Sunfleck Quantification Method and Apparatus*

by

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Background

"Sunflecks are brief increases in solar irradiance that occur in understories of an ecosystem when sunlight is able to directly reach the ground. They are caused by either wind moving branches and/or leaves in the canopy or as the sun moves during the day. Although each sunfleck only lasts for seconds or minutes at a time, they can be responsible more than 80% of the photons that reach plants in the understory, and up to 35% of carbon fixation. This makes them important sources of energy for plants in the understory of forests. The amount of energy that a sunfleck provides depends on their duration, size and shape and the intensity of photosynthetically active radiation (PAR), which itself depends on the arrangement of vegetation in the canopy and the position of the sun in the sky." [1]

Background—Prior Art

In U.S. patent 4,678,330, Gutschick et al. [2] show an apparatus and method for measuring solar radiation received in a vegetative canopy. They attach light sensors to leaves of plants and report the intensity of PAR solar radiation received at each leaf. While this apparatus can measure the amount of light at a leaf, attaching a sensor to a leaf necessarily changes the leaf's orientation and position, thereby introducing an error in the measurement.

In U.S. patent application 2005/0030526 A1 [3], Tanaka shows a system for mobile measurement of a photo environment. The system uses a plurality of photosensors to capture light data arriving at the photosensors from different directions. These data are recorded for later study.

A hand-held commercially available device measures the amount of PAR light that is intercepted by a canopy. The device comprises a hand-size instrument case with controls and readout and a sensor probe that extends approximately 34 inches from the case. A remote sensor probe is also available. The Model LP-80 “Canopy Interception and Leaf Area Index” device is available from The METER Group of Pullman, Washington, USA. While the device measures PAR light, it does so with a linear array of photosensors or a spot sensor and therefore does not simultaneously measure light over a predetermined area.

Summary

Accordingly I have devised a system, method and apparatus that greatly improves over the prior art. My system comprises a camera comprising at least one image sensing input that collects and reports both PAR and full visible spectrum image data over a region of interest (ROI). Sunflecks shine on a canopy floor and their intensity, wavelengths, positions, and motion are sampled by a rapidly and periodically moving reflector that is viewed by the camera. The sunfleck data are then saved in computer memory for analysis by image recognition software. The responses of plants such as sun tracking, shape changing, color change, flowering, fruiting, growth, etc. are also recorded. A spherical reflector enables recordation of the azimuthal angle of the sun for use in normalizing light reflected from a moving reflector. An optional, ground level camera captures an elevational view of the scene in and around the ROI.

