A New Instrument for Comprehensive Study of Infrared Remote Sensing of Physiological Properties of Vegetation Covers

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Abstract
An instrument to remotely study the physiological properties of vegetation canopy has been designed and developed. The radiometer is a passive microcontroller-based optoelectonics system, using series of multi-feedback band pass electronics circuits coupled to a 200 by 24 refracting system. The output is taken via an eight-readout 16 by 4 display console: 1. Reflectance RF1(at 430-450nm); 2. RF2 Greenness index(at 510-530nm); 3. RF3(at 730-780nm); 4. RF4 (at 630-650nm); 5. Fluorescence FL(at 660-680nm); 6. Chlorophyll Luminiscence CLM: 7. Vegetation Moisture VM and 8. Canopy Temperature VT. The radiometer has beeen radiant calibrated. The radiometer was tested and used to observe some stress-mediated physiological properties in vegetation canopy.Reults confirmed predictions in the literature.
Keywords: Instrument, Infrared Remote Sensing, Physiological Properties, Vegetation covers

1 Introduction

Several airborne or space-borne multispectral or hyperspectral sensors have been fabricated to measure the elctromagnetic radiation reflected or emitted from vegetation canopy. Data obtained from these have been found useful in deducing large-scale spatio-temporal distribution of vegetation and estimation of its biochemical properties as chlorophyll or leaf water content and leaf surface moistures or temperatures (Sader, 1987 : Malinovsky et al, 2009 : Iversion et al, 1989). These parameters amongst others have been known to serve as stress indicators in vegetation (Jago et al, 1999)).

Several techniques have been employed in the fabrication of these radiometers. These techniques have been found not only to be complex but in most cases measurements are infered or indirect. There is need for higher temporal, spatial, and spectral resolution in future radiometers. Higher spatial resolution may be possible with infrared detectors so that smaller signals can be measured with adequate signal to noise ratio (Menzel, 2002)). Adekolawole and Balogun (Adekolawole and Balogun, 2012)) reported a new technique that offers direct and accurate measurement of solar-induced infrared reflectance and fluorescence from vegetation canopy at relatively low-cost, low-powered, using simple elctronics circuits and filters.

This work reports the use of this new technique [6] to develop a micro-controller based multispectral radiometer that senses physiological parameters as reflectance, fluorescence, canopy surface moisture and temperature at eight spectral bands. Unlike the previous, having two readouts, the present device has eight readouts: all the physiological parameters as fluorescence, canopy moisture content, canopy surface temperature, chlorophyll luminescence as well as infrared reflectance at panchromatic wavelengths could be studied simultaneously from vegetation covers.

2.0 Methodology

All the materials used in this work were sourced from the local market.
After due considerations of the literature and data sheets, appropriate infrared transistor were selected for transducing the measurands: canopy reflectance, fluorescence, moisture and temperature into electrical signals. In previous work, infrared diode was used (Adekolawole and Balogun, 2012). All the electronics circuits employed were first designed and simulated, using the Proteus professional 07 for workability. The PCB layout was prepared using the selective chemical-etching standard method; the circuit boards for each segment of the work were thus made. All circuits were designed to have a common ground to minimize interference losses. The design segments consisted of three-stage amplification circuits; multifeedback band pass filters and; multiplexers. By writing appropriate programs using the 2011 WIN Programmer, the outputs of these were micro processed into eight required outputs via a 16 x 4 LCD display console, using standard techniques; Standard power stage was also provided. For portability and safety, a plastic casing was made of dimensions: 22.5cm x14.5cm x 6cm. The sensing head was protruded outside the casing and appropriately shielded to screen-off extraneous signals.

