Plant Physiol. (1973) 51, 812–814

Short Communication

Modified Photoelectric Device for Recording Leaf Movements[1]

Received for publication October 26, 1972

T. W. TIBBITTS, G. D. NUTTER,[2] T. HOSHIZAKI,[3] AND R. R. BADEAU[2]
Department of Horticulture, University of Wisconsin, Madison, Wisconsin 53706

The description of a photoelectric device for monitoring leaf movements was published previously (5). This instrument eliminated physical attachment of sensors to the plant and provided a direct readout of up and down movements of leaves during light periods. The equipment has been modified to monitor rotational movements of the leaf about its longitudinal axis while simultaneously monitoring up and down movements. In addition, the servo-actuating incandescent radiation source has been replaced with a modulated infrared source to assure that radiation originating from the leaf monitor does not influence leaf movements and to permit the recording of leaf movements during periods of darkness, as well as during periods of light. Samples of recordings obtained with it are described.

PRINCIPLE OF OPERATION

Sensing Up and Down Leaf Movements. The device operates with a beam of infrared radiation directed across the leaf into a matched pair of detectors as shown in Figure 1. The detectors consist of two rectangular photocells placed end to end, between which the center of the shadow of the leaf is held via the servo system.

The infrared emitter is a gallium arsenide infrared light emitting diode (Monsanto ME 2), having a very narrow spectral band of emitted radiation with a peak emission wavelength of 900 nm. This near infrared wavelength was chosen to eliminate phototropic effects (of the sensor-activating light) on the leaf being monitored. The intensity of the emitted radiation is electrically modulated at a frequency of 60 Hz for the purpose of separating its signal from that caused by ambient light, as well as to provide a convenient drive for the servo system. Modulation reduces ambient light effect, since most ambient light appears as a steady state or dc signal on the detector, while the flicker of artificial overhead lighting driven by 60 Hz current appears as 120 Hz on the detector. Both dc and unwanted 120 Hz signals are electronically separated from the 60 Hz emitter signal. The system design originally contemplated the use of a frequency that would not coincide with 60 Hz or it's harmonics, to eliminate possible interference; this precaution turned out to be unnecessary in this instance.

To eliminate possible photothermic effects due to heat dissipated by the diode, the light-emitting diode is located some distance away from the plant, and its radiation output is directed through a 25 cm length of bifurcated fiber optics (Electro Fiberoptics Corp. Type 2), as shown in Figure 1. The radiation beam is then collimated and projected onto the two silicon photocells (Centralab 52 C). The two cells are connected with opposing polarities to the preamplifier. A leaf of the plant is positioned in the center of the yoke with the tip of the leaf just below the bottom of the detector housing, so that the leaf is tracked near its tip, as shown in Figure 2. The pulvinus at the blade and petiole junction is aligned with the axis of rotation of the yoke. The yoke is adjustable to accommodate leaves of from 2 to 5 cm in length and from 1 to 4 cm in width. It is operated with about 2 cm extra width on each side of the leaf to allow for any sidewise movement of the leaf.

When each sensor receives equal infrared signal radiation, the summed output of the preamplifier (Fig. 3) is zero. When the leaf moves slightly off-center, one detector receives more radiation than the other, and the summed output of the preamplifier becomes a 60 Hz sine wave. This error signal is amplified by the power amplifier and then drives the motor in a direction determined by the phase of the signal. The yoke revolves until the leaf is again centered, under which condition the servo drive signal drops to zero. Due to the summing of the two detector signals, the ac component of ambient light acts as a common mode signal and is cancelled out as long as it falls equally on both detectors. The servo system is phase-sensitive and does not respond to the dc component of ambient light. The yoke rotates a maximum of 150° at 0.5°/sec. The movement of the yoke is monitored by a potentiometer geared to the shaft. The instrument is able to track leaf movements (up and down) as small as 0.5 mm.

A stop-switch was incorporated to keep the instrument from locking on the plant stem when the leaf is in its down position, and the servo-action is automatically resumed when the leaf comes back up within range of both detectors.

