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ABSTRACT
of the dissertation for the degree of Doctor of Philosophy

İMPROVEMENT OF MULTİ-SPECTRAL MEASURİNG SYSTEMS WİTH LİQUİD CRYSTAL FİLTRATİON İN THE STUDY OF NATURAL OBJECTS

Specialty: 3337.01 - İnformation-measuring and control systems

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The work was perfomed at the Department of "Optical-electronic devices for remote sensing "of the Institute of Space Research of Natural Resources of the National Aerospace Agency.

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GENERAL DESCRIPTION OF WORK

The relevance of the topic. Currently, the methods of hyperspectral and multispectral measurements are widely used for environmental monitoring**.**In addition to environmental research, these methods are widely used in geophysics, agriculture, industry and other areas. Electronically tuned filters in front of the optoelectronic channel are widely used for their implementation. In this way, with a certain sequence of wavelengths, many multispectral images are formed, these are also called "cube of images." Combined spectral-spatial analysis is performed by using the specified "cube of images" and is widely used for the study of inhomogeneous samples or processes.

Adjustable spectral filters based on liquid crystals have a wide range of applications in optical communications, information-measuring systems for the spectral reflection of images and in environmental monitoring studies and so on .Adjustable liquid crystal filters with low power consumption and a wide range of settings provide high-quality images. Compared to acousto-optic filters, liquid crystal filters have a relatively simple design. Until recently, it was assumed that the process of connecting and disconnecting in liquid crystal filters occurs within tens of milliseconds. This has delayed the widespread use of such filters in information-measuring systems where hyperspectral and multispectral devices are used. However, ferroelectric liquid crystal filters have recently been created with duration connection - disconnection time less than a millisecond, and the aforementioned disadvantages have been eliminated.

Liquid crystal filters also have a high transmission coefficient , a wide viewing angle and a wide input aperture. The full realization of such important advantages of liquid crystal filters requires a detailed study of the accuracy and information characteristics of hyperspectral and multispectral measuring systems for various purposes, where they are used or can be used .In this case, the purpose of the analysis of such systems to study the potential of the considered systems is their implementation in the optimal mode of

operation. All of the above highlighted the importance and significance of the dissertation on the development of methodological bases for creating highly informative, multispectral and hyperspectral information-measuring systems for measuring various parameters and indicators of aquatic environments, plants and the atmosphere in which liquid crystal filters can be used. Compared to dispersion and interference-type filters, the main advantages of liquid crystal filters are their high aperture and high quality image formation. Liquid-crystal filters are widely used in military and civilian remote information-measuring systems that produce high resolution images. These filters are usually durable and can also be exposed to heat, humidity, ultraviolet radiation and mechanical factors.The importance of solving the problem of improving the monochromators currently being used in hyperspectral techniques implies a wider use of the potential of liquid crystal filters, which can be adjusted as monochromators. This, in turn, provides ample opportunities for further improvement of the methods and means of environmental monitoring in marine, atmospheric and plant environments.These features are primarily due to the functional properties of liquid crystal filters, including electronic tuning, structural simplicity and faster operation, etc.In the dissertation work was carried out improving methods and means for monitoring marine , atmospheric and vegetation cover using various information-measuring systems ,increasing informational content and accuracy, developing generalized models, synthesizing optimal work algorithms, developing new methods for measuring various parameters of environmental objects.

Aims and purpose of the research are to develop a scientific and methodological base for creating highly informative multispectral information-measuring systems in which liquid crystal filters are used as a monochromator for environmental monitoring of the atmosphere, water and plant environment.

To achieve the main goal, the following tasks were proposed and solved in the dissertation:

1. The analysis of the main factors affecting the sensitivity of photometers with imbedded liquid crystal filters at the input and study of the experimental properties of the sensitivity of the solar photometer according wavelengths is carried out

2. Study of the possibility of increasing the spectral measurement in the narrow strip wavelength range of 685-705 nm, where the radiation is continuously absorbed by water vapor and O2 and in the wide spectral range of 400-700 nm, which can be affected by events such as moistening and drying of the aerosol.

