"Earn the Victory, Move the World"

Utilization of the EKO MS-80S Pyranometer in Solar Racing Strategy

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Background

Founded in 1989, the University of Michigan Solar Car Team designs, manufactures, and races some of the world's most advanced solar-powered vehicles. The team is run by undergraduate students at the University of Michigan – offering these students an opportunity to gain invaluable real-world experience while still in university.

Every two years, the team goes back to the drawing board to design a brand-new car – with the 17th in the midst of the design process. This car then goes on to compete in the prestigious Bridgestone World Solar Challenge in Australia during the fall of odd-numbered years. Going up against solar racing teams from around the world, this race brings together some of the greatest minds of this generation.

After returning from Australia, the team evaluates the vehicle's performance and makes any necessary modifications in preparation for the American Solar Challenge which takes place in the summer of even-numbered years.

While building an efficient car is paramount to a successful race, determining the most effective race strategy is essential. As such, the team has an entire group of strategists who are tasked with creating tools to predict the car's performance in a wide array of conditions. These simulations are continually refined and are used during the vehicle's design process as well as the race itself. Once manufacturing is complete, the strategists compare the car's real-world performance to those predicted by the simulators. This allows the team to make adjustments to any assumptions made in regard to the car's various characteristics – ranging from rolling efficiency to the solar array's efficiency. However, in order to determine the array's efficiency, the strategists need to have access to the current weather conditions – including solar irradiance.

For the summer of 2022, the team diverged from the norm and chose to create its own exhibition race. Dubbed the Michigan Sun Run, the 5,000-kilometer journey took the team from New Jersey to California. On top of the Sun Run, the team also did several thousand miles of additional testing during mock races, route survey, and vehicle proving at test tracks. During the thousands of miles of real-world driving, the team utilized EKO's MS-80S Pyranometers to monitor solar irradiance, humidity, temperature, and gyroscopic data (yaw, pitch, and roll) – allowing the strategists to make more accurate predictions in order to minimize race time and improve their models.

Products Used

Throughout the thousands of miles covered during the summer of 2022, the University of Michigan Solar Car Team used EKO's MS-80S Pyranometers and its accompanying software, Hibi, to monitor the solar irradiance of the environment in which the vehicle was driving through.

MS-80S Outfitting

The MS-80S Pyranometer was mounted to the roof of the Chase vehicle (a minivan that follows immediately behind the solar car) to get precise, real-time weather readings in the location the team was actively racing. The pyranometer was powered by an inverter located in the Chase vehicle. Pictures of preliminary pyranometer outfitting can be found in Appendix A.

MS-80S User Experience

The first time that the team used the MS-80S was during the route survey and selection for a mock race around the border of Michigan. The MS-80S was a crucial aspect of this trip as it allowed for the investigation of the variation of irradiance due to tree coverage – a particular feature of Michigan and the Midwestern states. Previously, the team had ignored this due to a lack of such a feature in Australia. The analysis of the pyranometer data from the route survey and the mock race itself played a crucial role in determining how the additional trees and shadowing would impact irradiance. The strategy team found that the irradiance stayed relatively constant despite these features. The irradiance would rapidly spike, then return to the average value as we drove. Therefore, when establishing the strategy calculations for the Michigan Sun Run, tree coverage was omitted.

