

LASER REMOTE SENSING OF FOREST AND CROPS IN GENETIC-RICH TROPICAL AREAS

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ABSTRACT:

The benefits of using laser remote sensing are discussed in the context of inspecting large and inaccessible South American areas of forest and crops. Laser remote sensing advances traditional radar technology with benefits of shorter wavelengths, less beam divergence and wavelength selectivity. In the South American areas of interest, species that need to be monitored are either only locally available or show important local genetic or soil influences. The application of LIF lidar techniques for forest and crop monitoring thus has to be developed in close contact with the large genetic variety found, for example, in the Amazon Region.

KEY WORDS: LIF lidar, SAR, chlorophyll *a*

1. INTRODUCTION

Optical remote sensing from airborne operations can be either active, by inducing a distinctive response through a broad-band or selective stimulus, or passive, by purely spatial and spectral analysis of reflected light.

Active monitoring of environmental changes, terrain profile, water abundance, gas temperature and concentration for various molecules, clouds and other parameters of special relevance to forest studies, have been carried out using various laser techniques. Purely passive spatial and multispectral analysis of LANDSAT and SPOT data have also provided valuable tools for remote sensing of forest areas. (Hurtak, 1986)

Helped by field studies, both techniques can be used to classify land use mainly as forest, cleared areas, pasture, and secondary growth vegetation. These four main classes are, however, highly variable and transitional into each other. For example, pasture can be only grass or a mixture of grass, crops, soil, and slash. This further complexity lowers the analysis confidence factor and even prohibits a finer analysis, such as crop type determination or species monitoring.

However, there is a need for more information than current land usage analysis can provide. Crop estimates, spread of plant disease, control of illegal crops, selective deforestation, crop species abundance profile, and other detailed vegetation data, are highly needed on a reliable, short-time basis. In the Amazon region, collecting the detailed vegetation data can be even more challenging because of the genetic variety observed even in same plant species. Furthermore, the inaccessibility and vastness of the majority of the Amazon region forest and farm areas make it mandatory to use remote sensing methods, because field analysis would not be feasible.

This paper deals with measurement techniques and issues pertinent to the remote sensing of finer vegetation data, by using laser induced fluorescence (LIF), both differential and excitation-selective.

2. PLANT LUMINESCENCE

Lasers, by inducing fluorescence in plants, can be used to monitor plant species, through its signatures in multiple

wavelengths. *Yentsch and Menzel (1963)* showed that a fluorescence technique could be used to determine the concentration of chlorophyll *a* with phytoplankton. The fluorescence time is short, close to a nanosecond. Many plants demonstrate high spectral absorption in the 430nm-575nm within the violet and blue visible spectrum. Chlorophyll *a* molecule P_{680} is detected between 650-685nm and its return fluorescence can be used to measure the efficiency of photosynthesis.

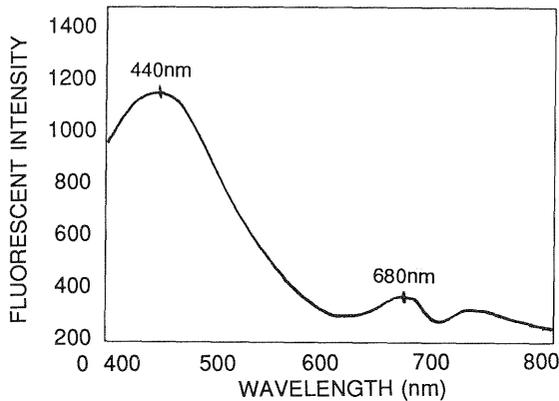
Plants also fluoresce in the presence of UV wavelengths (300-380nm) from pigments other than chlorophyll *a*. Bands from 530nm-575nm can be used to locate paved surfaces and minerals such as iron in rocks and soil. Bands of 770nm-810nm show cellular arrangement and water content.

Chlorophyll *a* generally shows little variation over different types of leaf, although chlorophyll combines with different proteins to form chloroplasts where one leaf cell can contain 50 chloroplasts. Four kinds of chlorophyll exist (*a-d*), with chlorophyll *b* absorption peak in the 480nm region. Leaf pigments of carotenoid, and anthocyanin are relevant in determining plant types. The presence of carotenoids appears at 460-500nm. Absorption by anthocyanin is within similar wavelengths of 400-550nm, both far shorter than the P_{680} chlorophyll peak.

