Development of a solar diffuse radiation mapping instrument

Introduction

With a growing need for solar resource utilisation comes a growing need for accurate estimation of solar resource on a tilted plane so an owner of a PV System can assess the systems economic feasibility of installing a new PV System as well to assess an existing systems performance. These estimations are done through transposition models which uses available global horizontal radiation data from meteorological sites nearby and transpose that data to a site in examination. In order to do that, these models require the separation of the different components of radiation – the direct beam coming straight from the sun, the diffuse component of radiation is the radiation that has been scattered from molecules in the atmosphere and the albedo component (smallest component) which comprises of the ground reflected radiation. These models work with estimations, out of which the diffuse radiation can be assumed to be isotropic which leads to an increased error probability.

This project consist of developing an instrument that can scan the sky for diffuse radiation with the intent of mapping the data In order to better understand its distribution over different sky conditions.

Project Objectives

- Develop sensor circuitry to measure irradiance from a patch of sky.
- Develop the sensor positioning apparatus.
- Develop the motor controller and data logger.
- Sub system integration.
- Data evaluation and visualisation.

Design Methodology

In order to scan the sky a radiation sensor is required. Due to the similar spectral response to a solar cell, its fast response and it's availability, the photovoltaic pyranometer was chosen. These sensors output very small signals, which therefore need to be amplified in order to be measured. By pondering the best possible circuits out of transimpendance amplfiier (sensor in current output mode) or a non-inverting amplifier (sensor in voltage output mode), the transimpendance amplifier in photoconductive mode provided more benefits due to its quick measuring speed and precision over the desired measurement range. Hence, by using an Arduino in conjunction with an external 16-bit ADC, an SD Card and an RTC circuit, a data logging system was developed.

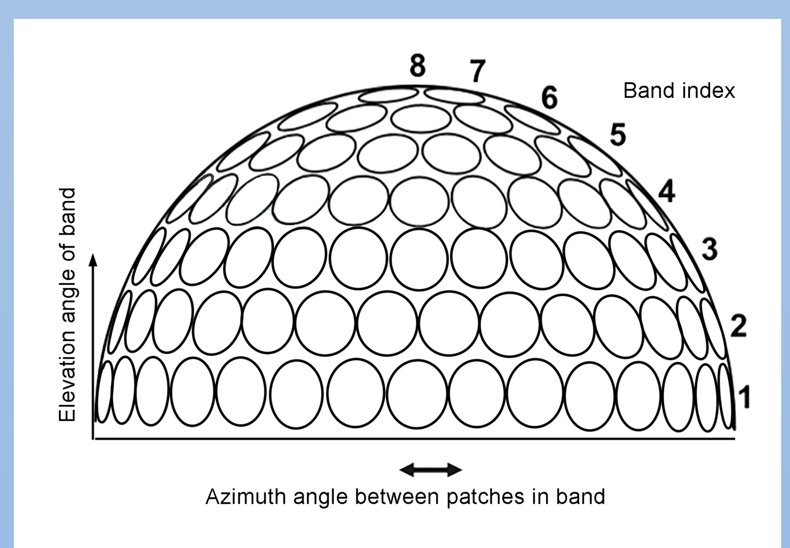


Figure 1 – Skydome Mapping configuration

The sensor was placed in a tube which limits it's field of view, thereby increasing the resolution of the skydome mapping, each measuring point is smaller and is only pointing at a certain patch of sky. Figure 1 illustrates the adopted skydome mapping configuration which comprised of equally sized patches across the skydome. A field of view of 12°was chosen which defined the angle of separation between the patches. This is also the case for the azimuth bands, the number of measuring patches reduces with increased elevation band.

By positioning the sensor in a two-axis moving structure, the system that was able to scan the sky was developed.

