Estimation of Vegetation Cover Biomass by Remote Sensing

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ABSTRACT

It is shown that the use of traditional methods for assessing the condition of agricultural crops does not meet the requirements of modern precision farming requirements. Existing methods for remote determination of vegetation biomass based on registration of reflected solar radiation or radar signals are not very accurate. The use of a remote laser-optical system installed on board fast-moving flying objects has shown significant effectiveness in probing vast areas of plant crops. In this case, the fluorescent response of plants to the excitation of their leaves by laser radiation served as a useful signal. It is shown that the accuracy of biomass estimation is achieved by measuring the three-dimensional distribution pattern of the fluorescent organs of plants. For this purpose, a lidar complex consisting of a pulsed laser and high-speed recording equipment was used. The results of field flight experiments have shown encouraging results.

INTRODUCTION

Based on the registration of optical signals emanating from the Earth's surface, it is possible to monitor the state of natural environments – vegetation and reservoirs. For this purpose, chromaticity sensors of reflected sunlight are widely used, as well as measuring systems based on recording microwave, radar, and laser responses from ground-based objects.

To solve the problems of precision farming and monitoring of local vegetation characteristics, simultaneous collection of qualitative information about plant types, as well as quantitative data, is required. The application of such methods using unmanned aerial vehicles (UAVs) is of urgent importance. Of particular interest in remote sensing is the task of measuring the biomass of vegetation cover. Using data obtained by remote sensing of aircraft,it is possible to estimate biomass and determine the spatial distribution of various plant species. This approach, for example, has proved to be very useful for early warning of the danger of the spread of invasive plants [1].

Known remote methods for determining quantitative characteristics are based on fixing the geometric structure of plants and the configuration of their shadows, observed from various angles of view [2,3]. However, such methods have a number of disadvantages that do not allow for an accurate assessment of biomass. For example, when using a radar station, an antenna mounted on a carrier aircraft scans the Earth's surface only in the horizontal plane. The main disadvantage of such methods is also the low azimuth resolution.

The most promising approach to obtain comprehensive information about the state of crops is methods based on measuring the spectral and temporal characteristics of secondary fluorescence radiation stimulated by a laser beam. In this case, it is possible to obtain information not only about the class of plants being probed, but also about the physiological changes caused by the influence of various factors in their habitat. Taking these factors into account makes it more accurate to estimate biomass based on optical signals.

Keywords: biomass, fluorescence,laser, plant, remote sensing

MEASUREMENT PROCEDURE

The optical characteristics of the objects being probed are determined through the values of the instantaneous photocurrent at time *t*, in the spectral channel ($\lambda,\lambda+\Delta\lambda$) corresponding to the emission of echo signals from an area element with an *x,y* coordinate in the probing path. In the case of signal registration in pulse mode, the signal power *P* (*x,y*) b allocated in each of the photodetectors of the multichannel recording system tuned to the length ($\lambda,\lambda+\Delta\lambda$) from the object element located on the site with the *x, y* coordinate of the sensing path is determined by the expression

$$P(x,y) = \iint I(\lambda,x,y)dxdy \quad (1)$$

where y is the instantaneous height of the layer from the earth's surface covered by the pulse, I(,x,y) is the laser-induced spectral density of the energy brightness at the wavelength of the area element of the object with coordinate x, y.

In the general case, the luminosity of the element of a fluorescent object is due to the radiation of excited molecules:

$$I(\lambda,x,y) = \sum_i \frac{N_i^*(x,y)hcF_i(\lambda)}{4\pi\lambda\tau_{fl}^i} \quad (2)$$

Here $N^*_i(x,y)$ is the concentration of the fluorescent molecules of component i excited by laser radiation at the point x, y of the trace, $F_i(\lambda)$ is the fraction of radiation emitted by the fluorescent molecules (or atoms) of component *i* in the wavelength range ($\lambda,\lambda+\Delta\lambda$); τ_{fl}^i is the radiation lifetime of the excited molecules of component*i*, *h* is Planck's constant, and *c* is the speed of light in a vacuum.

In the case of vegetation sensing, there is no unambiguous and direct relationship between the spectral density of the energy brightness of the fluorescent echo signal $I(\lambda,x,y)$ and the concentration of fluorescent molecules $N_0(x,y)$. Therefore, direct quantitative estimates based on known absorption and fluorescence cross-sections by chlorophyll molecules are not possible. The fact is that the fluorescence yield *in vivo*, unlike *in vitro*, depends more on the state of the photosynthetic apparatus than on the concentration of fluorescent pigments such as chlorophyll.

