Small Scale Irradiance Measuring Device

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Team 20

Project Progress Report

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 Background Research

Next Era Energy is one of America's top 10 producers of power. Next Era is North America's largest owner and operator of wind and solar electricity generating assets. Working with ISES, Next Era is determining the viability of installing a photovoltaic power plant in northern Arizona.

The Institute for Sustainable Energy Solutions is associated with the College of Engineering, Forestry, and Natural Sciences (CEFNS) at NAU and aims to provide society with broadly educated energy experts to promote renewable energy resources.

1.3 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.

1.4 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.

1.5 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.

Table 1. Basis of measurement for objectives

Objectives	Basis for Measurement	Units
Scales Down Site	Surface Area	Ft^2
Location of Sensor	GPS	Lat./Long.
Easy Set-up/Operation	Set Up Time	Hours
Longevity	Durability	Months
Transportable	Packed Volume	Ft^3
Transportable	Weight	lbf
Inexpensive	Cost	$

1.6 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. 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.

2.2 Mount

The interface between the Tripod and Sensor assembly will consist of a simple mount machined out of a low-grade Aluminum such as 2024. This part, found in Figure 1, accepts the mounting hardware that comes with the Li-Cor Pyranometer and provides a sturdy plane for the sensor to be leveled upon. The mount is fixed to the tripod using the cylindrical sleeve located on the bottom of the mount using three setscrews. Once the team receives a Praynometer assembly the dimensions will be finalized and the part will be manufactured on campus at the machine shop.

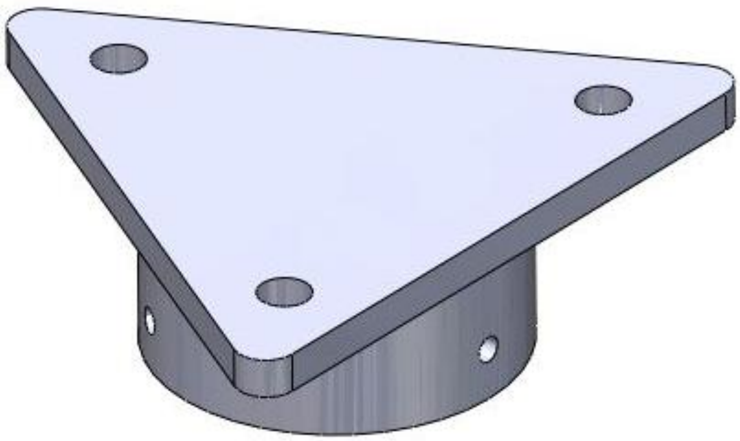


Figure 1. Sensor Mount

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 2 and the plot of irradiance versus time can be seen in Figure 3.

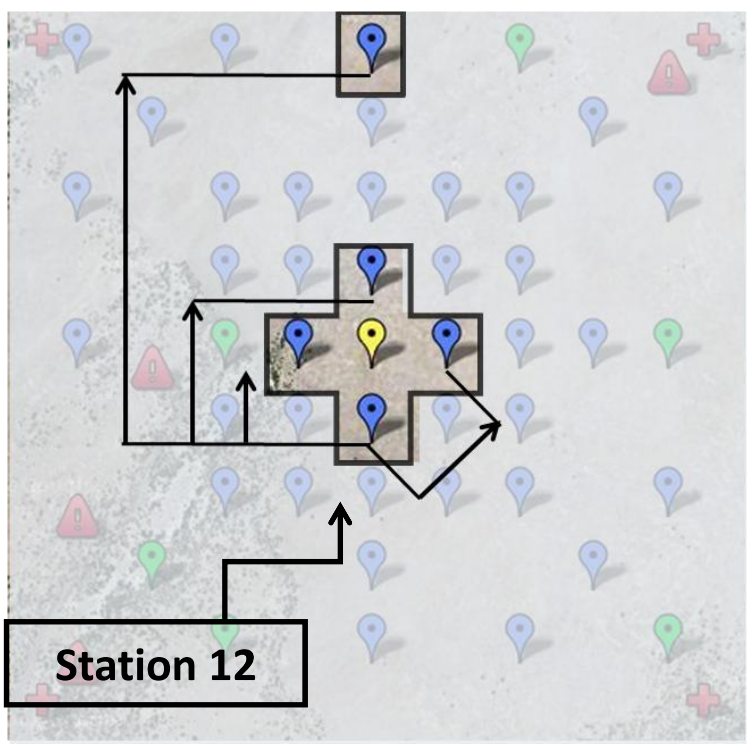


Figure 2. Configuration of Sensor from which Data was Received.