Visible pulses from argon or dye lasers with powers in milliwatts are known to excite chlorophyll and phycoerythrin (a red pigment phycobilin). The difficulty has been in determining calculations for reflectance applicable to a majority of plants due to their complex multi-layered structure (i.e., monocotyledonous, dicotyledonous) containing both scattering and absorbing materials. *Willstatter and Stoll (1918)* explained plant reflectance based on light at the cell-wall-air interface of mesophyll tissue. Another approach tested is to treat the leaf as a scattering and absorbing turbid medium (Yamada, 1991) using the KMT theory (Kubelka-Munk theory) of modeling light in a multilayered object.

A dicot leaf can be composed of as many as six layers, i.e., two waxy external cuticular layers, an upper and lower epidermal layers, a mesophyll layer, and a palisade tissue layer. The cuticle layers are composed of cutin and contain no pigment; hence no absorption, whereby the sum of reflectance and transmittance of the layer is equal to unity. The palisade tissue layer containing pigments and chlorophyll is densely packed allowing negligible scattering.

The mesophyll layer contains the absorbing and scattering materials such as chlorophyll, other pigments, and cells that are uniformly distributed in them, according to their unique optical properties. Calculations are best gained from analysis of both the palisade and mesophyll layers.



Florescence Studies for Corn Crops (Monocot)

The monocots can be differentiated from dicots by virtue of having a higher fluorescence intensity at 440nm than the fluorescence intensity 675nm-740nm from the chlorophyll *a* molecule P_{680} . Present evidence indicates that the fluorescence in the 675nm-740nm range may also determine different plant types by the working of two different photosystems. In one photosystem, the chlorophyll *a* molecule P_{680} peaks as previously described. In the second photosystem, the chlorophyll *a* molecule P_{700} peaks which may not be a unique molecule but a dimer of two chlorophyll *a* molecules in association with special proteins in the membrane. Both systems can occur within a plant simultaneously.

Analysis can be made thus by measuring reflectance and transmittance integrated over a hemisphere at each wavelength. For the chlorophyll *a* molecule P_{680} wavelength from λ_0 (875nm) to λ_x (650nm) can be used. A minimum of three bands of close proximity best determines the scattering coefficient and the slope of the peak. This peak range eliminates the contribution from other kinds of scattering and absorbing materials within the leaf so one can calculate the chlorophyll content per unit area.

The results are aimed at confirming the spectral absorption coefficient of chlorophyll pigment with maximum peaks at ~ 440 and ~ 680 nm, as well as the absorption coefficient of other pigments contained in a leaf.

According to Yamada, by selecting wavelengths with large absorption coefficients, one loses accuracy at large chlorophyll contents and gets accuracy at small chlorophyll contents. By using wavelengths with small absorption coefficients, one can achieve relatively lower accuracy over the whole range. Wide bandwidths usually reduce errors in the reflectance and transmittance measurements. However, they also reduce the linearity between absorption coefficient and pigment content, especially when measuring the slope of the peak. (Yamada, 1991)

3. LASERS

Candidate lasers are the solid-state lasers such as the Nd:YAG (532nm-3 μ m) pulsed from 100 - 200 Hz proven

effective for measuring chlorophyll *a*. Other possible laser wavelengths have been used, but for spaceborne lidar Nd:YAG currently offers the most developed technology. The 355nm is sufficiently short to be dominated by Rayleigh scattering. The 1064 nm wavelength is sufficiently long to be dominated by aerosol particle scattering in the lower troposphere, with poor noise properties from available APD detectors. The 532nm wavelength is suitable for both aerosol and molecular scattering having good detector characteristics.

Both flashlamp-excited or diode-array excited Nd lasers can be used, to provide the necessary S/N ratio. The lasers and accompanying equipment can be assembled as mobile land units or airborne devices. In the case of choice, as airborne devices whenever possible, the equipment can be flown by helicopter or plane and must be light-weight and sturdy.

In addition solid-state lasers, the TEA CO₂ laser at up to 11 μ m can be operated at PRFs of up to 300-400Hz with pulse energies of a few hundred mJ.