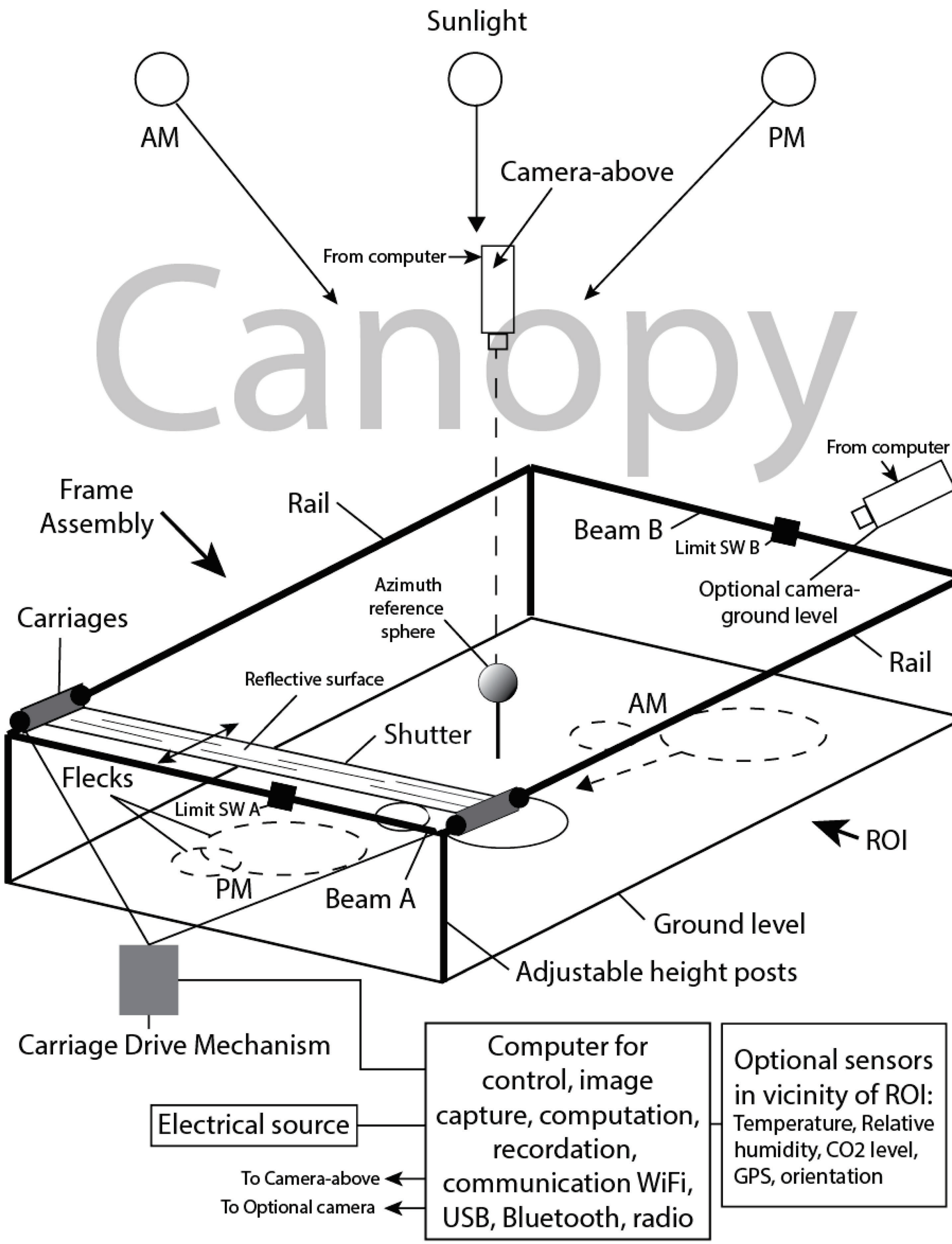


Figure 1. A sunfleck quantifying apparatus according to one aspect.

Apparatus

Figure 1 shows an aspect of an embodiment of the present apparatus. A frame assembly defines an ROI on a canopy floor. The frame assembly can range in size from a few centimeters (cm) to several meters (m).

The frame assembly comprises a plurality of posts, rails, and beams that are rigidly joined, as shown. The posts are of adjustable height to accommodate the height of plants in the ROI as well as unevenness in the canopy floor. The height of a post can vary between a few cm to a m, depending on the height of plants within the ROI.

A shutter assembly comprises at least a pair of carriages and a flat shutter plate. A flat shutter plate comprises a rigid bar of width between about 1 and 3 cm, and length equal to the width of the frame assembly. The shutter plate is rigidly connected to and supported by a pair of carriages that are arranged to travel along a pair of rails. A Carriage Drive Mechanism (CDM) comprises a motive force such as a motor and a linkage such as a drive cable that is connected to the carriages and is arranged to move the carriages upon command by a computer. A pair of limit switches, SW A and SW B, are parts of the CDM and signal the Computer when the shutter assembly reaches beams A and B, respectively, when urged by CDM under control of the computer.

The upper surface of the shutter assembly is coated by a white, diffuse reflective coating that reflects light, in this case sunlight, in all directions. Such coatings are well-known to those skilled in the art of optics. A typical coating is “6080 White Reflectance Coating” manufactured by Labsphere, Inc. of North Sutton, NH, USA.