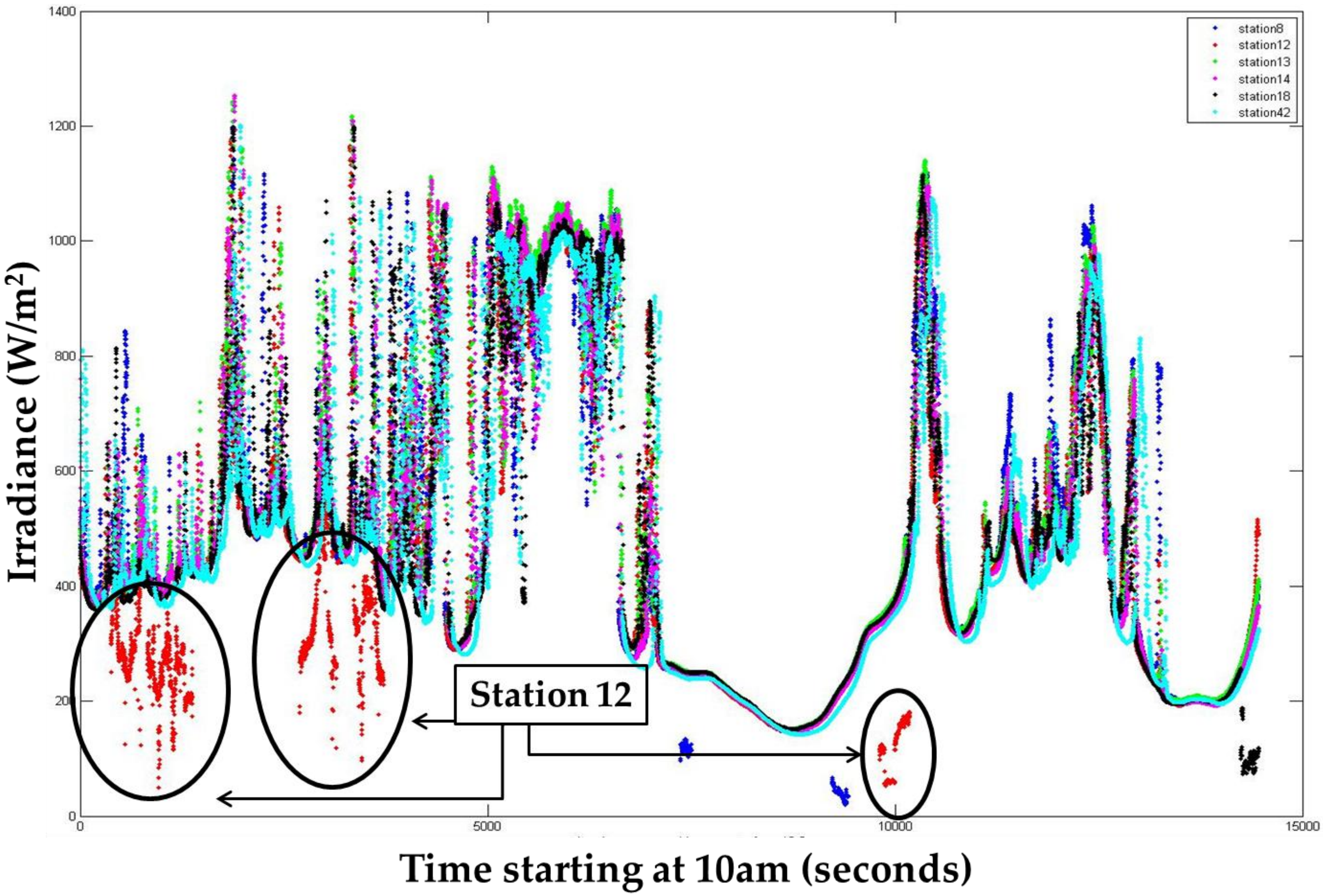


Figure 3. Irradiance versus Time for all Sensors.