3.The study of the role of the fluctuation factor of the water surface due to the instability of wind speed in the formation of distortions during the determination of the color of sea water. Development of adaptive measurement method to eliminate the distorting effects of wind speed instability on the color components of sea water.

4. Formation and solution of the optimization problem from the information point of view of measuring the color of water at several points in the marine basin.Determination of the optimal dependence between the number of measurements at different wavelengths and the wavelength.

5. Investigation of the error in the determination of vegetation water index by the effects of aerosol moistening and drying as a result of variations in air humidity in an environment where photometric measurements are carried out in plant areas.

6. Development of a general model of optical thickness of atmospheric aerosols for the purpose of forming objective function used for optimization of correlation calculations of color signals, synthesis of optimal mode taking into account external atmospheric factors.

7. Investigation of the possibility of optimization of forest cover structure oblique scanning system by using the appropriate range of amplitude-spectral penetration characteristics of liquid crystal filters by establishing a mode of changing the period of the line depending on the angle of inclination in remote scanning.

8. Improvement of the method of calibration of indicators of the environmental model FAO-56 using remote measuring devices, analysis of the possibility of precise determination of the empirical coefficient between the leaf index (LAI) and the normalized differential vegetation index (NDVI).

Research methods. Optical atmospheric measurements, optimal processes and information theories, as well as elements of mathematical analysis were used to solve the problems presented in the dissertation**.**In order to validate the theoretical clauses and proposals a special place was given to model calculations taking into account practical results.

Main provisions to the defence:

1. Systematic presentation of the results of analysis of the main factors influencing the sensitivity of liquid-crystal filters imbedded in photometers, justification of the fact that the sensitivity of the filters have a typical maximum in the operating range of wavelength and that this feature should be taken into account during selection the parameters of the solar-photometric measurement mode.

2. The problem of increasing the accuracy of three-wave remote spectral measurements by eliminating the negative effects of O2 and water vapor continual absorption in the narrow spectral range of 685-705 nm and its solutions . The results of the solution of increasing the accuracy of three-wave remote spectral measurements 400-700 nm in a wide spectral range, by eliminating the negative effects of moistening and drying of water vapor and atmospheric aerosols.

3. Clause that depending on wind speed variability , fluctuations of the sea surface of varying degrees lead to distortions in the results of measuring the color of sea water. Adaptive measurement method to eliminate the effect of wind speed variability on sea water color components measurement.

4. Proposed problem and solution about optimization informativeness of water color measurement data at several points in the sea.In the optimal mode, the wavelength and number of

measurements have the inverse relationship, that is, more measurements are needed at short waves and less at long waves.

5. Theoretical bases that the actual value of the plant water index during photometric measurements of plant area may have bipolar errors and that it occurs as a result of aerosol moistening and drying due to variations in air humidity.

6. General mathematical model designed to formulate objective function used to optimize the operating mode of correlation type counter of color signals and characterizing the optical thickness of atmospheric aerosol.Synthesized optimal mode of the correlation calculator taking into account the external atmospheric factors.

7. Clause about the presence of trapezoidal distortions in the scanner frame during oblique remote shooting of the forest strip structure and optimization of spectral measurements in adaptive control mode depending on the angle of inclination of the line times. Optimization method of oblique scanning system of the forest structure based on information criteria using the corresponding shoulder of the amplitude-spectral characteristics of liquid crystal filters, if the mode of continuous change from the time of the filter transmittance strip during the frame is provided.

8. Improved method of calibration of indicators of environmental model FAO-56 using spectral remote measurements.Since in the used methodology there is no need to determine the minimum NDVI indicators, the total amount of necessary calculations is reduced; Proposal on the possibility of accurate estimation of the empirical coefficient value determining the relationship between the LAI and the NDVI indices.

The scientific novelty of the research:

1. The main factors affecting the sensitivity of photometers where fluid-crystal filters are imbedded were analyzed and shown that the solar photometers have the typical maximum of wavelengths in the working range and was reccomend to take it into account during choosing the mode parameters of solar-photometric measurements.