A camera is preferably positioned above the center of the ROI and records all events of interest within the ROI when actuated and activated by the computer for control and image capture. The height of the camera above the ROI is about equal to the diagonal dimension of the ROI, although other heights can be used. A typical camera useful in this application is the Model GS-3-U3-51-S5C-UC, sold by Point Grey Research, now

Teledyne FLIR of Wilsonville, Oregon, U.S.A. This camera has full, high dynamic range color capability and connects to a computer through USB or other ports. The camera has a lens suitable for capturing the entire ROI with minimal spatial distortion.

An Azimuth Reference Sphere (ARS) is positioned directly beneath the camera. The ARS is supported by a post at a height that will be cleared by the shutter plate as the plate moves between beams A and B. The ARS surface is a specular reflector.

Although a rectangular ROI is shown, other shapes such as circular can be used.

Operation

A moving reflector, the shutter, shown in Figure 1, is mounted on a frame that spans the area of interest. The shutter is carried by the carriages and moves on the rails as it passes over the ground area being observed. The reflector is narrow, i.e., a few cm, and it moves rapidly from beam A to beam B so as to minimize blocking of sunflecks that would otherwise illuminate the plants in the ROI. The shutter plate traverses the ROI every 30 seconds, although other times can be used.

The overhead camera continuously captures an image that includes the ground level understory plants in the ROI, and the reflecting surfaces on the shutter plate and azimuth reference sphere. The optional ground level camera captures changes in plant height and the angles of tilt of plants as they move in response to sunflecks and other stimuli such as moisture, etc.

The diffuse reflection of light from the upper surface of the shutter is used in quantifying the intensity, wavelength, and angular position of sunflecks relative to the ROI. An explanation of the properties of diffuse reflection is available in a Wikipedia article at https://en.wikipedia.org/wiki/Diffuse_reflection.

Figure 2A. Still from video showing shutter motion.

