WHITE PAPER

Campbell Scientific Control Systems for Absolute Cavity Radiometer

Josh Peterson, Rich Kessler, Frank Vignola
University of Oregon

The University of Oregon Solar Radiation Monitoring Lab (UO SRML) recently upgraded the control system for its Absolute Cavity Radiometer (ACR) to a controller designed and developed by Campbell Scientific, Inc. This white paper describes the new system and summarizes several of the initial results.

The UO SRML is a regional solar radiation data center. The goal of the lab is to provide high-quality solar-resource data for planning, design, deployment, and operation of solar electric facilities in the Pacific Northwest, United States. The SRML began operation in 1975 with a simple need to understand the solar resource in the region. Since that time, it has developed into one of the premier monitoring networks in the country.

The SRML currently consists of 14 monitoring stations located in Oregon and Washington. Each of these stations has a variety of pyranometers and pyrheliometers of various makes and models. These instruments are used to measure the Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), and Direct Normal Irradiance (DNI). These three components of light are related through the component sum equation:

$$GHI=DNI\ Cos(SZA)+DHI$$

Where *SZA* is the solar zenith angle.

To maintain data quality, each of these sensors is calibrated once a year. For calibrations, the SRML uses an ACR manufactured by The Eppley Laboratory, Inc. The ACR makes a high-quality measurement of the direct normal irradiance. The calibration of the SRML ACR is performed annually at the National Pyrheliometer Comparison (NPC) calibration event held in Golden, Colorado. This ensures the calibration is traceable to the world reference standard.

A photograph of the ACR is shown in Figure 1. The ACR is a cylindrical type of device mounted to a two-axis sun tracker. The aperture of the instrument is directly facing the sun. At the back of the collimated tube is a thermopile sensor that is heated by the incident radiation.

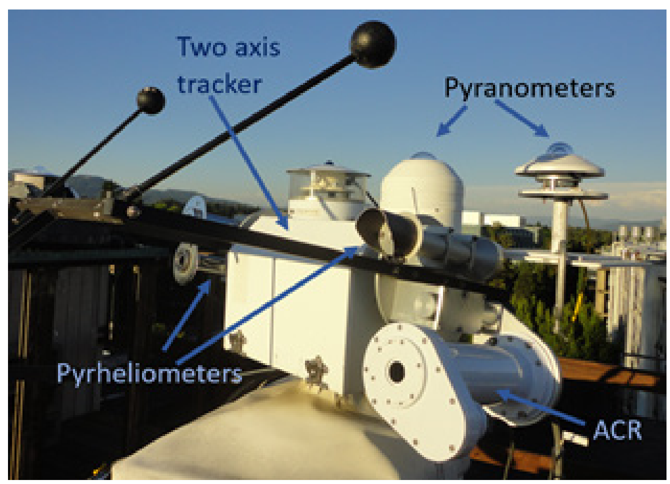

Figure 1. Photograph of the ACR during a calibration in Eugene, OR. The ACR is mounted on a two-axis tracker that follows the sun throughout the day.

The ACR is a self-calibrating instrument that is intermittently calibrated between trial runs. During the calibration process, a shutter blocks the light from reaching the thermopile sensor and the sensor is internally heated using a resistance heater. The electrical power requirements of the heater are recorded to determine a correlation between the thermopile temperature and power. Following the ACR self-calibration, the shutter is opened and the sensor again faces direct light, where the temperature of the thermopile is recorded. This is an active measurement technique, which is significantly more involved than simply recording the voltage signal of an instrument such as a traditional pyranometer.

The control system for the ACR consists of the following important features:

- A high-quality measurement of the output voltage from the ACR thermopile
- A control system to heat the ACR during self-calibration
- A timing mechanism to control the timing of the entire process
- A processor to compute various parameters
- A way to display and record the results

In previous years, the SRML operated the ACR using an external control unit. In 2019, the multimeter component of the control unit failed and the manufacturer no longer maintains the product.