2.2 Calibration

As in Adekolawole and Balogun (2012), the calibration equations could be written as:

$V_Z = R_\lambda R_z + V_n$ ……… [1]

$V_{bb} = R_\lambda R_{bb} + V_n$ …….. [2]

Where

$R_\lambda = \frac{V_{bb-} V_z}{V_{bb-R_z}}$ ………….. [3]

Setting $R_z = 0$ in Equation [3],

Then,

$R_\lambda = \frac{R_{bb}(V_t - V_z)}{V_{bb-} V_z}$ ……… . [4]

From radiometric parameters of Multispectral Radiometer,

Responsivity, R_λ,

$R_\lambda = 1.67 \times 10^{18}$ V/W at 450nm
$= 1.9 \times 10^{15}$ V/W at 530nm
$= 3.1 \times 10^{18}$ V/W at 780nm
$= 2.02 \times 10^{18}$ V/W at 650nm
$= 2.46 \times 10^{17}$ V/W at 680nm
$= 2.36 \times 10^{19}$ V/W at 6563nm
$= 1.106 \times 10^{21}$ V/W at 10000 nm
$= 2.64 \times 10^{18}$ V/W. at 1750…………….[5]

Offset Voltage $V_0 =$ .01 volts.

Thus, From Equation 1,

$V_t = 1.67 \times 10^{18}$ (V/W) R_t + 0.01V

Or,

$R_t = \frac{0.01 + V_t}{1.67 \times 10^{18}}$W. at 450nm

i.e. $R_t = \frac{0.01 + V_t}{R_\lambda}$ ……………………..[6]

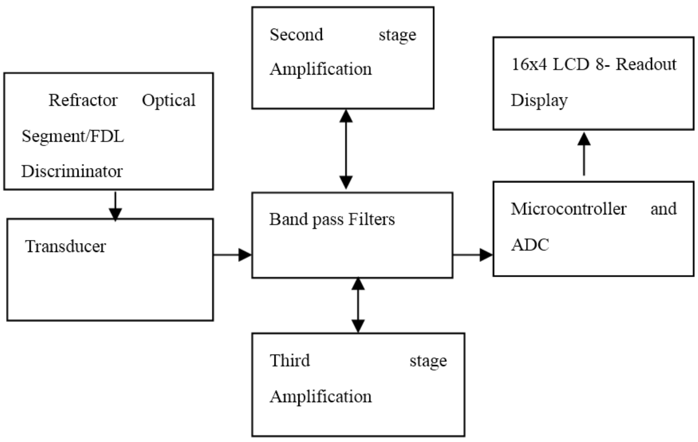

Figure 1: Block diagram of the Instrument (Adekolawole and Balogun))

2.3 Testing and Field Measurements

The fabricated radiometer was radiant calibrated (Adekolawole and Balogun, 2012) and tested, using it to study some physiological properties as solar-induced reflectance, fluorescence, canopy moisture and canopy temperature, amongst others of vegetation covers, nondestructively, within the peak tropical summer period of the month of August, 2013 six hourly daily intervals. The data obtained from the field measurements were analysed using the NDVI procedure in the literature and were illustrated on line graphs to observe and compare the spectral responses of the measurands under natural conditions.

3.0 Results and Discussion

The results of the comparative study of Solar-induced Canopy Reflectance (SIR) and Solar-induced Fluorescence (SIF) responses amongst others for *Pennisetum glaucum*, *Zea mays* and *Lycopersicum esculenta* under normal conditions of growth, were as discussed and shown below:

A (i) Responses of Solar-induced Canopy Reflectance from plants canopy

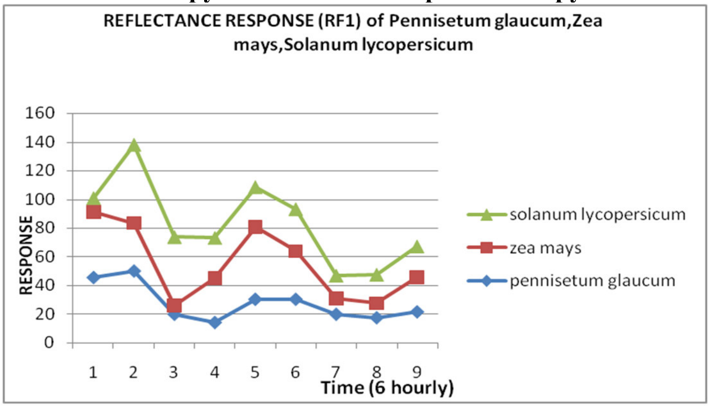

Figure 2: Graph of solar-induced reflectance (at 430-450nm) vs. Time (6 hourly)