Video showing shutter motion at: https://paedia.com/Docs/MOVING_REFLECTOR.mp4

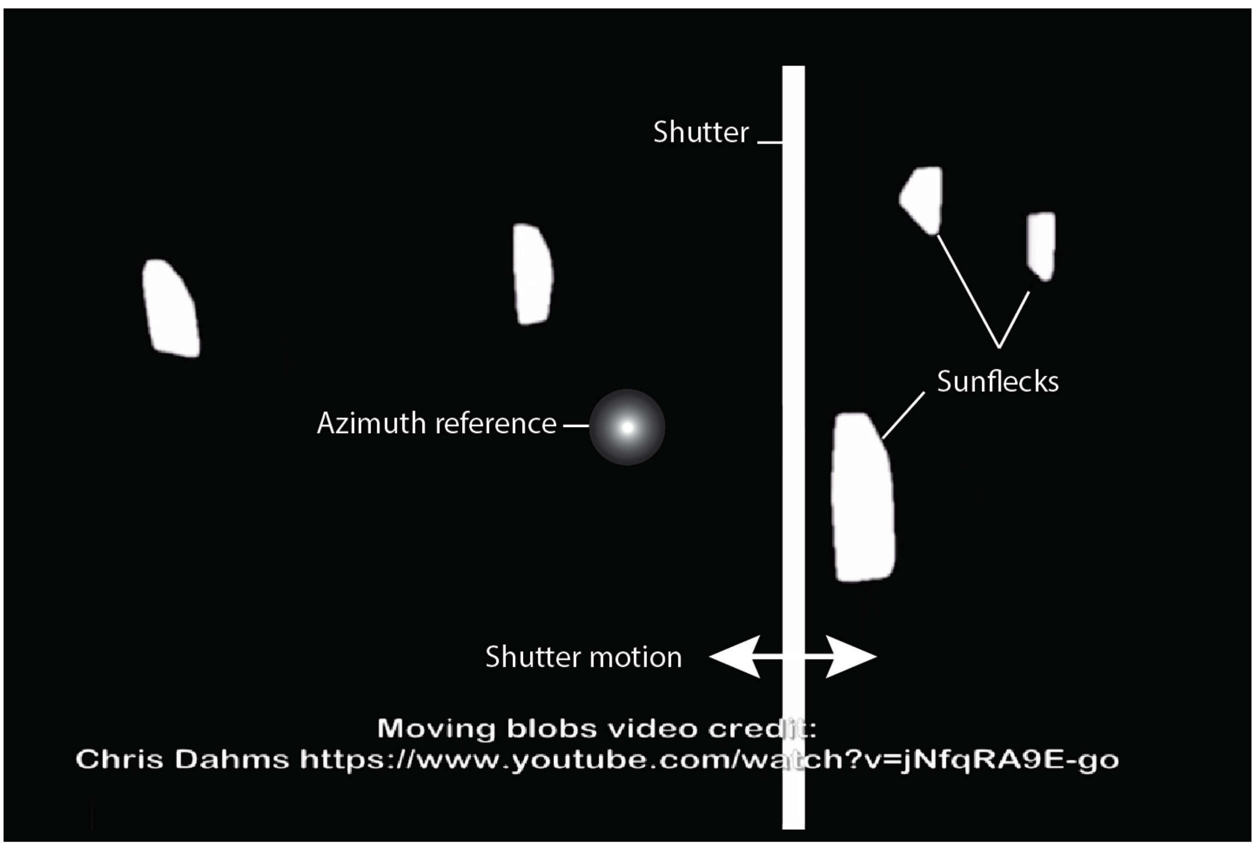


Figure 2B. Shutter and Azimuth Reference Sphere.

The Azimuth Reference Sphere (ARS)

An ARS used in the present application has diameter between 6 and 12 cm, although other dimensions can be used. The ARS has a specular reflective surface, i.e., a mirrored surface. Instead of a sphere, a half-sphere can be used.

Figure 3 shows a plan view of an ARS as seen by the camera that is positioned above the ROI. The reflection of the sun appears as a bright area on the reflective surface of the sphere.