2. The issue of spectral measurements in three wavelengths in the narrow spectral range of 685-705 nm, which is negatively affected by continuous absorption of O2 and the water vapor and the issue of increasing accuracy in the wide range of 400-700 nm with a negative impact due to humidity and non-humidity of atmospheric aerosol was formed and solved.

3. Errors were established during the determination of the color of sea water, due to ignoring the fluctuation factor of different degrees of the sea surface due to the variability of wind speed, and an adaptive method that can eliminate these errors was proposed.

4. The problem of informational optimization of measurements at several points of the sea area for the determination of sea water color was formulated and solved and it is established that in optimal mode the parameters such as wavelengths and number of measurements have the inverse relationship that is, it is necessary to carry out more measurements at short waves and less at long waves.

5. It was shown that the calculated real value of the plant water index, based on photometric measurements in plant areas due to moistening and drying of the aerosol due to variability of air humidity, has bipolar errors.

6. A generalized model of optical thickness of atmospheric aerosol was proposed to form the objective function of optimization of the operation mode of the color signal correlation type calculator. As a result of optimization of this model of colorimeter, the optimal mode of correlation calculations with consideration of external atmospheric factors was synthesized.

7. The possibility of trapesiodal errors during the oblique remote scanning structures of forest arrays and taking into account that hyperspectral measurements may, if necessary, result in a reduction in system informativeness if the line periods changes depending on the inclination angle ,the possibility of optimizing the shift regime of the filter transmittance zone during the frame by using an increasing curve of the amplitude spectral characteristics of liquid crystal filters according to the information criterion of the oblique scan system was shown

8. Improved method of calibration of indicators of ecological model FAO-56 using remote measuring devices was proposed, since this method does not require the determination of the minimum NDVI, it is possible to determine the exact value of the empirical coefficient that determines the relationship between the LAI and the NDVI indices, reducing the total amount of calculations to be made.

Theoretical and practical significance of research

1. The use of multifunctional fluid-crystal filters in different-purpose information-measuring systems enables to simplify the spectral channels formation nodes both functional and constructive, thus increasing the efficiency and reliability of such systems.

2. Proposed methods and technical studies to study the components of the marine environment, its water color and pollution levels will increase the effectiveness of environmental monitoring of the aquatic environment, develop recommendations and measures for improving the marine ecological situation.

3. Proposed methods and techniques for taking into account the negative effects of different atmospheric components on the study of various surface objects by remote multispectral measurements increase the accuracy and reliability of the results of environmental monitoring of the Earth's surface and makes it possible to correctly identify key directions of environmental remediation activities.

4. Recommendations and improvements in the study of the health of the flora using colorimetric methods, including the RGB method have particular importance in the proper assessment of the environmental status of green areas, improving the efficiency of agricultural plants and the conservation of wildlife in general.

Approbation and implementation:

The main results of the dissertation were reported and discussed at the meetings of the Scientific and Technical Council of Space Research Institute of Natural Resources of the National Aerospace Agency, as well as at the following scientific and practical conferences:

IX международная научно-практическая конференция «Аграрная наука Сельскому хозяйству», Барнаул, 2014;

- VII заочная международная научно-практическая конференция «Актуальные проблемы экологии и охраны труда» Курск, 2015;

- V международная межвузовская научно-практическая конференция. Великие Луки, 2015;

- X международная научно-практическая конференция «Аграрная наука сельскому хозяйству», Барнаул 2015.

-IX International Scientific and Practical Conference "Agricultural Science to Agriculture", Barnaul, 2014;

- VII extramural international scientific-practical conference "Actual problems of ecology and labor protection" Kursk, 2015;

- V international interuniversity scientific-practical conference. Great Luke, 2015;

- X international scientific-practical conference "Agricultural science to agriculture", Barnaul 2015.

The results of the dissertation work were applied in the experimental design work carried out at the Scientific Research Institute of Aerospace Informatics by the order of the "Radio Installation" plant of "Ufug" İB.

20 scientific articles and conference materials were published in various publications on dissertation topics.

Name of the organization where the dissertation has been performed:

The main results of the dissertation was carried out in the department of "Optical-electronic devices for remote sensing "of the Institute of Space Research of Natural Resources of the National Aerospace Agency.