Sensing Rotational Leaf Movements. Sensing rotation of the leaf about its longitudinal axis is accomplished by monitoring the detector signal corresponding to the width of the leaf shadow. The detectors are rectangular (0.5 cm × 2.0 cm) to accommodate large variations in shadow width. Since the signal present on each detector is proportional to the amount of modulated infrared radiation it receives, this signal represents the rotational position of the leaf. The output signal amplitude of one of the preamplifiers is detected by first filtering to remove any 120 Hz signal component due to room light, and then rectified and displayed as a dc recorder output.

The 120 Hz signal component could have enough amplitude

[1] The research was supported by Grant 50-002-109 from the National Aeronautics and Space Administration. Computing assistance was obtained from the Health Sciences Computing Facility, University of California Los Angeles sponsored by National Institutes of Health Social Research Resources Grant FR-3. Published with permission of the Director, Research Program Division, College of Agricultural and Life Sciences, Madison, Wis.

[2] Present address: Instrumentation Systems Center, University of Wisconsin, Madison, Wis.

[3] Present address: Space Biology Laboratory, University of California, Los Angeles, Calif.

to be quite troublesome, since the output from only one detector is being observed, and there is no common mode rejection of this unwanted signal. However, the notch filter incorporated in the electronics (Fig. 3) adequately removes the 120 Hz component for illumination of 1.4×10^{-3} watts/cm^2 (900 ft-c). This 120 Hz component could have been removed with an optical bandpass filter, since it occurs mostly in the visible spectrum, whereas the true signal is in the near infrared. Electronic filtering was chosen here for its lower cost.

Sensitivity and linearity can be enhanced by simple masking of the edge and ends of the detector. Linearity of leaf rotation sensing is typically adjusted to within 5%, while repeatability is typically better than 1% which is more than adequate for the present application.

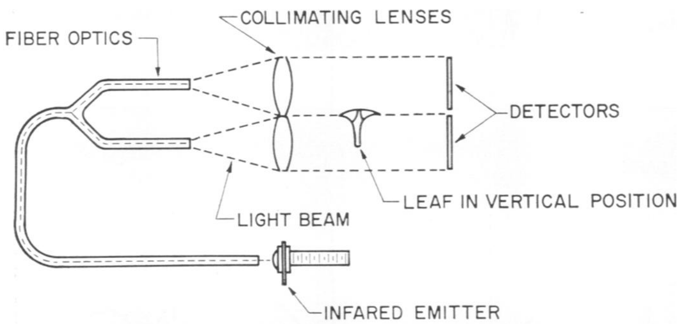

FIG. 1. Diagram of the optical system.

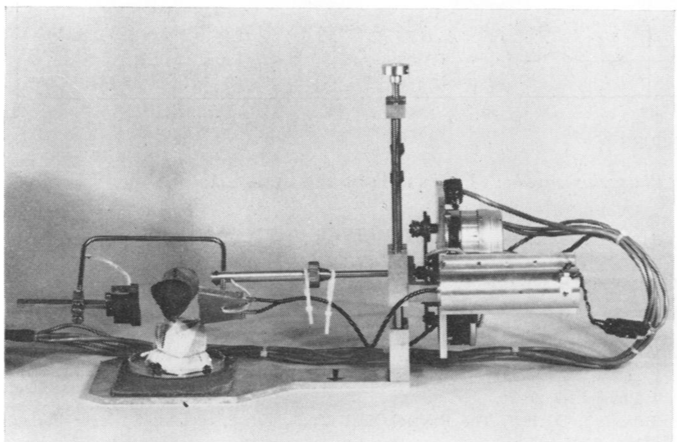

FIG. 2. Leaf movement sensing unit positioned on leaf showing optical system, adjustable yoke and servo-drive with wires leading to preamplifier.