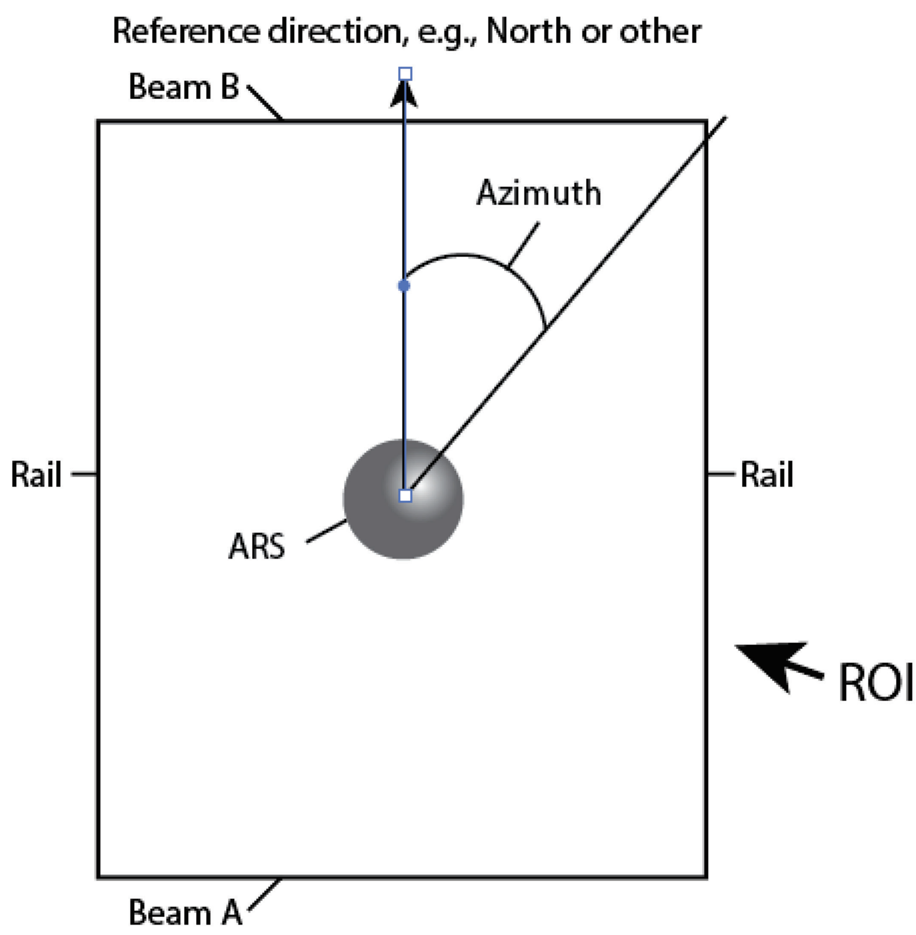


Figure 3. Plan View of ROI and ARS.

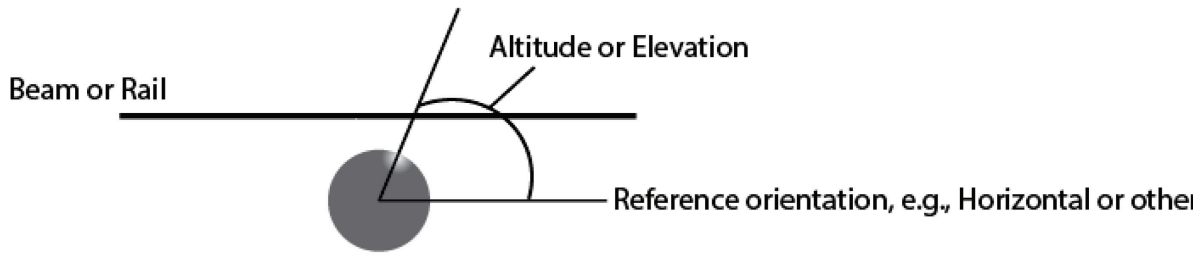


Figure 4. Elevation View of ROI and ARS.

The orientation of the sun relative to the ROI is given by the azimuth and altitude or elevation obtained from these two views. These coordinates are described in detail in a Wikipedia article at https://en.wikipedia.org/wiki/Azimuth. (Credit to the Wikipedia Azimuth page for the illustration below.)

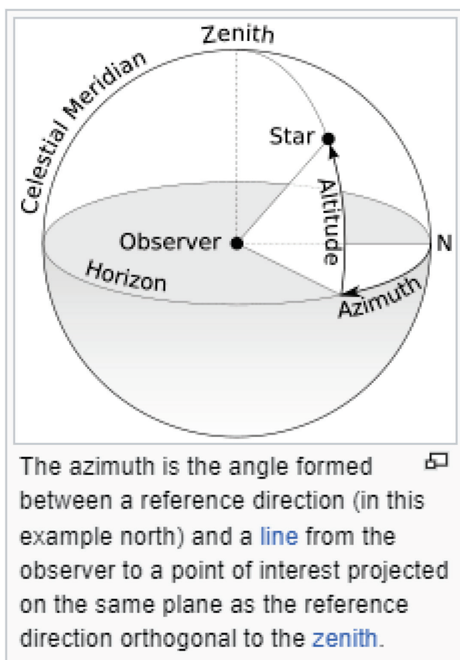


Figure 5. Azimuth Definition

A reasonable approximation of the position of the sun is obtained from the view of the ARS in Figure 3. If the reference direction shown in Fig. 3 is North, Azimuth is represented by the vertical position of the sun's reflection on the ARS and Altitude or

Elevation is represented by the horizontal position of the sun's reflection on the ARS, relative to the center of the ARS, i.e., the position of the Observer in the above figure.

In the present aspect, these coordinates are determined by image analysis of the appearance of the ARS. The position of brightest spot on the ARS is noted along with an a priori knowledge of the orientation of the ROI relative to geographic North.