Volume, structure and the main content of the dissertation:

The dissertation consists of an introduction, 4 chapters, the result, a list of publications used in 123 titles, 31 figures, 5 graphs and in general the dissertation consists of 223895 characters.

CONTENT OF WORK

The introduction presents the relevance of the topic, the purpose of the work, resolved issues, scientific innovations, the practical significance of the work and key points for defense.

In chapter it was reviewed the development of multi-spectral remote sensing systems with liquid-crystal filters and the sensitivity of hyperspectral solar photometers formed on such base was investigated. The functional diagram of a hyperspectral solar photometer with a liquid-crystal filter is shown in Figure 1.

It was shown that a solar photometer with a liquid crystal filter has the maximum sensitivity at the wavelengths corresponding. It is shown that the maximum sensitivity detected in solar photometers is taken into account in selecting the mode indicators of solar-photometer measurements.

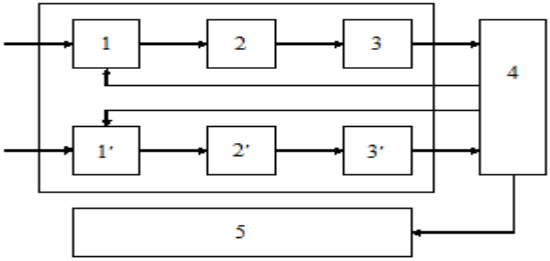

Figure 1. Functional scheme of hyperspectral solar photometer: 1, 1′ –Liquid crystal filters 2, 2′ – primary amplifiers 3, 3′ – Photodetectors, 4 – rotational supporting device , 5 – managed computing processor.

It was noted that the application of liquid-crystal filters allows the creation of highly efficient RGB type colorimetric remote measuring systems.It has been shown that using an intermediate switch method can eliminate the effect of aerosol moistening and also calculate the radiation intensity of a surface object in the nearest infrared region at three wavelengths.The issue of eliminating the influence of the absorption band of water vapor at a wavelength of

685-715 nm on the accuracy of spectral measurements in the near infrared zone was also considered.

Mathematically it has been shown that if the spectral optical thickness in the specified wavelength range of water vapor and O2 is approximated by the linear function effect of aerosol moistening and O2 can be eliminated using certain variations of the intermediate switch method.

This chapter also investigates the issue of achieving maximum informativeness about spectral measurements performed by group-based unmanned aerial vehicles (UAV).Two optimization problems characterized by different constraints were formulated and solved. The solution of these optimization problems allowed finding the optimal expression of $I_\lambda(t)$-which is a function of the dependence of the input signal value of the liquid crystal filter on the passage time.

At the end of the first chapter, the calibration of photo receivers based on load-related devices in combination with optoelectronic filters was analyzed.

The second chapter of the dissertation is devoted to the research of the sea by hyperspectrometric and colorimetric methods. The first section discusses the hyperspectral method of measuring the concentration of chlorophyll in coastal waters.

It was noted that the accuracy of measurements on a known Sea WiFS device prevents spectral transparency of the water environment in the wavelength range of 400-600 nm. As a result, it is not possible to say that the results of measuring 500-600 nm wavelength of the WiFS are accurate and correct. An aditive-parametric-extreme method for measuring chlorophyll has been proposed.

According to this method dependence of the signal on the wavelengths 412 and 443 nm from the concentration $f_1(x)$ of chlorophyll is determined as

$$f_1(x) = 10^{(-a_1 - b_1 \cdot \ln x)}$$

and at wavelengths of 555-565 nm is defined as $f_2(x)$

$$f_2(x) = 10^{(-a_2 + b_2 \cdot \ln x)}$$

It is shown that $k_1 f_1(x) \cdot f_2(x)$ product gets the maximum value when

$$x_{opt} = 2^{-\left(\frac{k_1 a_1 - a_2}{k_1 b_1 + b_2}\right)}$$

So, to check the accuracy and validity of measurements ,it was recommended to check if $k_1 f_1(x) \cdot f_2(x)$ product has maximum or not.If the chlorophyll concentration is low or the signal increase tendency is broken in the 600-800 nm range due to the high water content that maximum cannot be achieved and the measurement result is considered inaccurate in this range.