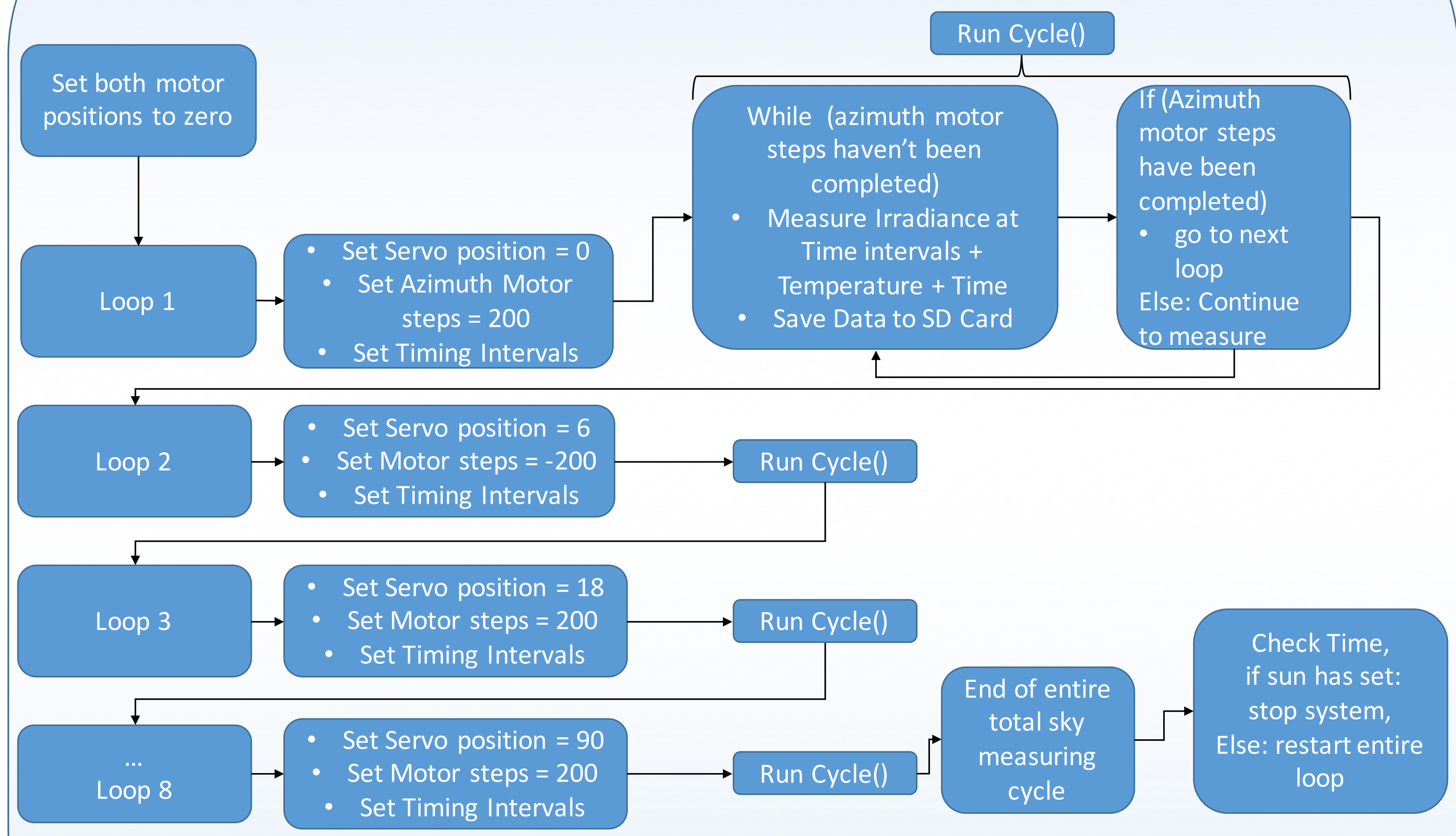


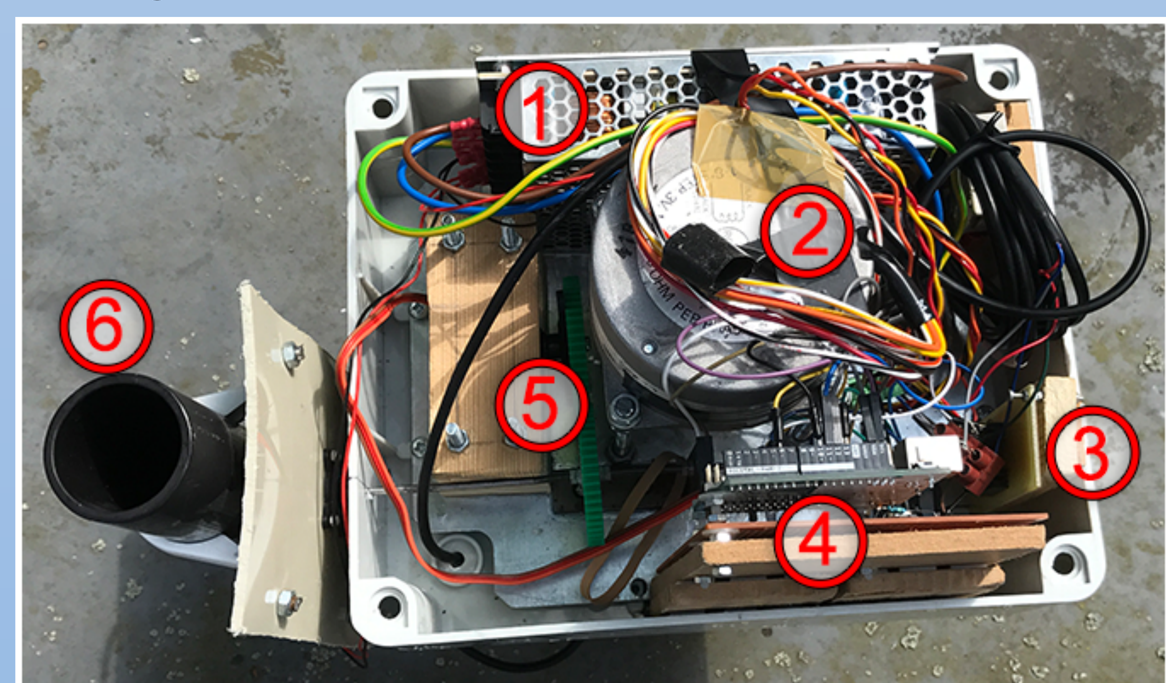
Figure 2 – Flow chart demonstrating operating principle.

Operating Principle

The operating principle of the system is illustrated in Figure 2. The flow charts starts by setting both motors to zero and for every loop initialisation, different motor positions and timing intervals are assigned. The time intervals represent how often the system is supposed to measure irradiance. Once the measurements are taken, they are saved along with the time at which they were taken into the SD card for post-analysis.

Figure 3 demonstrates the finalised system. The sensor collector tube in the side of the electrical enclosure contains the pyranometer which measures the irradiance why the two motors provide the two-axis movement for the effective sky scanning.

Figure 3 – Finalised system in operation



1. Power Supply; 2. Stepper Motor with Optical Encoder attached at the bottom; 3. Stepper Motor Driver; 4. Amplifying Data logging Circuit; 5. Servo and Gear Mechanism; 6. Sensor Collector Tube

Figure 4 – Interior of finalised system.

Results

The developed allows for the scanning of the skydome. Dataset were taken in two different sky conditions illustrated in Figure 5 a) and b).