The Shutter

Figure 6 shows an arrangement including the sun, a shutter, and a camera. The diffuse reflecting surface of the shutter reflects a portion of light from sunflecks into the camera. The intensity of light reflected from the shutter depends on the angle of illumination of the shutter by the sun and the angle between the shutter and the camera. A resultant angle is the sum of these two.

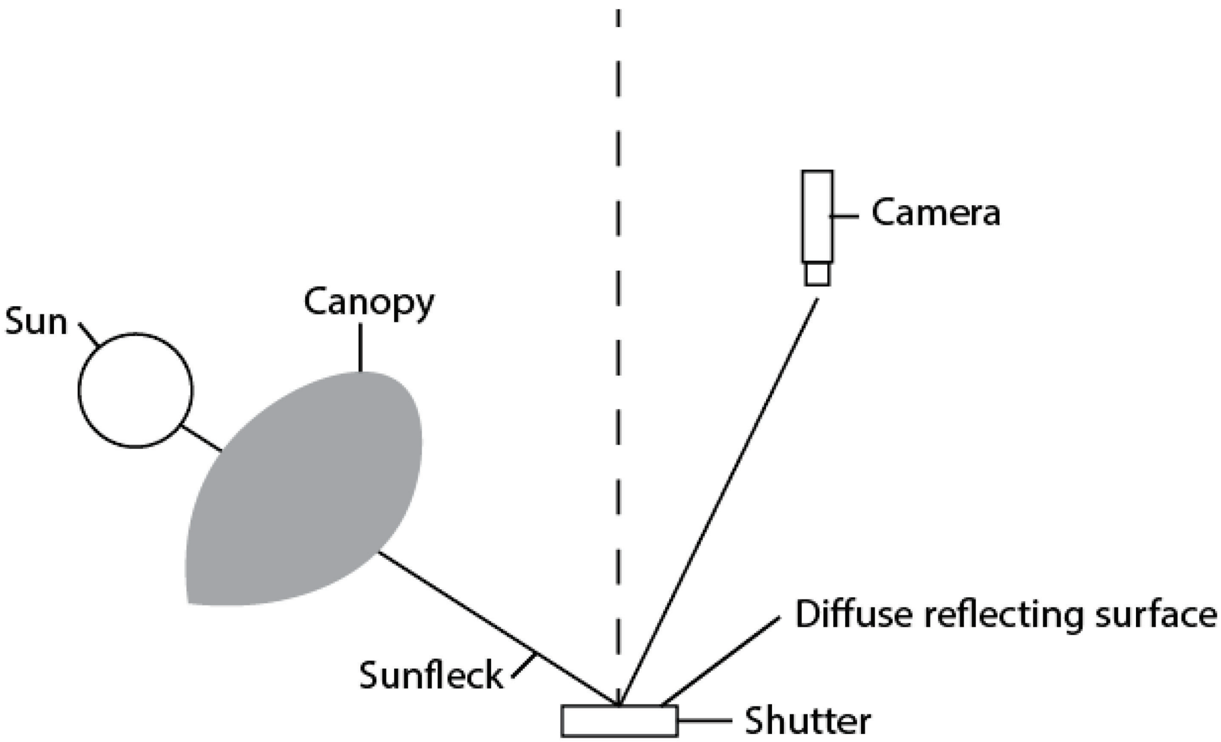
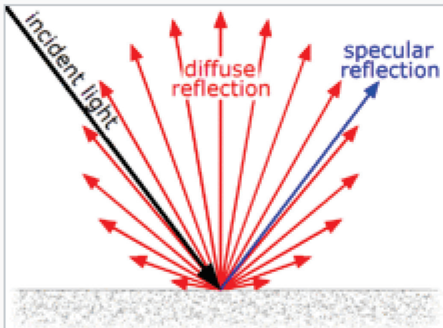


Figure 6. Reflection from a shutter.

