Using the cumulative probability density function, probability values were selected to see what velocity values could be seen, for example selecting a probability of 90% would see cloud speeds of about 60 m/s and less. So to see 90% of all cloud movement, the new site would have to be able to capture clouds that are moving up to 60 m/s. Using the known spacing of the pyranometers for the new site (40 feet), the amount of time it would take for a cloud to travel that distance at a given speed was found. The sampling rate (in Hz) at which would be needed to see that particular cloud movement is one over the time found. A summary of the sample rate needed for a given percent of velocities to be captured can be viewed Table 3.

Table 3: Sample rate needed

Velocities Seen (%)	Sample Rate Needed (Hz)
80	3.21132
85	3.58319
90	4.07677
95	4.85806
100	Infinity

4 Final Design

4.1 Physical Setup

The physical setup of the components includes 4 posts with a LI-COR 200 mounted axially on the top, see Figure 9, to prove the concept is viable. Once the concept is proven, individual tripods for each pyranometer will be used to increase the conformity to varying ground conditions and speed setup time. The tripod will be used to support the Campbell Scientific CR800 and one LI-COR LI200. The system will be set up in the orientation found in Figure 10. Sensors will be connected to the Data Acquisition Center with wires running through a flexible metal conduit.

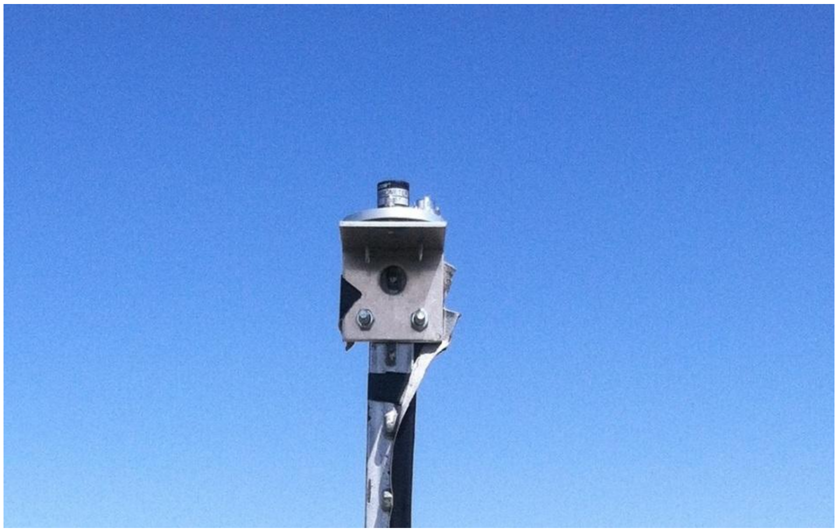


Figure 9. LI-COR on Top of the Post

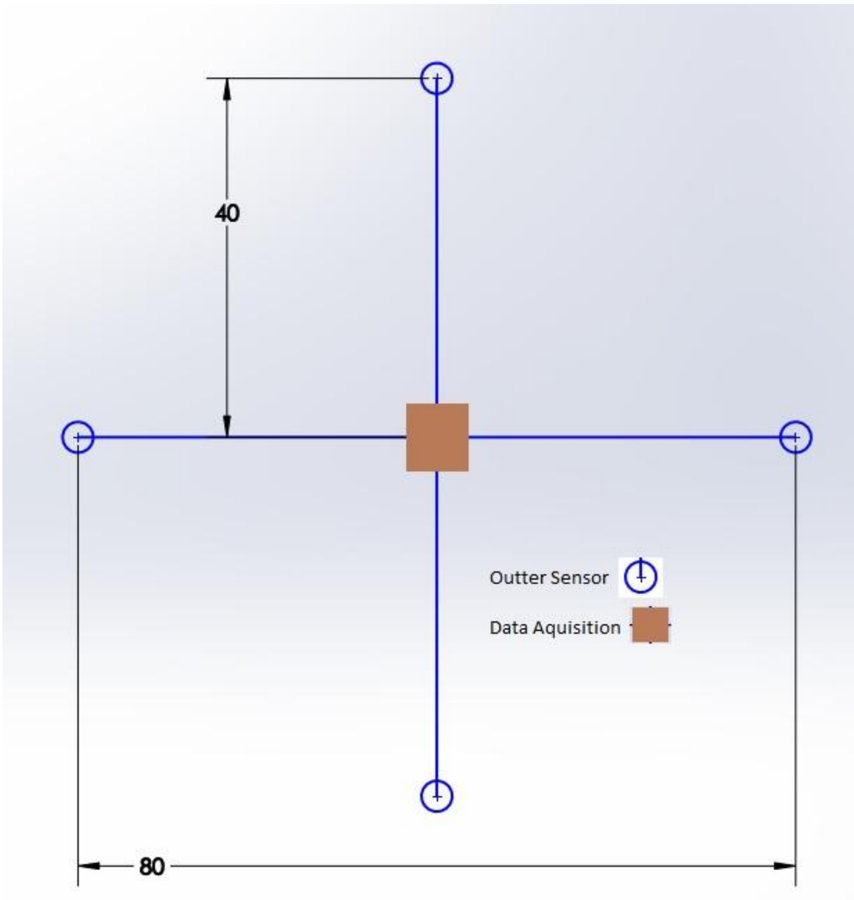


Figure 10. Diagram of Site Setup

4.2 Data and Analysis

The Campbell Scientific CR800 will be programmed to store data in a format that will be readable by MATLAB. The benefit of having this singular data acquisition center is that the data will be collected at a consistent frequency and in a consistent format. This data will then be analyzed with the algorithm discussed below in Datalogger Logic.

Pyranometer Connections:

Each of the Li-Cor LI200 pyranometers produces a small voltage through the same means that a PV cell would when exposed to sunlight. The voltage produced can be determined by the datalogger in several ways with the most common being across one of the three voltage difference channels. The other method is a single ended voltage measurement where a common ground is used and shunt resistors connected between the ground and the pyranometer lead will allow the datalogger to determine the potential difference. For this project single ended voltage measurements will be used because of the ability to connect up to six analog signals instead of only three with the difference channels.

Additional processing of the voltages will be required because, as each pyranometer ages, a unique, linear coefficient is needed to calculate irradiance from the voltage produced. This aging of the pyranometers demands recalibration to determine the needed coefficient and will be required on four of the five pyranometers. The fifth pyranometer is new from the factory and will be used to calibrate the others. This recalibration is reccomended by the manufacturer to occur every two years and therefore will be done only once during the remainder of the project.

Pyranometer Readings:

Some initial outputs from the pyranometers by the datalogger can be seen in Figure 11. The figure shows five pyranometers voltage outputs with the significant drop coming from intentional shading of the pyranometers during collection. There are two pyranometers with very low voltage outputs at the bottom of the figure because they are temporarily using shunt resistors seen in Figure 12. With a significanly lower resistance the potential difference seen by the datalogger is also lower. All shunt resistors will be replaced with five identical 100 ohm resistors to improve the readings from the datalogger. The different calibrations are very apparent, otherwise the lines would overlap each other when equal irradiance values are seen.

Future Tasks:

For proper readings of the pyranometers, calibration values must be established for each of the four that need them. In addition, wiring on each will be extended to 50 feet and new shunt resistors will be soldiered on.