In looking at the plot in Figure 3, 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 2, 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 2.

Table 2**.** 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 3, Figure 4, and Figure 5 respectively, noting that the bold lines in Figures 4 and 5 are the average NVI for all station.

Table 3. 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

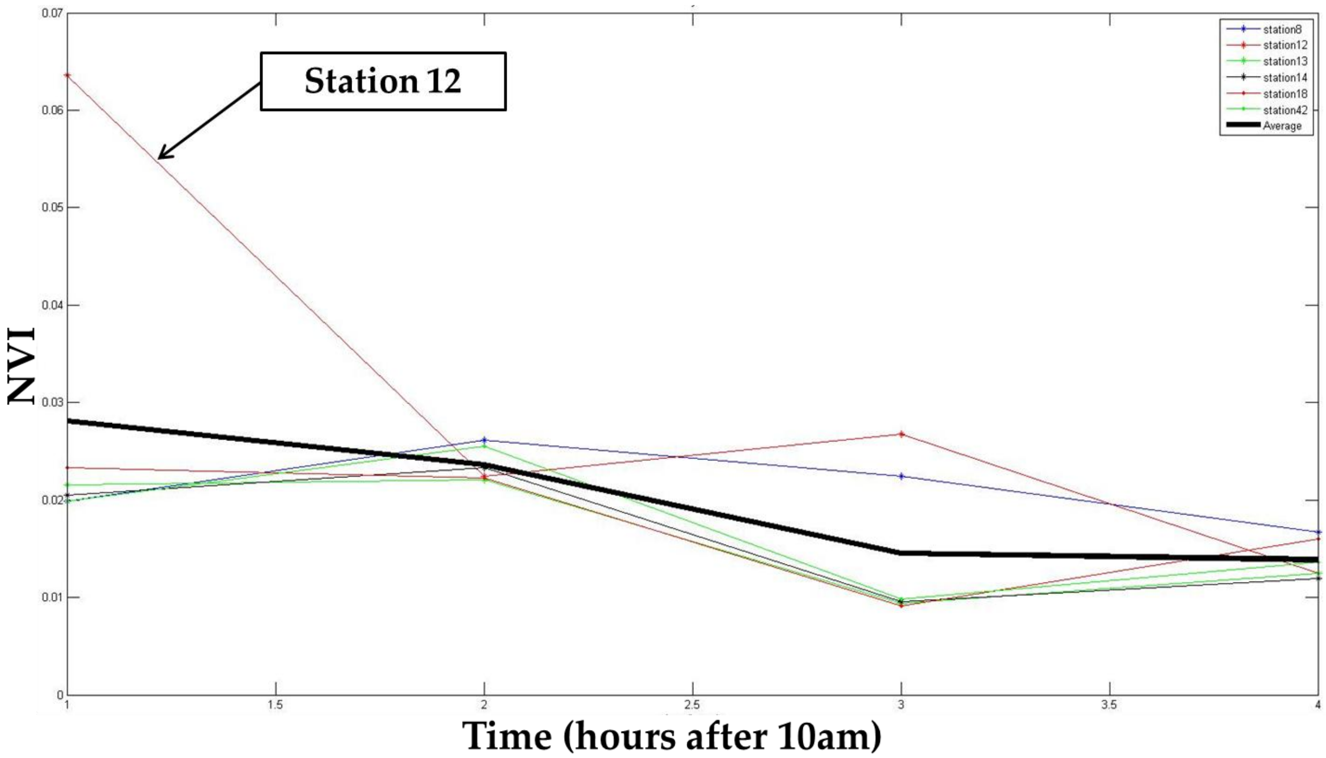


Figure 4. Hourly NVI

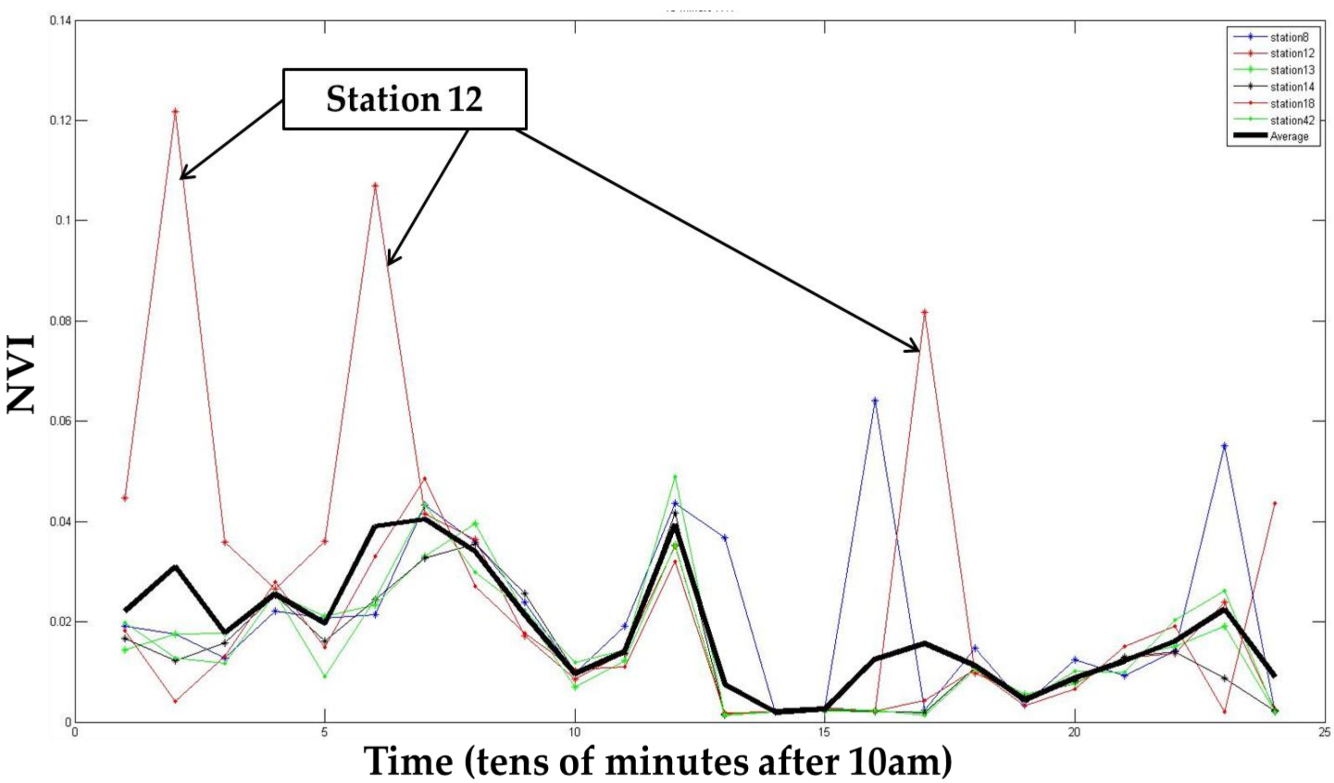


Figure 5. 10 Minute NVI

3.2 Calculating Needed Sample Rate

To calculate the needed sample rate for pyranometers placed 40 feet apart, one second data from Stations 13, 14, and 18 was used. The MatLab Correlation function (corr2) was used to relate data from Stations 14 and 18 to Station 13. This correlation was ran through iterations, each iteration removing one data point from the end of the Station 13 data set and one data point from the beginning of both the Station 14 and 18 data sets. Removing these data points allowed for looking at the relationship between Stations 13, 14, and 18 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 14 and 18 to see the same irradiance values that Station 13 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 18 to Station 13 and Station 14 to Station 13 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 12.2 m/s. This value was applied to a Rayleigh distribution. The probability density function can be seen in Figures 6 and 7 respectively.