A third angle occurs because of the relative positions of the camera and the positions of sunflecks along the length of the shutter as they are intercepted by the shutter. These angles are determined by simple geometry. Each of these angular offsets reduces the amount of light reaching the camera. The amount of light reaching the camera can be determined by a one-time calibration procedure that provides correction factors derived from the position of the sun and position and angle of the shutter for each point in the ROI. Thus the light intensity from all sunflecks within the ROI is accurately recorded.



Diffuse and specular reflection from a glossy surface.[1] The rays represent luminous intensity, which varies according to Lambert's cosine law for an ideal diffuse reflector.

(Credit: https://en.wikipedia.org/wiki/Diffuse_reflection)

Figure 7. Diffuse reflection.

A Flow Chart for Recordation of Sunflecks

The flow chart in Fig. 8 depicts a typical recordation of sunflecks. At the Start, the computer (Figure 1) is turned ON and a data collection and control program is started. Under program instructions, the CDM moves the shutter toward Beam A. This action continues until the shutter is at Limit Switch A. At that time, the computer program causes the overhead camera to begin recordation. A typical video frame rate for recordation is 25 Hz. Any other optional sensors are actuated at this time and typically take a single reading, although any number of readings can be taken. Next, the CDM moves the shutter toward Beam B at a predetermined speed, such as 0.1 m/s, although other speeds are used. The overhead camera continues recording the scene in the ROI until the shutter reaches Beam B, actuating Limit SW B. At this point, the CDM is instructed to stop shutter movement and recordation by the overhead camera is then stopped. A delay of 10 seconds to several minutes ensues while sunflecks move an incremental amount. After the delay, the camera is started again, sensor readings (if any) are recorded in the computer's memory, and then the shutter is moved toward Beam A at the same predetermined speed as before, although other speeds can be used. The overhead camera records the scene in the ROI, including sunflecks reflected from the shutter, until the shutter reaches Limit SW A at Beam A. At this point, the CDM is actuated and stops shutter movement. The camera is stopped as before and another delay, preferably but not necessarily the same as the previous delay. At any time, the program in the computer can be interrupted with a HALT signal by pressing a key on the computer's keyboard or other such signal. If such a signal has been received, the computer program stops issuing motion-recording signals and enters a STANDBY state. If no such signal has been received, the data-recording process continues as above.