Solar-induced Reflectance at the panchromatic (bluish) wavelengths, 430-450 nm, in Figure 2, is more intense in *Solanum lycopersicum* and least in *Pemmisetum glaucum*. Photosynthetic activity is more intense at the peaks observed at 2 and 5 which corresponds to readings taken at midday of bright sunny days but less intense in the morning and evening periods typified by the troughs at 1, 3, 4, and cloudy days.

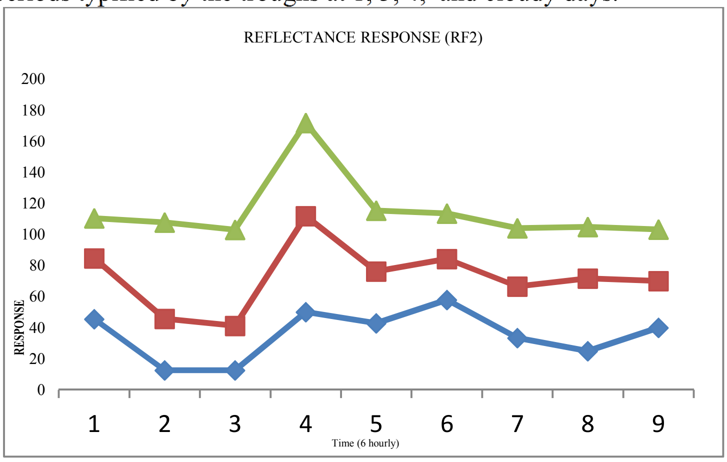

Figure 3: Graph of Greenness index (at 510-530nm) vs. Time (6 hourly)

Solar-induced Reflectance at the panchromatic (greenish) wavelengths, the greenness index at 510-530nm, in Figure 3, is generally pronounced but more in solanum lycopersicum and least intense, in Pemmisetum glaucum. This is consistent with the literature: Reflectance at the green wavelengths is very intense, hence plants exhibit green color. The difference in the greenness index could be due to the pigment characteristics of the individual plants, amongst others. The sharp peak could be due to the sunshine insolation/ hours.

A(ii). Responses of Solar-induced Fluorescence (SIF) from Plant canopy

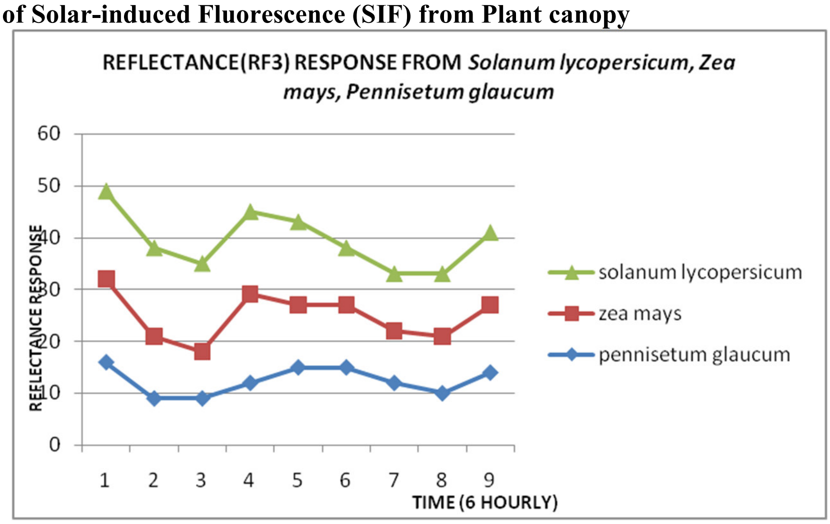

Figure 4: Graph of reflectance (at 630-650nm) vs. Time (6 hourly)