LEAF MOVEMENTS

The instrument will effectively track the movements of bean leaves and provide a simultaneous recording of both up and down movements and rotational movements. The movements of primary leaves of two *Phaseolus angularis* plants over a 48-hr period are shown in Figure 4. The plant in A was grown in continuous light, and recordings were made in this light. The plant in B was grown in continuous light but placed in the dark at the start of the recording. The leaves exhibit a dominant up and down oscillation of slightly more than 27 hr (circadian period) that is well documented in the literature and recognized to be endogenous to the plants. A discussion of circadian movements can be found in a previous publication of Alford and Tibbitts (2) or in books by Bunning (3) and Sweeney (4). During the "down" movement, the follower was set to stop as the leaf reached about 20° from the vertical, so that the follower would not sense the stem or the opposite leaf.

The rotational movements were quite regular during the continuous light recordings and had oscillation periods of 35 min to 1 hr. The leaf usually rotates to the left and then to the right, so that a complete oscillation involves two peaks on the graph. No dimension for this movement is indicated, for as the leaf enlarges, the amplitude of the output signal increases, even though the amount of angular movement may be the same. Previous measurements have indicated that the angular movement averages about 20° in each direction. With plants placed in the dark, the rotational movements disappeared quite rapidly and did not exhibit the regular motions observed in the light. Some rotational movement was recorded during the "down" phase of the leaf, because this particular leaf did not move all of the way to the stem, and the edge of the leaf partially covered the sensor in its stopped position. Rotational movements are described in detail in a recent publication (1).

The reliability of the system was checked by mounting and

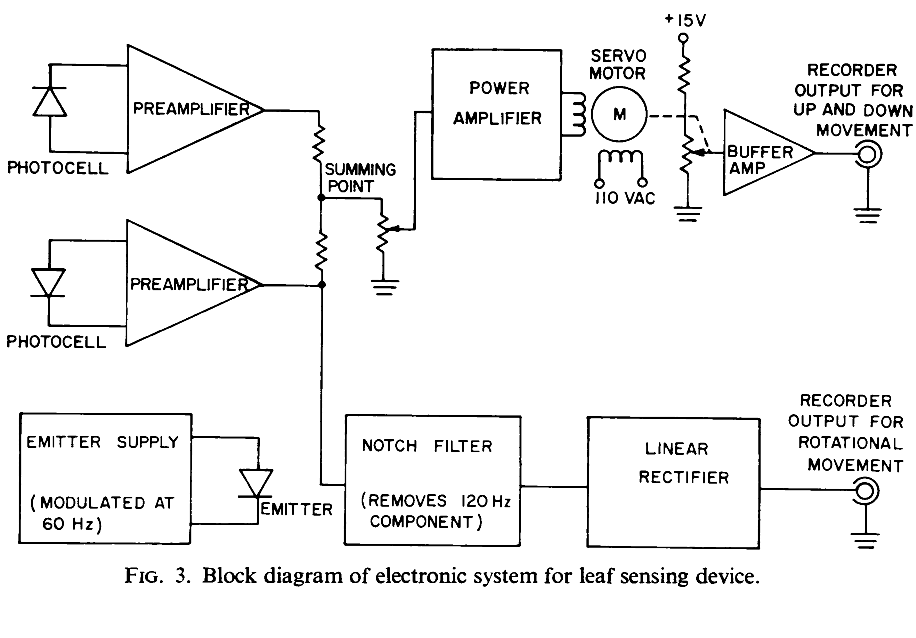

FIG. 3. Block diagram of electronic system for leaf sensing device.