4. LIDAR FOR AIRBORNE REMOTE SENSING

Monitoring of crops and environmental changes can be performed from airborne operations to provide large scale surveillance uses topographic lidar based on high S/N ratio. In studying soil or topography, each laser pulse can be used for a unique range measurement and waveform data.

Essential in airborne monitoring interpretation is aircraft pointing attitude data for range measurements, recovery of accurate surface elevation, and assignment of the elevation data to the correct Earth surface location. Laser altimeter signal strength depends on laser pulse power backscatter from the target surface and collected by the receiver telescope. Competing processes are optical background noise and detector noise. (Bufton, 1991)

For detecting soil, plant, and man-made surface features, the surface backscatter coefficient R_s varies due to the surface type, but can be approximated by $R_{s,ground} = \rho/\pi$, (Reagan, 1991) where ρ is the surface hemisphere or albedo with an albedo percentage value of 4-5% for wet soils and 30-40% for concrete structures. Trees and crops have a 15% albedo value for 532nm and 60% for 1064nm wavelengths. Using two or three beam pulses, the beams can be transmitted simultaneously and then detected in order to derive backscatter profiles at these wavelengths.

5. DIFFERENTIAL-SAR DETECTION TECHNIQUE

During one measuring event, the plant species is selectively excited by a narrow-band laser emission and fluoresces. The intensity dependent fluorescence band and the fluorescence decay time must be measured.

Because of the relative movement between source and target and because of the non-specular nature of the fluorescence, if the fluorescence radiation is collected by a line detector then the total yield is very low.

Also, if the detection method does not compensate for wind, moisture, background fluorescence from unwanted species, angle of absorption, etc., then the measurement is masked by important calibration factors that are time-varying and weather dependent.

The LIF method being reported in this paper, proposes to solve both problems by a combination of Synthetic-Aperture Radar (SAR) signal processing with differential fluorescence measurement.

Analogous to SAR, the receptor is a bi-dimensional array of point detectors, connected (in parallel in each row and with a computer controlled delay for each row) to a series of summing units that coherently adds the light intensity collected in each point to a point further in time. The coherence is maintained between source-target velocity and summing point, achieving a synchronism between the time scan of the array and the areas scan of the target. This technique is also similar to the Time Delay and Integration (TDI), nowadays a common signal processing technique for CCD detectors [EGG&G, Sierra Scientific, and DALSA are the main manufacturers] in low-light level moving inspection systems. The analogy to SAR is the effective increase of the detector (antenna) area, by signal processing. Since the intensity addition is performed immediately upon detection, the S/N ratio is not largely influenced by the further processing stages.

After the SAR-type detection (with on-line signal processing), the signals are available in various bands as a function of the target scanlength for each fly-by coordinate. These bands are chosen to provide for a variety of differential combinations that can uniquely identify a particular species by its fluorescence spectra. With the time analysis of the differential combinations (based on the fluorescence lifetimes for each chosen bands of the particular species), a further discrimination factor is added as a time-correlation for each differential signal, in pairs. The time-correlation data reduces to a function of the target scanlength, which is the confidence level in 0% to 100% of finding the particular species in the target. The spatial resolution is a trade-off between sensitivity and background noise and can be adjusted by adding together one or more detector lines in each row.

The experiments under way to apply the above technique to an actual case have three main steps: (1) Modeling the method and calculating the actual laser/detector/electronics parameter; (2) Measuring the various differential spectra in the laboratory for typical plants of interest; and (3) Setting-up a first system for mobile or aerial use. The first step is being completed together with some sample measurements.

6. DISCUSSION

This paper has presented a high-sensitivity method for detecting plant species in genetic-rich areas, with a LIF technique. The method is based on increasing the S/N ratio immediately upon reception by coherent addition of the multispectral fluorescence intensities, band for band, and by performing a ladder of cross-correlations of the time-dependent band signals, that takes into account the dynamics of the decay channels. The resulting signal is a function of the scanlength covered by the plane after the starting coordinate, and represents a series of confidence levels of finding the species along the flown line.

The application of this technique can lead to better law-enforcement control of present issues such as illegal crop production and unlawful deforestation, as well as an improvement in agricultural planning and crop estimation.

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