We needed to find a suitable replacement controller. At this point, we contacted Campbell Scientific for assistance. The Campbell Scientific solution to these problems was an elegant, self-contained control unit. The heart of the control unit is a CR1000X datalogger. The data logger has the ability to control the timing of the opening and closing of the shutter and the turning on and off of the ACR internal heater. The data logger records the thermopile voltage and processes the data to convert voltages to solar radiation data, which is basically everything the multimeter and laptop did combined in the previous system [1].

The data logger, power supply, breakers, and other small electronics are all contained in a conveniently sized case. There are a number of communication options installed with easy access through connectors on the outside of the case along with all of the other cable connectors needed to run the system. The new system is significantly smaller and more portable than the previous system. A photograph of the new control system is shown in Figure 2.

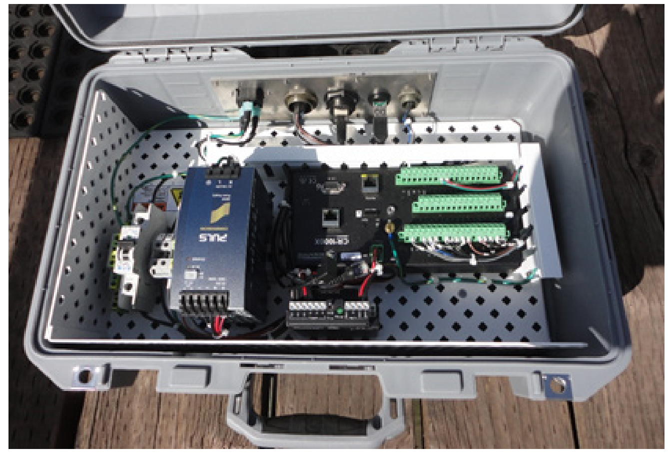

Figure 2. Photograph of the ACR control system. The CR1000X datalogger is located on the right side. The power supply for the heater is located to the left of the data logger. The connection ports are located at the top of the photograph.

To operate the ACR using the new system, Campbell Scientific's LoggerNet software program is started and the computer is connected to the CR1000X datalogger. Once the program is running on the logger, we open the Real-Time Monitoring and Control Software (RTMC) Run-time screen in LoggerNet. This screen allows us to adjust parameters such as start time, frequency of measurements, and timing of the calibration process. The RTMC also allows us to view the data that is being collected and stored in the data logger memory. While the data logger program is running, data can be sent to a file stored on the laptop computer as it is being recorded.

Screenshots of the setup screen and Run-time screen are shown in Figure 3. The new system is user-friendly and intuitive, making it very useful. Also, the primary control parameters are all adjustable from these two control screens.

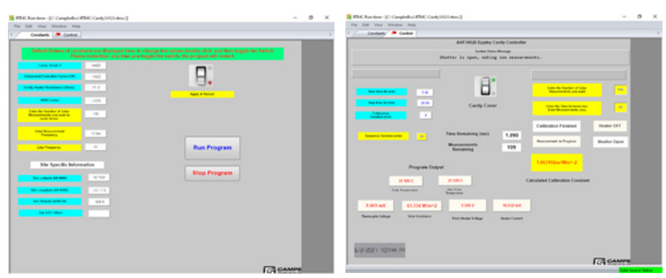

Figure 3. Screenshots of the RTMC Run-time control screens. The first is the initial setup screen. The second is the main display used during operation. Note that the irradiance is directly displayed to the user.

With the new system, a slight modification of the program would allow operation of the ACR without the use of the laptop computer. However, this would not allow visualization of the data in real time. Real-time data visualization is critical to ensure that the calibration is going as planned.

The goal of a calibration is to determine the responsivity of an instrument. The output of the pyranometer is compared to the output of a reference instrument. In this case, the reference instrument is the ACR. Because the ACR now has a new control system, the values output by the ACR are not guaranteed to be the same as they would have been with the previous system.

The responsivity of the instrument being calibrated is determined using the following equation:

$$R=\frac{V}{DNI_{Ref}}$$

Where R is the responsivity of the instrument being calibrated. The responsivity is the conversion factor between light and voltage with units of $V/(W/m^2)$. V is the millivolt signal from the instrument being calibrated. DNI_{Ref} is the reference DNI value from the ACR.