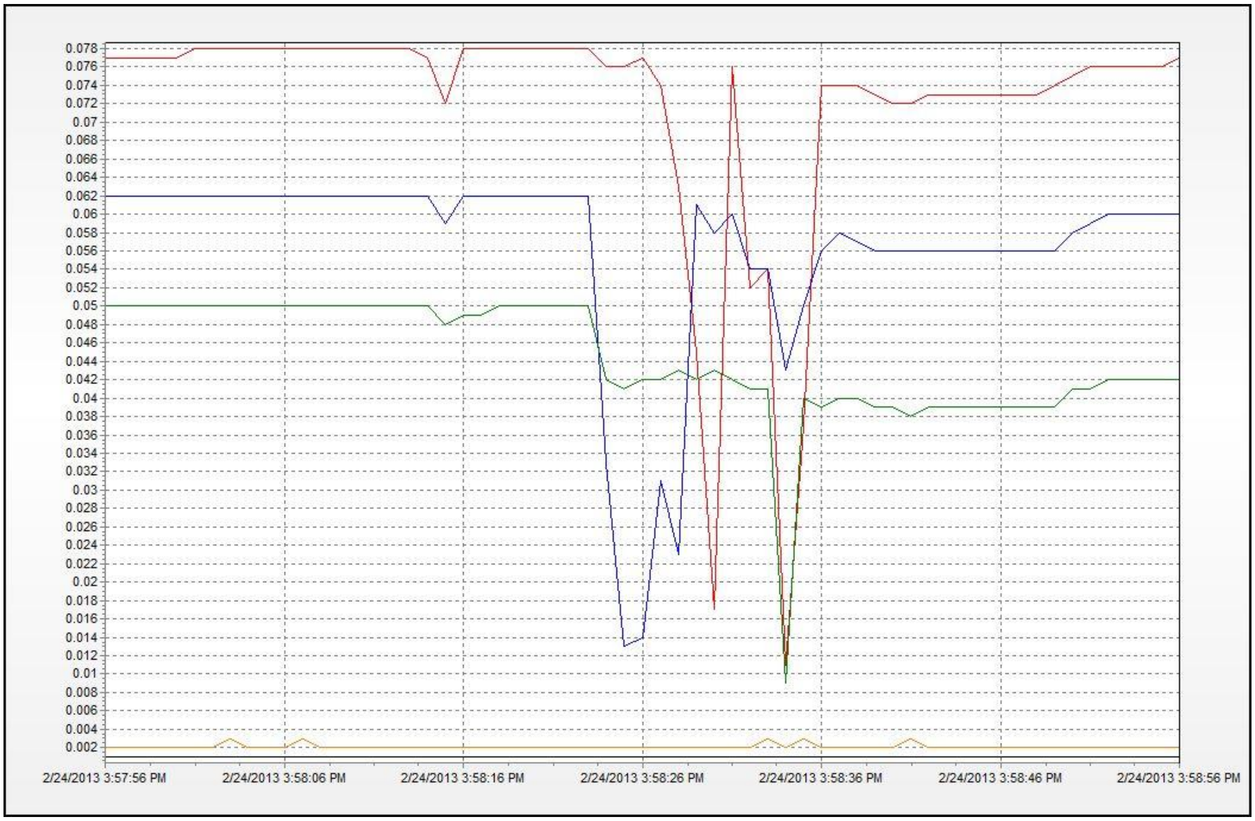


Figure 11. Pyranometer Voltage Outputs at 1Hz (left axis is mV).

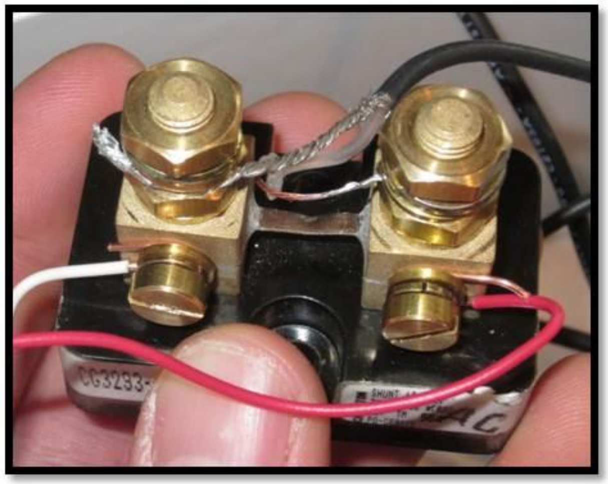


Figure 12. Temporary Shunt Resistor of 1 ohm.

Datalogger Logic:

To limit the amount of unnecessary data collection, the data acquisition center will have a basic logic program to sort the data it will be seeing. Since the entire project is interested in measuring the variation in the solar resource, the program will only record data when it sees a significant change. This will be achieved by taking the average of the previous 20 samples and comparing that to the current sample. If the absolute value of the difference is greater than 10 W/m^2, the data will be recorded for twenty seconds. To ensure that the program is running properly even when there is no difference in the solar resource, a sample will be recorded every ten seconds. This logic is outlined in the flowchart shown in Figure 13.