The second chapter also discusses the issue of improving the accuracy of determining the color of sea water using an RGB colorimeter. The results of well-known studies have shown that a change in wind speed depending on time can result in changes in the color of the colorimetric system output. A separate adaptive measurement method of R (red), G (green), and B (blue) colors is also proposed to overcome this effect.

Based on known formulas, it was shown that the stability of any of the components R, G, B in time can be written as follows:

$$\frac{L_{sky}(t)_i}{E_d^+(t)_i}\left[0{,}026 + 0{,}0001W(t) + 0{,}00006W^2(t)\right] = a\,.$$

Here, $L_{sky}(\lambda)$ - sky radiation, $E_d(\lambda)$ - solar radiation , ρ_{as} - radiation from the air-water zone, W –wind speed, a = const (reflection coefficient from the surface of the sea)

The following algorithm for measuring R, G, B components was proposed :

1. Wind speed w (t) is measured.
2. For components R,G,B,

$E_d^+(t)_R;\ E_d^+(t)_G;\ E_d^+(t)_B$ and $L_{sky}(t)_R; L_{sky}(t)_G;\ L_{sky}(t)_B$ are measured separately.

3. At the given value of a, the function

$$F(t)_i = -0{,}83 + \sqrt{0{,}83^2 + \left[\frac{\frac{a \cdot E_d^+(t)_i}{L_{sky}(t)_i} - 0{,}026}{0{,}00006}\right]}$$

is calculated $i = (\overline{R,G,B})$ The components of R, G, B at such a moment in time and the value of *a* are measured so that the condition *W(t)=F(t)* is implemented for each of the components of R, G, B separately.

4. Then, such moments of t_i is defined, so that at these moments and the values of a indicated for the corresponding color, the condition $W(t) = F(t)$ is carried out. If this condition is not met, then switch to relative color measurement mode and the value of a is changed in the amount of the same increase so that for R, G and B the condition $W(t) = F(t)$ is fulfilled. That is, the components of R, G, B are measured at such a moment in time and the values of *a* corresponding to a certain color, so that the condition *W(t)=F(t)* was fulfilled for each of the components R, G, B separately .

5. In view of the foregoing, the color component R should be measured at t_R time interval, G color component at t_G time interval and color B at t_B time interval.

The proposed method requires the addition of the device for measuring wind speed in the general block diagram of the measuring complex. A general block diagram of adaptive seawater color measurement was created.

Then, the second chapter discusses the optimization of hyperspectral remote measurement of the color of sea water. Figure 2 shows graphs of the dependence of the coefficient of reflection of the sea surface from the atmospheric boundary at 50% relative humidity for 4 types of aerosols on wavelength.

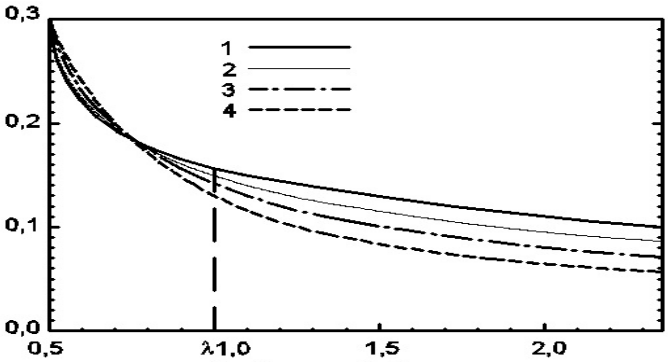

Figure 2. The dependence of the reflection coefficient on the wavelength at a relative humidity of 50% for four types of aerosols

A new method for estimating at a certain number of points the amount of information that can be obtained during calculations at λ_i wavelengths was proposed.

Based on the optimization problem, it was concluded that there is inverse correlation between the wavelengths and the measured values in the optimal mode, that is, measurements should be carried out at shorter wavelengths more, and at long waves less.

At the end of the second chapter some issues of optimization of remote measurements of objects using monochromatic measurement channels was considered.