The responsivity of the instrument is computed from 10-second data when the sun is at a zenith angle range of 42.5–47.5°. The responsivity of the instrument is the average of all the measurements in the zenith angle range. The responsivity of a pyranometer can be determined using a shade/unshade calibration technique. Further details of how calibrations are performed are beyond the scope of this paper. See reference 2 for more details.

The results of the first trials of the ACR with the Campbell Scientific control system are presented in Figures 4 and 5. Results prior to 2021 are for the previous control system. The instruments used in this calibration were quite stable, meaning that the responsivity of the instruments does not change significantly from year to year. In this initial round of testing, the SRML was looking to see if the responsivity of the instrument was the same using the new control system compared to the previous system. Since the calibration results using the new control system match the previous calibration results, this implies that the new control system is producing results similar to the previous system.

In September 2021, we plan to attend the International Pyrheliometer Comparison (IPC). This event is held every five years and will be the true test of the ACR with the Campbell Scientific control system. The comparison of the ACR with the world reference standards at the IPC will provide an exacting test of the new Campbell Scientific control system.

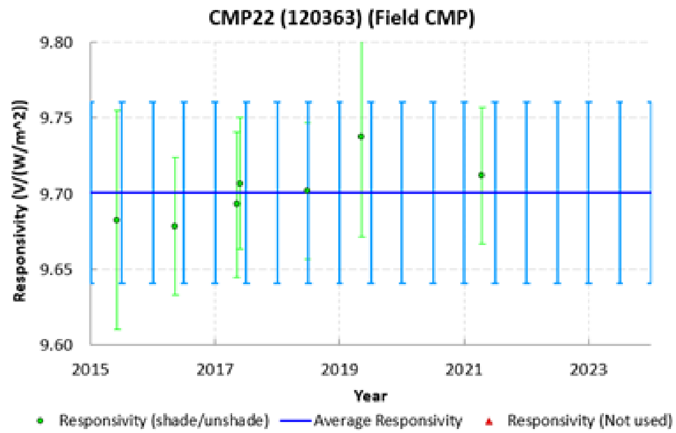

Figure 4. Plot of responsivity of CMP22 vs time. The CMP22 is a pyranometer that makes a measurement of a large field of view. To calibrate a pyranometer, the calibration is performed using a shade/unshade calibration technique.

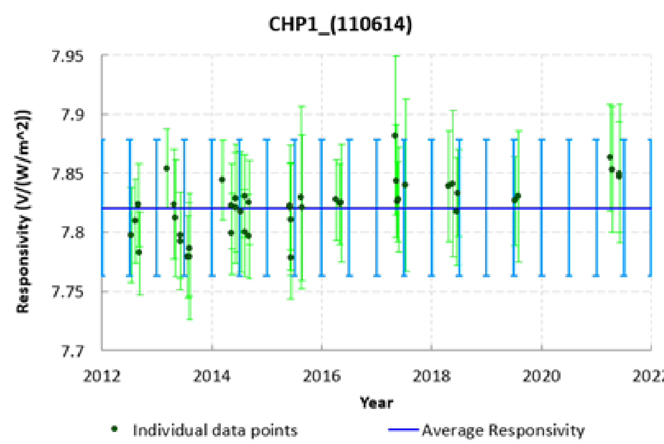

Figure 5. Plot of responsivity of CHP1 vs time. The CHP1 is a pyrheliometer that makes a direct normal measurement. A comparison with the ACR can be made directly as both instruments measure DNI.

References:

1. Singh, A., & Perry, M. (2016). Development of a new controller for absolute cavity radiometer for cavity calibration and solar irradiance measurement. *2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC)*, 1013-1015.

2. Vignola, F., Stoffel, T., & Michalsky, J. (2019). Solar and Infrared Radiation Measurements, Second Edition (2nd ed.). CRC Press. https://doi.org/10.1201/.