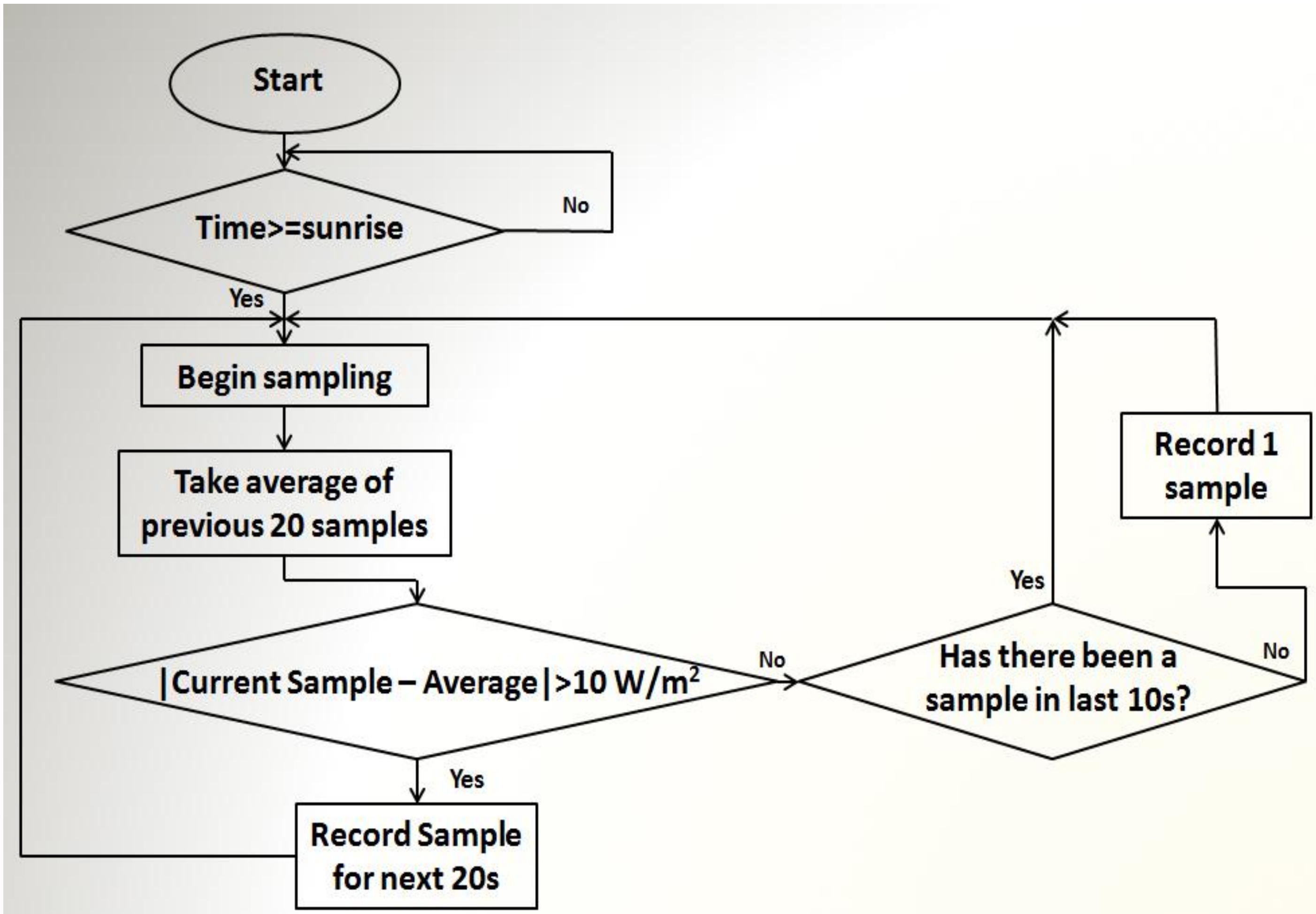


Figure 13. Datalogger Logic Diagram

4.3 Physical Components

The final design will consist of the components found in the Bill of Materials below, Table 4.

Table 4. Bill of Materials

	Quantity	Approximate Cost
Campbell Scientific CR800	1	$ 1,395.00
LI-COR LI 200 Sensors	5	$ 1,128.00
T Posts - 8ft	4	$ 21.00
Tripod	1	$ 71.17
Conduit	200ft	$ 76.36
Misc. Hardware	-	
Aluminum Sheet	1 (4 ½ x 1 ¾)	$13.12
Nuts and Bolts	7	$4.18
USB Cable	6feet	$41.58
Total		**$2,750.41**