The solar-induced reflectance at the reddish wavelength is quite low and lowest in *Pennisetum glaucum*, in Figure

4. This implied strong absorption of solar radiation by the plants at this wavelength. Chlorophyll absorption of light for photosynthesis is more intense at these wavelengths. The response is typical for these wavelengths indicating a different phenomenon than reflectance i.e. fluorescence. Chlorophyll utilizes unabsorbed solar radiation to fluoresce at these wavelengths (Adekolawole and Balogun, 2012).

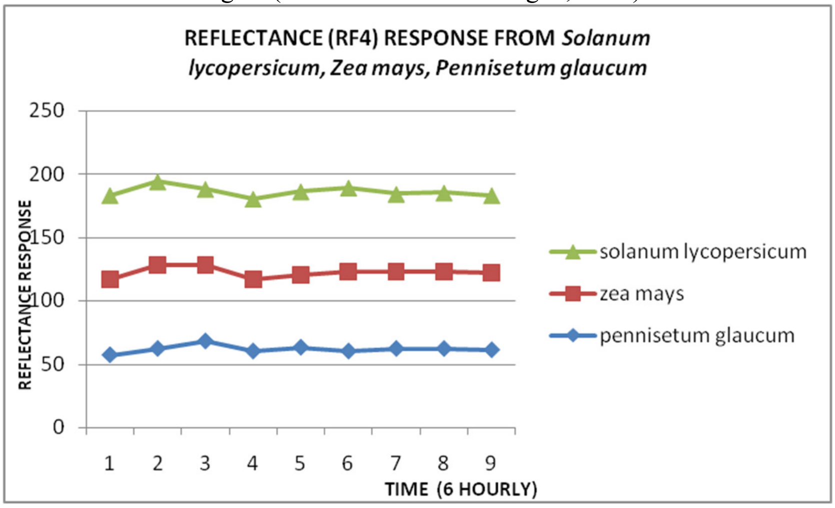

Figure 5: Graph of reflectance (at 710-780nm) vs. Time (6 hourly)

The solar-induced response is similar to previous at reddish wavelengths but at different amplitudes and more intense. Solar-induced Chlorophyll Fluorescence is more intense at the near infrared wavelengths, in Figure 5. This conversely implied low photosynthesis activity. The fluorescence intensity appears slightly uniform with time; that is, not too influenced by cloud cover/movement at near infrared wavelengths for the sampled plants. This made remote sensing of fluorescence at these wavelengths very valuable for satellite-based earth observations.

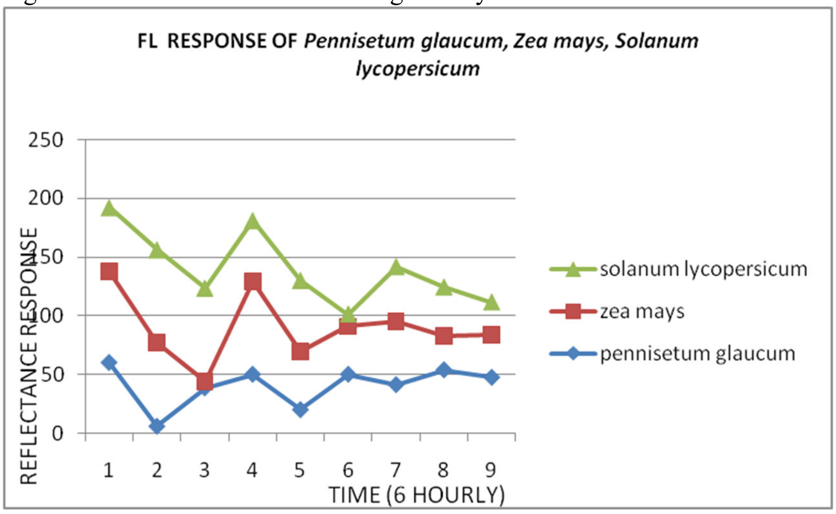

Figure 6: Graph of FL vs. Time (6 hourly)

The fluorescence response at 660-680 nm wavelengths band, in Figure 6, is more intense; vary significantly with cloud cover / movement, in all the sampled plants. The response peaked in the morning hours, indicating low photosynthesis activity in these plants within the period.