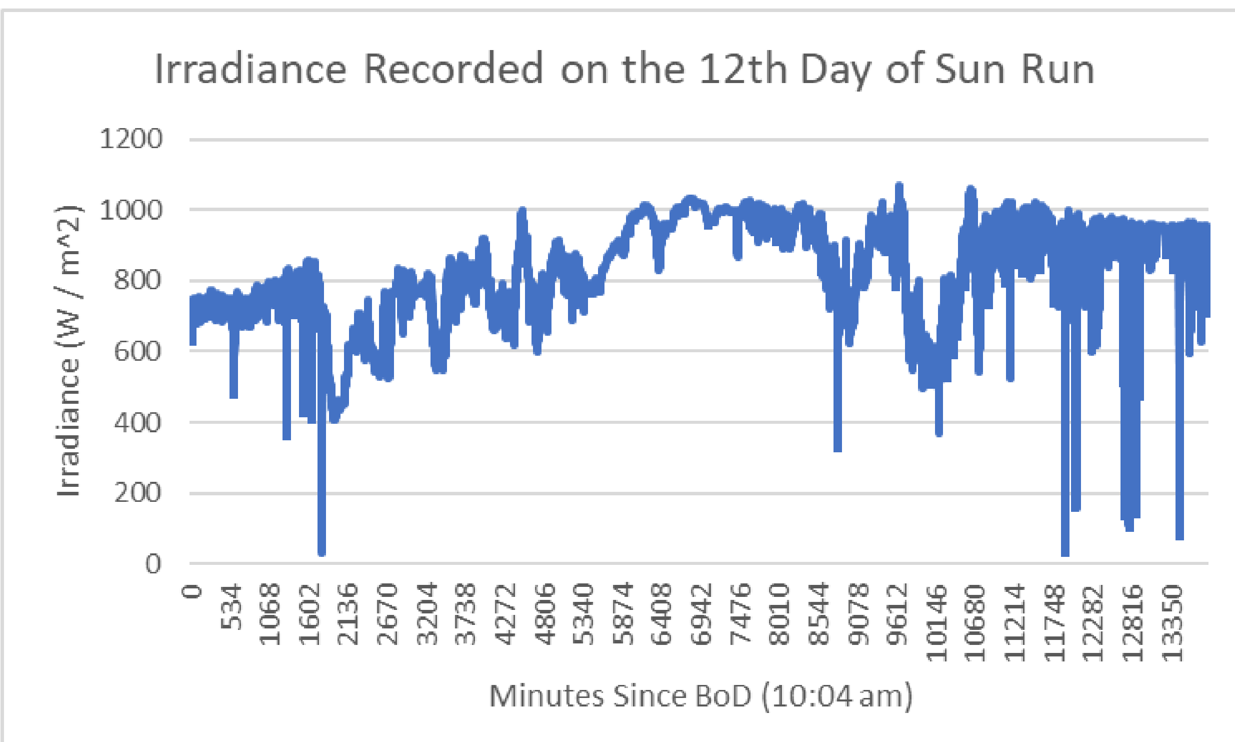

Figure 1. *Data collected on Day 1 of Mock Race*

After analyzing the raw data collected on Mock Race, in addition to seeing real-time power in values from the array, the strategy team determined that it was unnecessary to change the model of array efficiency to consider tree coverage as a factor. The power in didn't vary significantly to a level that the prediction can accurately determine, and (as shown above) during post-collection analysis, the irradiance measured only changes significantly (~200 W) when measured in small increments like seconds.

Figure 2: *Fully Outfitted Chase Car on Sun Run*

On Mock Race and Sun Run, the MS-80S Pyranometer was used for four main reasons:

(1) Short-term optimizations
(2) The validation of weather predictions
(3) System function validation
(4) Data collection

To illustrate the use of the MS-80S when making short-term optimizations, consider the following situation:

> During the five-day mock race, the team was simulating the schedule and regulations of the Bridgestone World Solar Challenge. On the third day of the simulation, the weather was partly cloudy with middle-to-low cumulus clouds. Thanks to high irradiance during the previous days, the car's state of charge (SOC) was higher than initially expected.
>
> Given this information, the strategists had to determine whether the solar car should increase speed to return to the higher-than-expected irradiance between the patches of clouds. To make this decision, they had to compare the energy required to increase the set speed and the potential energy to be gained by returning to clear skies. Utilizing the irradiance readings from the MS-80S, the strategists determined that the best option was to increase the set speed as it would result in lower net energy usage.

The pyranometer allowed for the accurate calculation of the power/irradiance differential and therefore made an informed decision when determining the best strategic move for the vehicle.