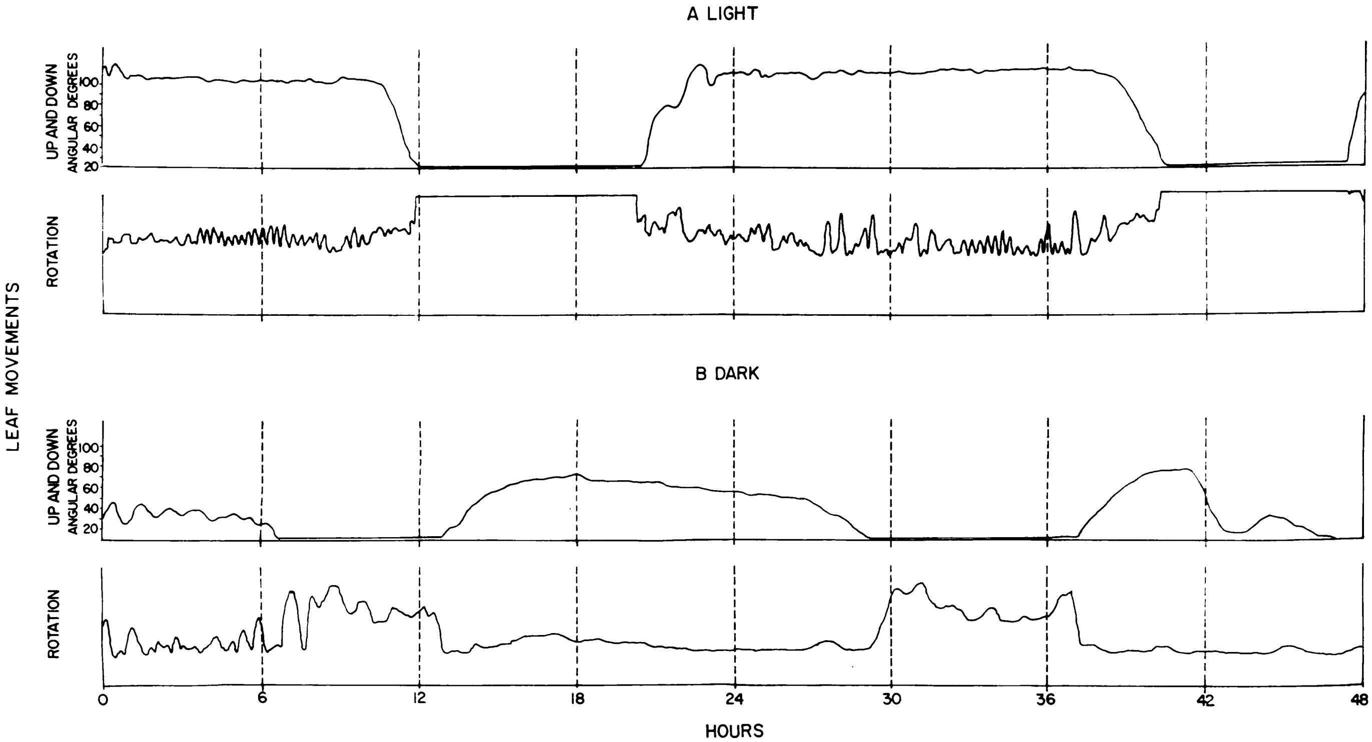

FIG. 4. Up and down and rotational movements of *Phaseolus angularis* leaves in light and in dark.

positioning a cardboard leaf within the yoke and recording the output for 24 hr under both illuminated and dark conditions. The recorder output was uniform and exhibited no oscillations in either output. There was less than a 2% reduction in detector signal as the lights were turned off.

The 900 nm of radiation, as emitted by the gallium arsenide light source, provided an effective waveband for use with leaves of *Phaseolus*, for there was no evidence of phototropic response to the signal, and less than 5% of the signal was transmitted through the leaf when leaves were placed perpendicular to the light source and shadowed the detectors completely.

LITERATURE CITED

1. ALFORD, D. K. AND T. W. TIBBITTS. 1970. Circadian rhythm of leaves of *Phaseolus angularis* plants grown in a controlled CO_2 and humidity environment. Plant Physiol. 46: 99–102.
2. ALFORD, D. K. AND T. W. TIBBITTS. 1971. Endogenous short period rhythms in the movements of unifoliate leaves of *Phaseolus angularis* Wight. Plant Physiol. 47: 68–70.
3. BUNNING, D. 1967. The Physiological Clock, Ed. 2, revised. Springer-Verlag, New York.
4. SWEENEY, S. M. 1969. Rhythmic Phenomena in Plants. Academic Press, New York.
5. TIBBITTS, T. W., T. HOSHIZAKI, AND D. K. ALFORD. 1970. Photoelectric device for recording of leaf movements. Space Life Sci. 2: 109–112.