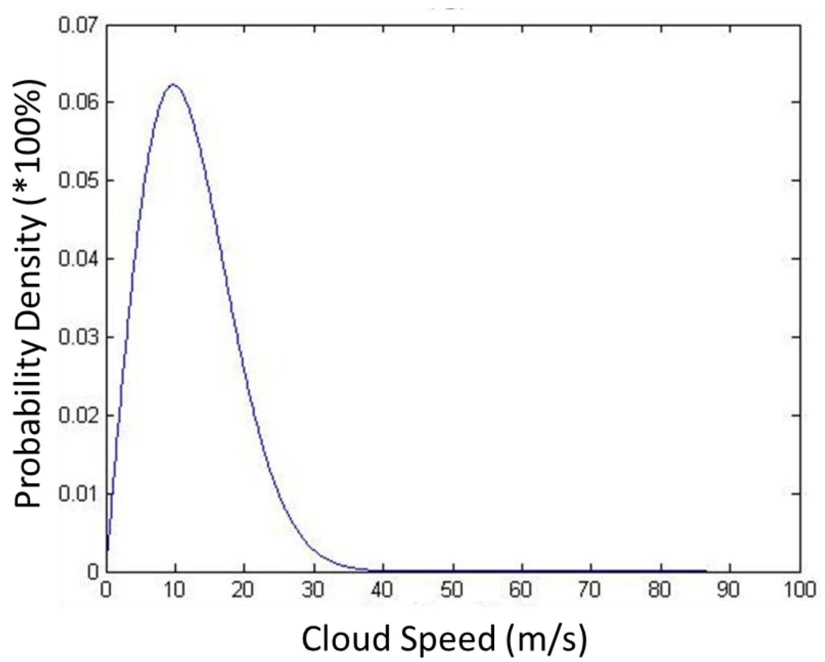


Figure 6. Probability Density Function

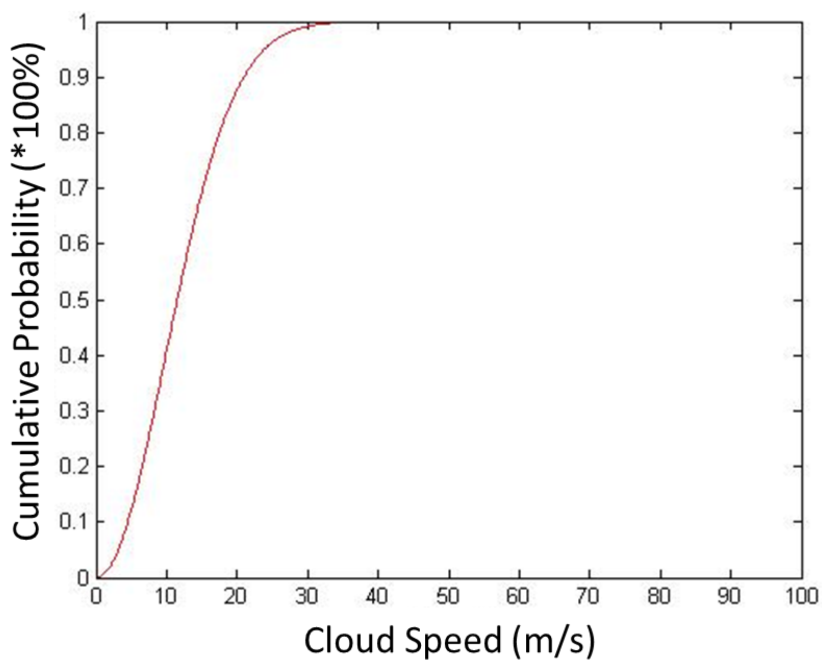


Figure 7. Cumulative Density Function

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 20 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 20 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 in Figure 8 and Table 4.