Secondary radiation corresponding to chlorophyll fluorescence is detected in the spectral range of 670-740 *nm*. To eliminatethe influence of fluctuations in laser radiation on the measurement results, the intensity of the fluorescent radiation is normalized to the intensity of the raman signal on nitrogen molecules of the subsurface layer. The vertical distribution of the echo signal level is constructed by scanning incoming signals over time using a strobe integrator, which allows sequential recording of picosecond signals. The first pulse in the plume, reflected by the surface, is recorded by a photodetector, which generates a synchro pulse for launching a second, high-speed picosecond photodetector. The launch of this photodetector, which registers signals at an offset frequency, i.e. in the chlorophyll fluorescence band of 670-740 *nm*, an echo signal from the next pulse in the array is produced by the starting pulse coming from the first photodetector through the delay line at the moment the echo signal from the next pulse enters the receiving part of the second photodetector.

In this way, the measurement results will be accumulated and averaged over all pulses in the plume, starting with the second one. As a result of the interaction of a laser pulse in a plume having a duration of 50 *ps* with luminescent organs (leaves located on different tiers of the plant stem), the fluorescence echo signal has a temporal sweep depending on the architectonics of the vegetation cover.

The spectrally decomposed components of the echo signal, having passed through the polychromator5, were fed to the photomultipliers *6* via the light guides. The energy of the second harmonic radiation was monitored using the photodiode *2*, the electric pulse was fed to the indicator device and to the alphanumeric converter in the CAMAC crate *8*. Then the count of the initial energy of the laser pulse was fed to the computer memory for further processing. The coaxial photocell *3* ensured the transmission of the readiness pulse to the nanosecond range strobe integrator7. Then two measurement modes were envisaged. In the first case, the signals were fed through fast amplifiers to the input of the strobe integrator, from the output of which the

signal values corresponding to the samples at successive moments in time were fed to the computer via the corresponding alphanumeric converters. In the second case, the signals from the photodetectors *6* were fed to the charge integrators, i.e. the mode of integral measurements of the echo signal level was carried out, which were then fed in digital form to the on-board computer.

THE RESULTS AND THEIR DISCUSSION

Table 1 shows the results of laboratory studies to establish a correlation between the anatomical and morphological parameters of cotton and the ratio of the intensity of fluorescent radiation of leaves during two-channel registration in the characteristic spectral regions $R = I_{685}/I_{735}$. The table shows that the concentration of chlorophyll contained in the leaves varies markedly depending on the condition of the plant. The structure of the fluorescence spectrum also changes, which is evident even from the ratio of fluorescence intensity in the red and far red part of the spectrum.

However, as experiments have shown [4], changes in the spectral structure of fluorescence are associated not only with variations in the concentration of chlorophyll, but also with the state of the photosynthetic apparatus of plants, which is sensitive to environmental changes such as lack of moisture, mineral nutrition, etc.

Therefore, it was necessary to include a correction K(ei) in the calculations of quantitative indicators, which establishes a correlation between the level of fluorescence and biomass for each class of plants. This indicator is selected from a database of spectral data generated based on the results of experiments on reference plant samples [5].

Thus, calculations of biomass based on measurements of a two-dimensional distribution pattern of the fluorescent signal level $I_{fl}(x,y)$ along the route are performed by numerical integration using the formula:

$$m_b = \frac{K(\varepsilon_i)}{S_t l_m} \iint I_{fl}(x,y)\,dx\,dy \qquad (3)$$

where S_t is the total length of the probing path, $l_m(x)$ is the maximum height of plants at the point of localization of the laser pulse, and ε_i is the signature of the fluorescent response of the *i*-th species or state of plants.

To measure the profile $I(x,y)$, a cluster of 10-20 *ns* laser pulses with a wavelength corresponding to the maximum in the absorption spectrum of chlorophyll molecules is sent from the aircraft towards the earth's surface (Fig. 1).

Multichannel recording is used to simultaneously measure the spectral shape of the echo signal (Fig.3*c*). The latter is used to identify the type and condition of plants by comparing them with the spectra described by the corresponding discriminant functions of reference samples [6] or by applying other pattern recognition algorithms [7-9].

CONCLUSIONS

Field flight tests conducted from aboard AN-30 research aircraft over the cotton fields of the Ferghana Valley during two growing seasons of plant maturation showed a good agreement between the results of remote assessment of biomass and measurements carried out by traditional ground methods.

Thus, it can be concluded that the use of a laser - optical system with high-speed on-board recording equipment makes it possible to obtain more accurate express information about the state of crops. At the same time, it is possible to simultaneously evaluate the biomass of various plants, including invasive plants, having a preliminary database of spectral data for each class of plants compiled on training samples.