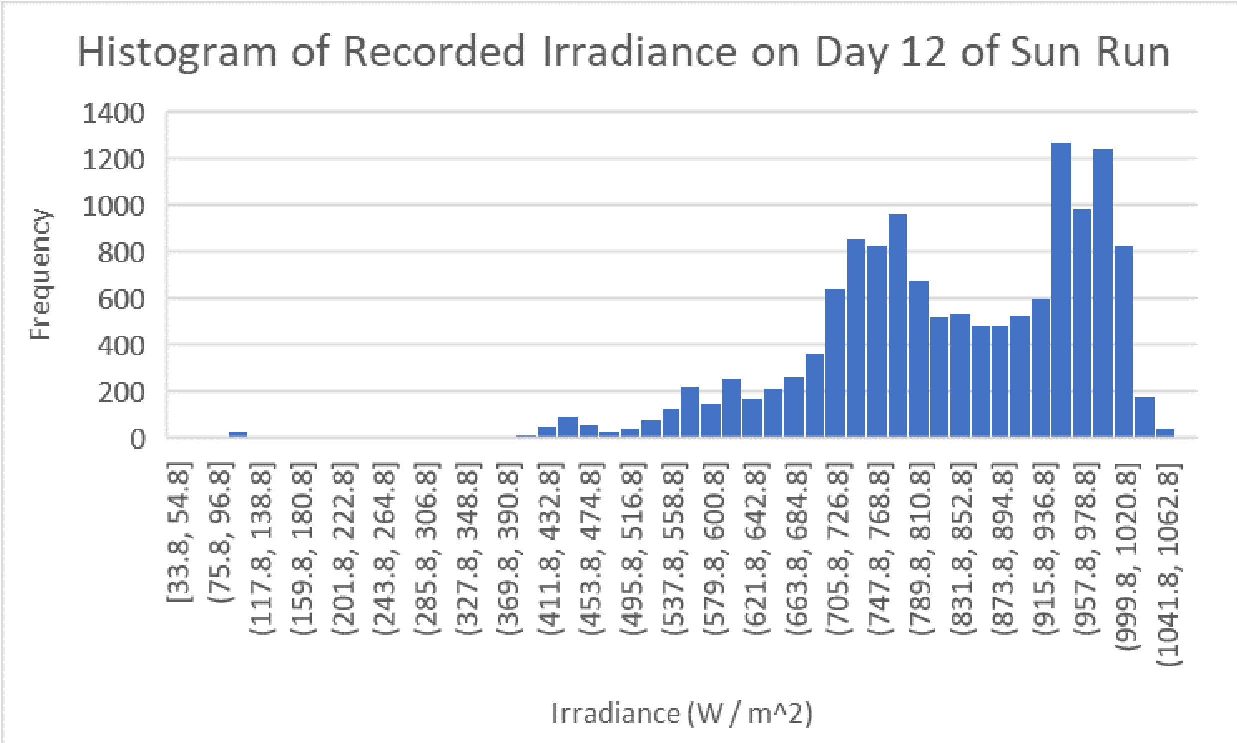

Figure 3. *Histogram of Irradiance on Day 12 of Sun Run*

Above is a typical race day shown through irradiance measurements, and below is a graph of the power collected on the last day of Sun Run. Having an accurate irradiance allowed the strategy team to calculate the expected power intake (knowing the efficiency of the car's cells), this allowed the strategy team to diagnose any potential issues, such as cell shorting for example, by looking at telemetry numbers.

Throughout the day, the team's weather strategist would regularly send updated weather projections to be utilized when making strategic decisions. However, in between these updates, it was not uncommon for real-world conditions to deviate from these projections. As such, the team constantly validated the irradiance projections using the data coming from the MS-80S – allowing for the accurate modeling of the current environment. Similarly, the car's array system efficiency could be verified by calculating power as a function of irradiance and the array's expected characteristics. Any deviation from the expected value could suggest a failure such as the array shorting or damage to array cells.

Lastly, one of this summer's goals was collecting real-world data for the validation of various assumptions made throughout the design process. The 2022 vehicle, Aevum, is the team's smartest car to date – outfitted with an advanced sensor suite featuring aerodynamics pressure sensors, temperature analysis sensors, inertial measurement units (IMUs), and steering angle sensors. Throughout vehicle testing, the mock race, and the Michigan Sun Run, the team captured unrivaled quantities of data. To provide context for this data, the team utilized Hibi to log the data collected by the MS-80S. During the eventual analysis of Aevum's readings, the information from Hibi could be used to potentially explain inconsistencies in any data collected through the weather.

Figure 4. *Image of MS 80S outfitting for Route Survey*

Hibi Integration and Uses

In tandem with the MS-80S Pyranometer, the team used EKO's S-Series Pyranometer Software, Hibi. Its easy integration and user interface allowed for the connection to the MS-80S. Constantly updating to reflect the current environment, Hibi allowed for the visualization of variance in irradiance. Even during the brief shading from driving beneath trees, Hibi immediately showed the dip in irradiance. Hibi's dashboard and graph made it possible to continuously monitor changes in irradiance, as well as other general parameters like temperature and humidity.

Additionally, its data collection functionality allowed for the easy collection of data – presenting it in a readable, usable format. Setting up Hibi and integrating it into the caravan was also extremely simple, and the software itself is easy to use.

Future Avenues of Exploration

Given the incredible benefits found through the use of the MS-80S, there is great potential for the further integration of other EKO products into the team's race equipment. These could include the MS-90+ Solar Monitoring Station, MS-57 Pyrheliometer, ASI-16 All Sky Imager, and other similar technologies. The advantage of being able to visualize the sky without physically attempting to look at the weather above would be a huge advantage. Using a solar monitoring station to determine the optimal angle to point the array when halted at control points would increase the vehicle's power intake, and thus its charge and ability to obtain a faster race time.

Conclusion

From a high level, the support provided by EKO in the form of MS-80S Pyranometers has had a clear and incredible impactful on the team's race strategy. The setup was smooth and a wide variety of useful information was recorded covering irradiance and array efficiency. The team was effectively able to use the pyranometer along with Hibi to verify weather predictions, validate the array system's functionality, collect data, and make short-term strategic decisions to optimize the use of the solar car. The work thus far indicates a strong potential for future collaboration, potentially leveraging other EKO products to further the team's strategy, make more informed decisions, and ultimately obtain the fastest race time.