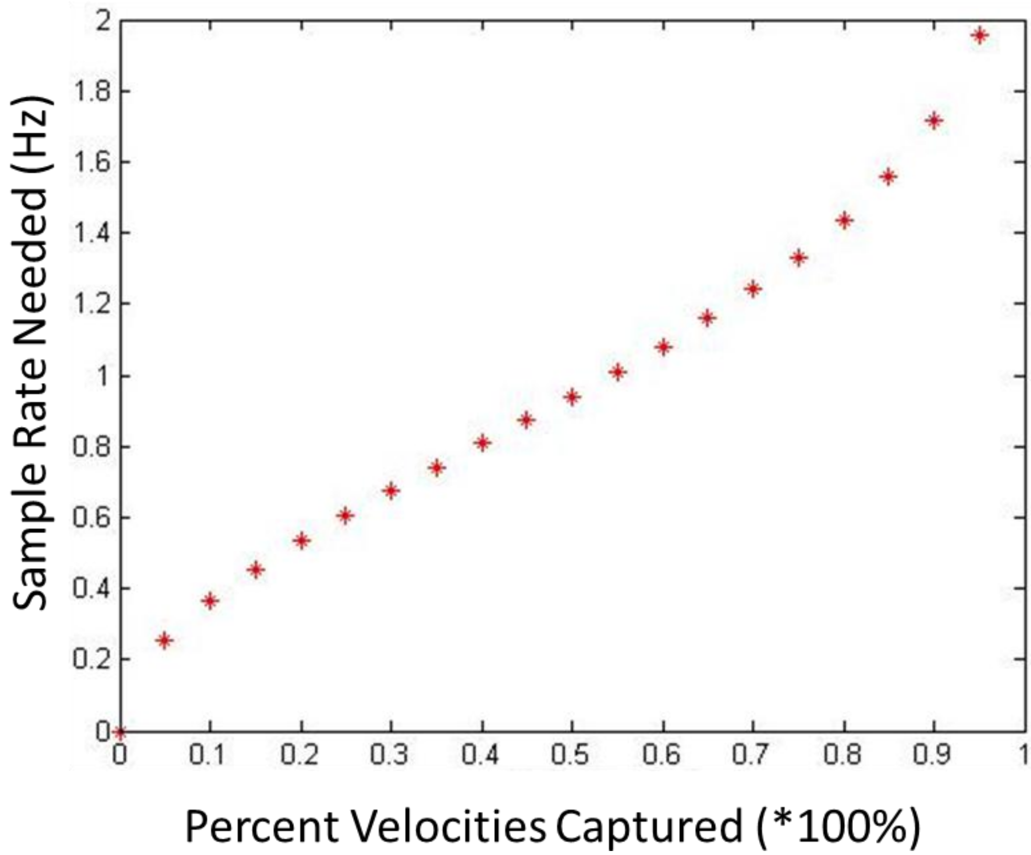


Figure 8. Sample Rate Needed

Table 4. Sample rate needed

Velocities Seen (%)	Sample Rate Needed (Hz)
70	1.24
75	1.33
80	1.43
85	1.56
90	1.71
95	1.96
100	Infinity

3.3 Continuation of Analysis

This analysis will be refined before the needed sample rate can be determined. There is much uncertainty associated with the data sets that were used. The data that was used only encompasses a short four hour period and there is much time drift associated with Station 13 (about 7 seconds is gained per day). This analysis will be completed running a month's worth of data for three new stations with the same configuration as Stations 13, 14, and 18, but with smaller and more consistent drift.

4 Final Design

4.1 Physical Components

The final design will consist of the components found in the Bill of Materials below, Table 5.

Table 5. Bill of Materials

	Quantity	Approximate Cost
Campbell Scientific CR800	1	$ 1,395.00
LI-COR LI 200 Sensors	5	$ 1,128
T Posts - 8ft	4	$ 21.00
Tripod	1	$ 80.00
Conduit	200ft	$ 70.00
Misc. Hardware	-	$ 50.00

4.2 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 design can be seen in Appendix B. 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 using simple 12 gage wires run through a flexible metal conduit.