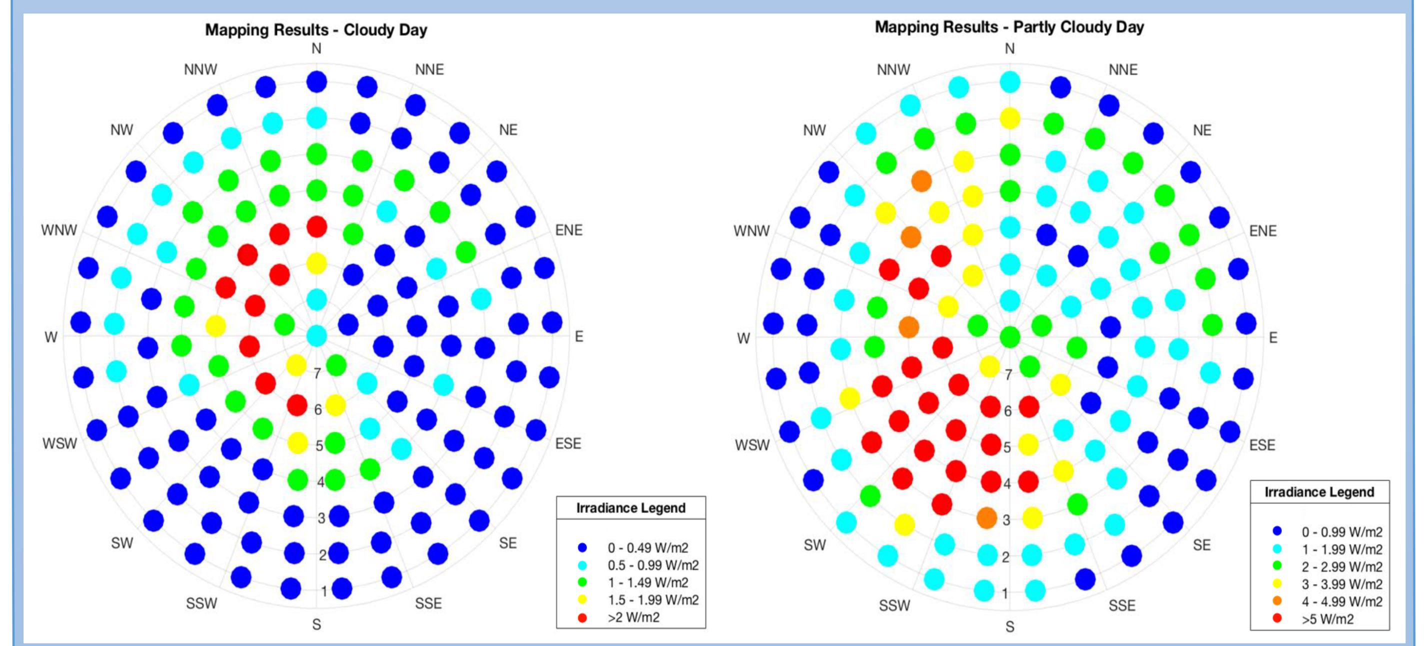


Figure 5 – Mapping results:
a) Cloudy day – 6pm 06/05/2017; b) Partly cloudy day – 2pm 07/05/2017

Due to the inability of using the encoder position sensor, the system was run in an open loop and therefore a measuring period of 15 min was done for each dataset so position accuracy wasn't lost as the system was being run in open loop.

It is clear that from these results, a cloudy day provides a more uniform distribution across the sky which is due to the more extensive scattering of light through the atmosphere. On the other hand, the partly cloudy day, provides a much more colourful graph indicating a more varied irradiance distribution across the sky. The red patches will mostly represent where the sun is positioned in the sky as diffuse irradiance is not expected to be above 5 W/m^2 per measurement. The exact position of the red patches matched with the calculated suns position on those specific days and time which validated the systems effective functionality.

Conclusion

The aim of the project was fulfilled by developing an instrument able of scanning and measuring diffuse radiation across the sky. Although the encoder positioning sensor wasn't functioning, the stepper motor was able to maintain it's position accuracy when running in open loop by simply counting its incremental steps. From the results acquired, it was found that cloud coverage leads to a more uniform distribution of diffuse radiation. As for the partly cloudy day, a more distributed irradiance distribution was observed with expected higher values of irradiance. This proves that the isotropic assumption can only be assumed in cloudy days.

From this study, further datasets should be taken in as many sky conditions possible with the intent of providing a more accurate way of identified the diffuse fraction of irradiance. This could lead to a significant improvement in transposing available horizontal radiation data from Meterological site towards sites under evaluation. Additional further validation of this system should be undertaken by comparing the global horizontal diffuse radiation with the sum of all the diffuse radiation measurements taken in the mapping cycles and a 360 camera should be placed on the system so the cloud coverage could be compared with the data collected from the system.

Wolfon School of Mechanial, Electrical and Manufacturing Engineering

Guilherme Barreiro Vieira, B315177, Electronics & Electrical Engineering, MEng

Supervisor: Dr. Tom Betts