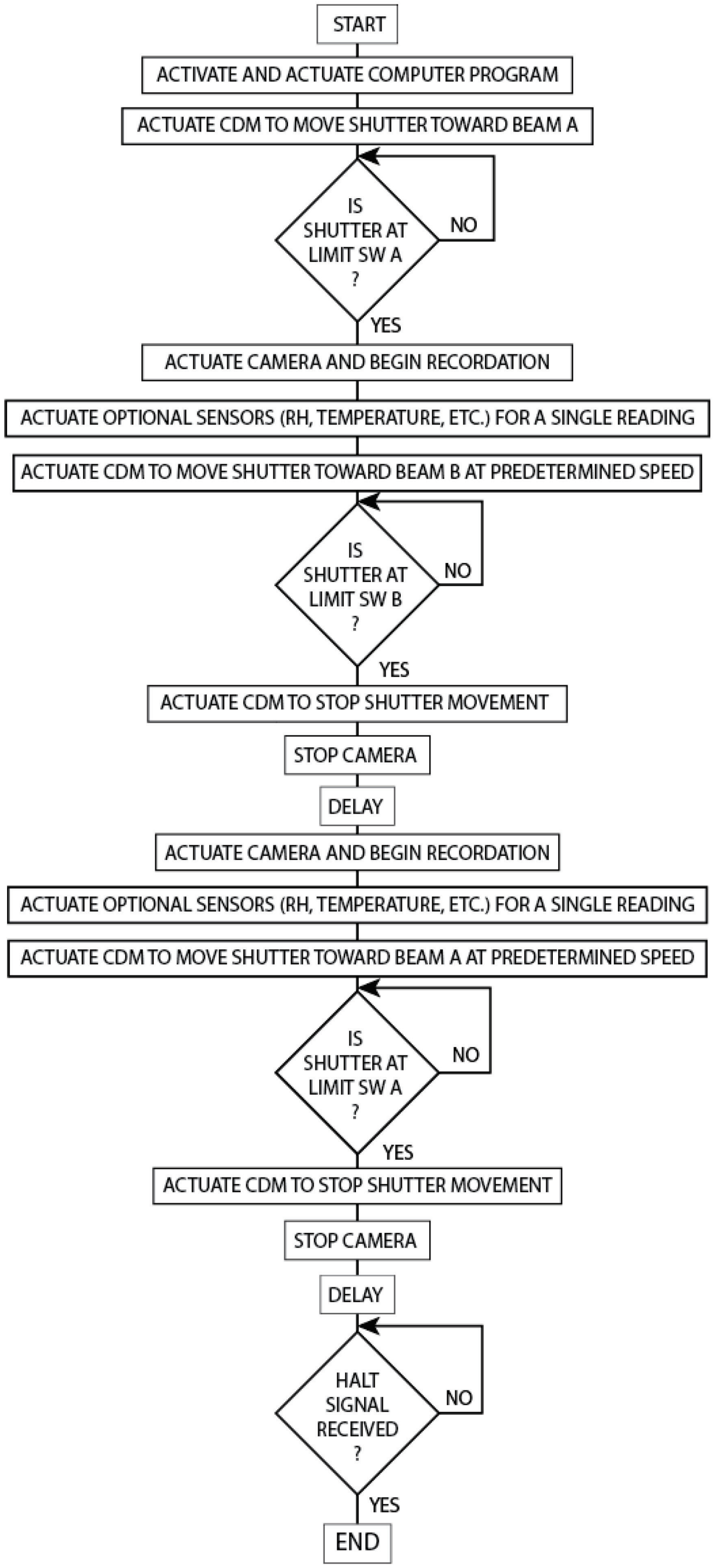


Figure 8. Flow Chart showing aspects of data acquisition.

Image Analysis

Data are saved in a computer memory. A video file containing images from each traverse of the shutter from Beam A to Beam B is a data set. The camera identified above has a resolution of 2448 x 2048 pixels. Each pixel has a dynamic range of 8 or 12 bits. If the 2448 x 2048 pixels are spread over one ROI, each video frame contains 5 megapixels (Mp) of data. The intensity of light reaching the camera from each position in the ROI is normalized using azimuth and elevation data from the ARS, as described above.

Data analysis follows aspects of the software code in a YouTube video at: https://www.youtube.com/watch?v=jNfqRA9E-go. Sunflecks are reflected from the shutter and received by the camera. In each video record of a shutter traverse, sunflecks are identified as objects having location, size, color, and intensity. An image of the plants in the ROI is also saved as a record of the size, shape, color, appearance, etc. of the plants at each shutter traverse, in order to show the effects of sunflecks on the plants.

***Disclaimer**

Some aspects of the present apparatus and method are the subject of research and development and as such are not guaranteed to work as described. Further work is ongoing and will be the subject of future disclosures possibly including patent applications and publications.

References

[1] Chazdon, R. L.; Pearcy, R. W. (1991). "The Importance of Sunflecks for Forest Understory Plants". BioScience. **41** (11): 760-766. doi:10.2307/1311725. JSTOR 1311725.

[2] U.S. patent 4,678,330 to Gutschick et al. https://paedia.com/Patents/US4678330.pdf

[3] U.S. patent application 2005/0030526 A1 of Tanaka.
https://paedia.com/Patents/US20050030526.pdf

See also:
https://en.wikipedia.org/wiki/Sunfleck ,

Brelsford, Craig (ca. 2016) “A timelapse of plant responses to sunflecks”
https://vimeo.com/168177935
and
Matthew Robson’s Research Group Pages (2023) “Canopy Spectral Ecology and Ecophysiology”
https://blogs.helsinki.fi/robson/ .