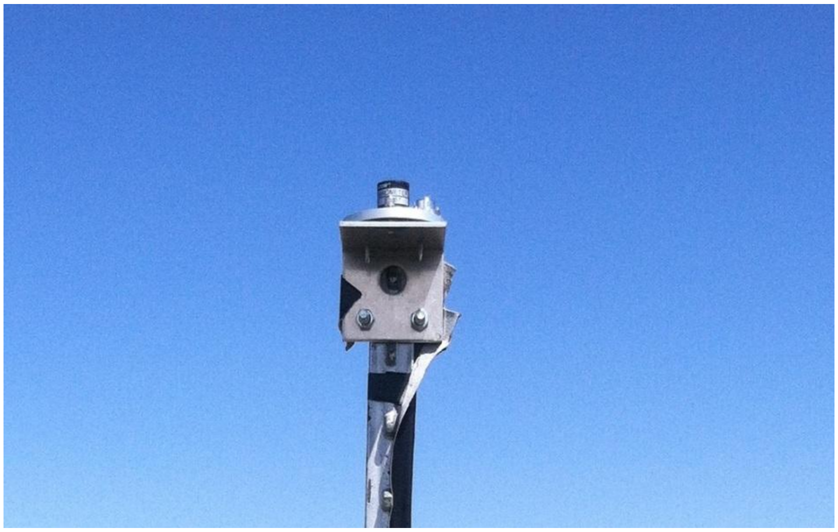


Figure 9. LI-COR on top of the post

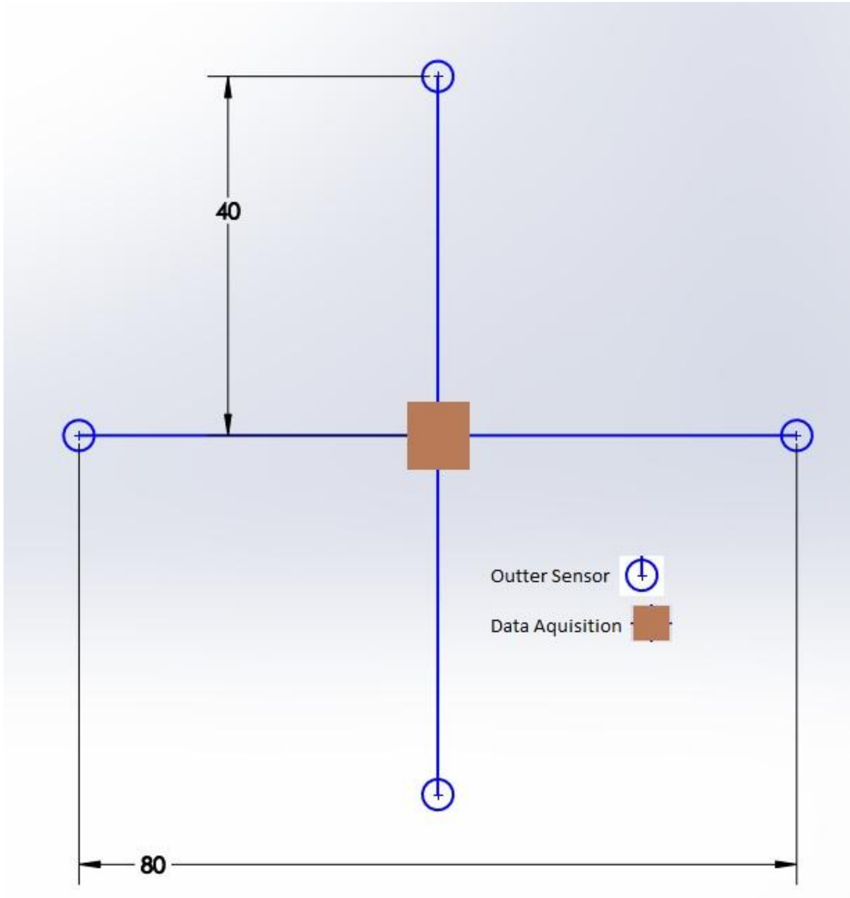


Figure 10. setup showing area

4.3 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 in section 3.