5 Future Tasks

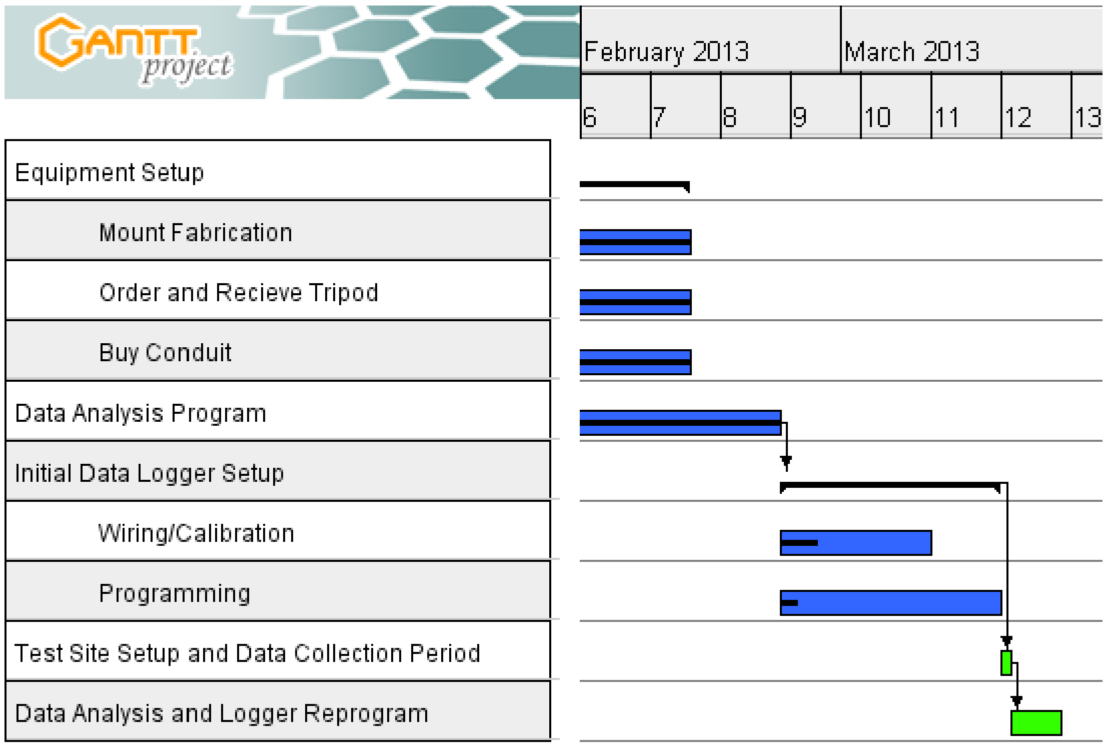
One of the primary concerns will be finding and establishing a temporary site, preferably closer to Flagstaff than the COBar Ranch location to allow little time to be wasted on data retrieval. Another will be continuing to program the DAC to communicate with the pyranometers in a desirable fashion. This task just requires eliminating the remaining few errors. Immediately after locating a suitable site the t-post apparatus will be assembled including the power source for the central tripod location. After initial setup, there will be an initial data collection period that will last approximately 2-3 days. This will allow ample data to be analyzed so changes may be made to either the temporary site or the programming of the DAC. This process, not including the initial setup will be iterated until satisfactory data can be collected. When the team is satisfied with the short-term data, the device will be moved to a location on the COBar to begin a longer-term data collection period. If there is enough time, after the iterative phase of the project, a month long data collection period will begin. This will allow the program to be tested on a large data set with our own data that has been verified for accuracy. The timeline can be seen in Appendix A.

6 Conclusion

Team 20 will implement a relatively small, portable solar irradiance measuring system that can accurately quantify variance in solar irradiance over a larger area. The reason for this is to determine the viability of a solar PV power plant at COBar Ranch. The objectives and constraints seen in sections 1.4 and 1.5 are met for the project by using the centralized tripod concept seen in section 2. The finalized design, in brief, will consist of a single tripod with the DAC, PV panel, and pyranometer in the middle of four equally spaced pyranometers on t-posts. These pyranometers will be hardwired to the DAC with their wires contained in flexible conduit for protection. Ultimately, the physical design is merely the channel by which data can be collected to determine the viability of using a small site to determine the irradiance variation on the larger site. With the design finalized the future tasks, seen in section 5, can now be pursued.

7 Appendices

Appendix A: Timeline



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