A(iii) Responses of Chlorophyll Luminescence from plant canopies

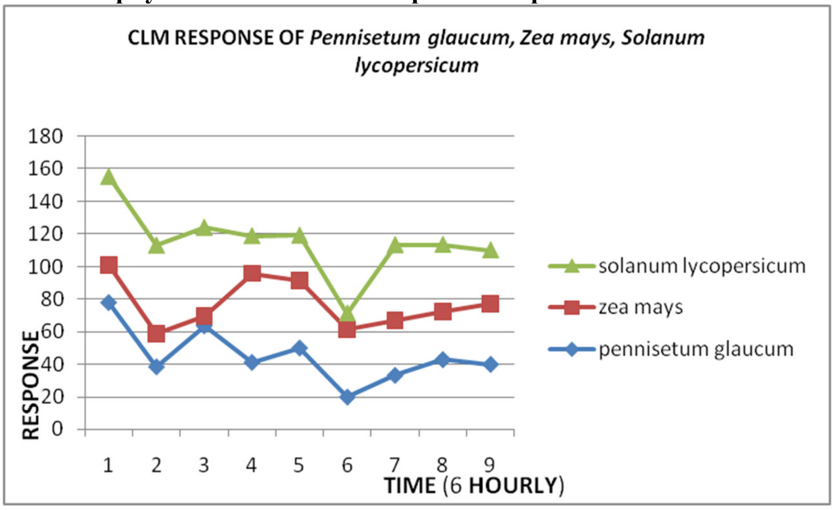

Figure 7: Graph of CLM vs. Time (6 hourly)

Chlorophyll luminescence signal has fairly similar response for the three plants but varied amplitude, in Figure 7. The plateau observed for *solanum lycopersicum* is reduced in *Zea mays* but reduced to a point in *Pennisetum glaucum*. This may be due to pigment contents in the plants. The dips indicated low photosynthesis activities which varied with cloud covers or sunshine hours.

A (iv.) Response of Solar-induced Vegetation moisture of canopy leaves

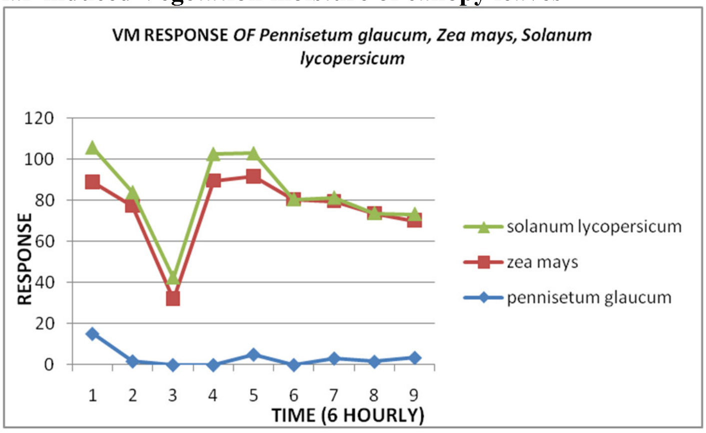

Figure 8: Graph of VM vs. Time (6 hourly)

Vegetation moisture, Figure 8, content response is reproduced in both solanum lycopersicum and zea mays but completely divergent in Pennisetum glaucum. The dips could be due to absence of or low sunshine hours while the response varied steadily with sunshine hours after the first day. The dips or lows indicate low photosynthesis activities and thus low carbon dioxide uptake or low oxygen release.