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Table 1. Correlation between the morphological parameters of cotton and the ratio of the intensity of fluorescent radiation of leaves

Experienceoptions	Experiencenumber	Chlorophyllcontent (*mcg*) per 1 *g* of raw weight *mcg/g*	per 1 dm^2 sheet on surface *mcg/*dm^2	per 1 plant*mcg/pl*	Average height of plants *cm*	Assimil. surface 1 plants (dm^2)	Number of leaves (pcs) per 1 plant	*R*
Plants grown with a lack of mineral nutrition	1	2743	3562	5703				1,870
	2	2898	3664	6025	13,1	1,6	3,5	1,394
	3	2854	3706	5933				1,780
Control plants	1	3323	4482	9282				2,090
	2	3451	4316	9640	16,4	2,1	4,1	2,130
	3	3385	4396	9153				2,168

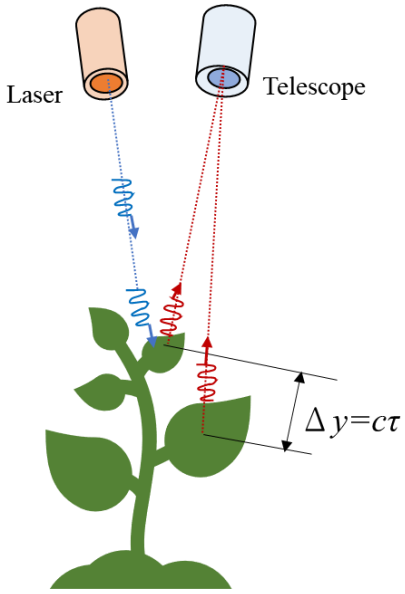

Fig.1. τ – the time between consecutive laser

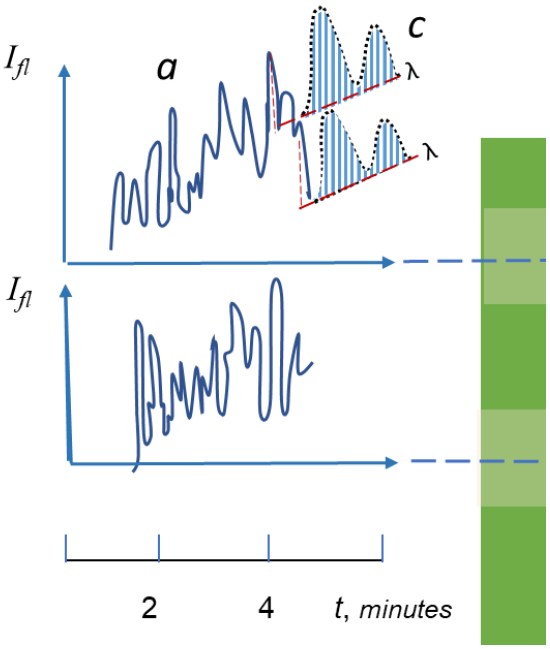

Fig.3. Distribution profile of $I_{fl}(x,t)$ (a) and signature$I_{fl}(x,y,\lambda)$ (c) during tacking along cotton fields (b).

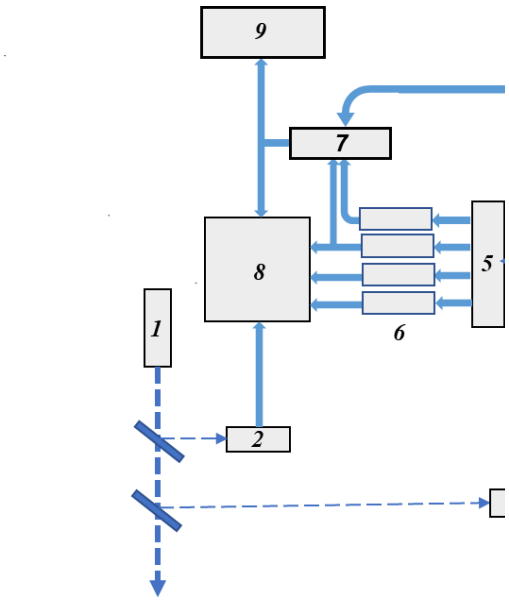

Fig. 2. Block diagram of the recording system: *1* - laser, *2* - photodiode, *3* - coaxial photocell, *4* - telescope, *5* - polychromator, *6*- photomultiplier tubes (PMT),*7* - strobe integrator,*8* - CAMAC,
9 - computer.