5 Future Tasks

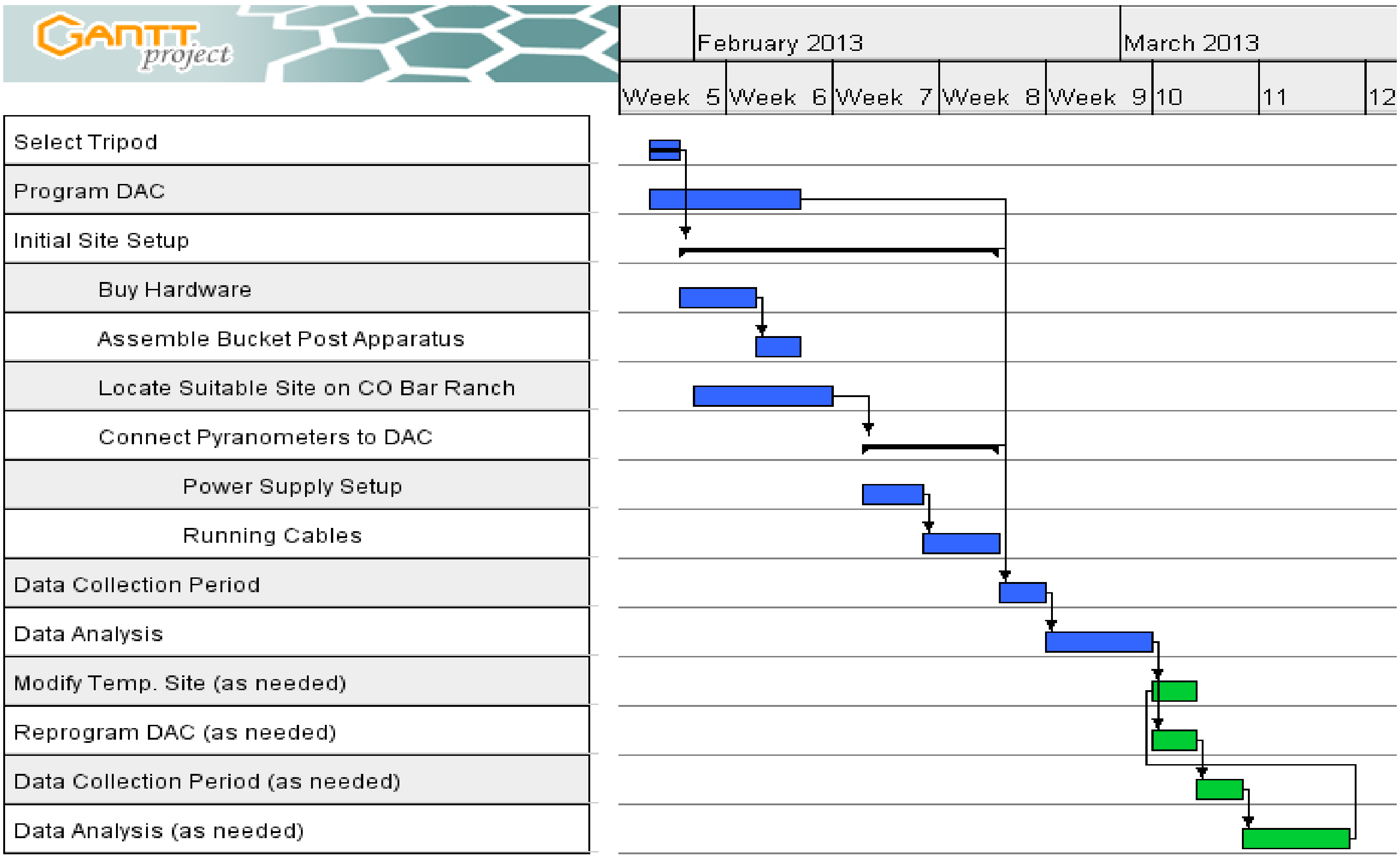
Beginning promptly at the start of the spring semester one of the primary concerns will be finding and establishing a temporary site, preferably closer to Flagstaff than the COBar Ranch location to allow little time to be wasted on data retrieval. Another will be initially programming the DAC to communicate with the pyranometers in a desirable fashion. 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 1.5 and 1.6 are met for the project by using the centralized tripod concept seen in sections 2.1 and 2.2. 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



Appendix B: Design Diagrams

Tripod

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