A (v). Responses of plants canopy leaves surface temperature

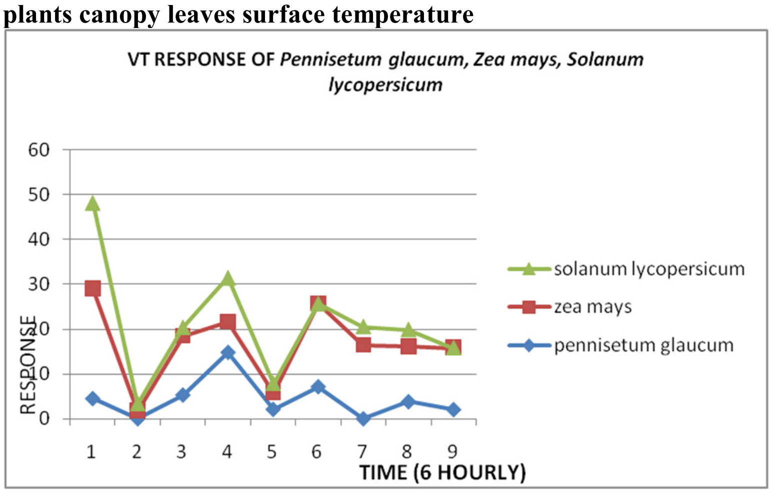

Figure 9: Graph of VT vs. Time (6 hourly

Vegetation temperature, Figure 9, varied proportionally with vegetation moisture and also varied with sunshine hours. The temperature response however showed more intensity.

A(vi). Mosaic View for all responses

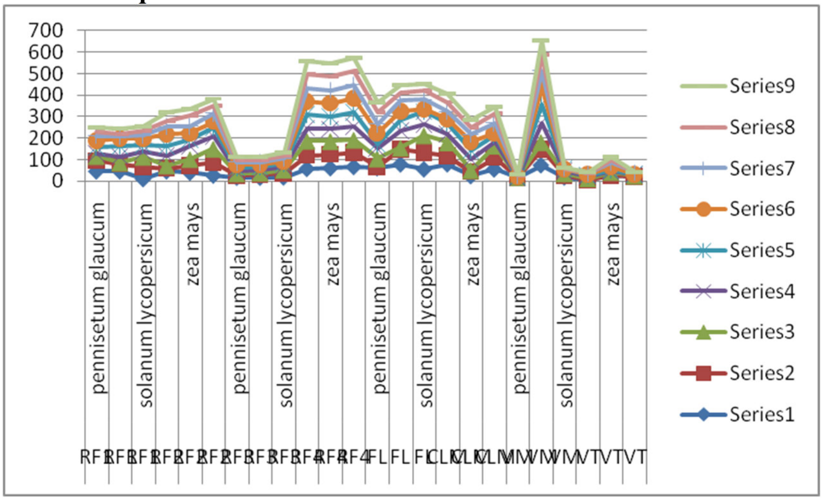

Figure10 Graph of all species from RF1-VT vs. Time (6 hourly)

The physiological spectrum, Figure 10, for all the plants exhibits a regular typical but uniform response. The dips and valleys indicate low photosynthesis activities while the peaks intense photosynthesis activities. The responses also indicate the behavior of the carbon dioxide draw down from the atmosphere by the plants canopy.

CONCLUSION

Thus a software-based Multispectral Radiometer that remotely sensed eight physiological parameters within eight spectral bands of reflectance, fluorescence amongst others, using a refractor telescope and electronics filters has been designed and developed.

The radiometer has been tested and used to comparatively study the solar-induced physiological parameters of plants canopy under normal growth conditions. The radiometer gave distinct spectral responses for each measurands as shown on Figures 1 to 10. It seems, the advent of this technique / device now makes it possible to comprehensively discuss almost all physiological parameters of a vegetation canopy, non-destructively, at an instance. This should be a welcome development to plant pathologists, physiologists as well as agricultural business community.

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