The optimal choice of the distance between the scene and the observer if used the monochromatic camera and the optimal correction of the spectral characteristics of the monochromatic camera depending on the weather conditions, were formulated and solved.

The third chapter of the dissertation is devoted to the optimal assessment of the role and impact of atmospheric aerosol in multispectral and hyperspectral remote measuring systems. To solve the problem, the function $R_{ToA} = f(R)$ was considered.

The mathematical solution of the optimization problem showed that when the optical thickness τ_{aer} of the aerosol and the $k_1 = \frac{\tau_{aer}}{f'_R}$ are known, the number of measurements N that maximize the reflection coefficient R_{TOA} measurement informativeness is defined as $N = k \cdot \frac{\tau_{aer}}{k_1}$.

The third chapter then investigates the effect of aerosol on the accuracy of determining normalized difference water index (NDİİ) of plants.

The analysis showed that the onboard spectral measurements the real value of normalized difference water index depend on weather humidity due to moistening or drying of the aerosol.It should be taken into account that a normalized differential water index can get both minus and plus values due to moistening or drying of atmospheric aerosol.As a result of the analysis, it was concluded it was necessary to take measures to compensate the effects of atmospheric aerosols.

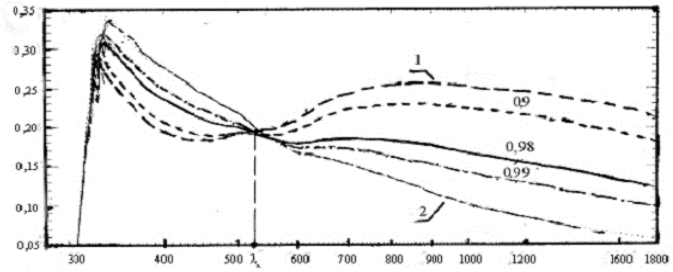

Figure 3 Model version of radiation curves reflected from the upper boundary of the atmosphere, depending on the fractional composition of aerosol and wavelength: 1- large dispersed fraction 2-small dispersed fraction

In this chapter, the problem of developing a method for determining the amount of content of small dispersed aerosols in the

coastal areas by measuring the radiation reflected from the upper limit of atmosphere was considered.

It is indicated that, from the spectral curves shown in Figure 3, the most optimal is determined by the expression $f'(\lambda) = \frac{C}{(\lambda_{max})^2} - \frac{f_0}{\lambda}$ Then, using the formula obtained as a result of the optimization problem, can be determined the amount of content of the small dispersed aerosol according to the corresponding curve.When the functiton *f(λ)* increases depending on λ ,it is shown that the reflected radiation measurement results have the highest informativeness.

At the end of third chapter, the question of creating a general model of atmospheric aerosol for optimal signal processing of colorimetric measuring instruments carrying out technological control was considered

To synthesize a noiseless apparatus for calculating the cross-correlation of color channel signals under the influence of a moistened aerosol, a new model of the optical thickness of the aerosol based on the Bird model was proposed.

Since the main research issue is the synthesis of correlation values of color channel signals without aerosol noise the proposed combined model of the aerosol optical thickness is expressed as the average total of weight coefficients of optical thickness

$$\tau_{\Sigma_1} = \frac{2^{\alpha_2-\alpha_1} \cdot \beta \cdot \lambda_1^{-\alpha_1} + \beta \cdot \lambda_2^{-\alpha_2}}{2}.$$

The problem of the synthesis of the optimal calculator of correlation between the color channels of the colorimetric system for measuring the distance was formed and was shown solutions based on the proposed aerosol model.

The fourth chapter of the dissertation is devoted to the use of onboard multi-spectral measuring methods to determine the indicators of plant development.At the beginning of the chapter, the proposed parametric method for determining the dry mass of plants by the hyperspectral method is explained.

It is shown that under the condition $C_1 \cdot R_{1450} = WI;\ C_1 = const.$ the product $C_1 \cdot R_{1450} \cdot WI$ gets the maximum value. Here *WI* is the water index, R_{1456} - reflection indicator at a wavelength 1456 nm.

To calculate the dry mass of the plant P_d, we use the formula $P_d = \frac{A_1}{PWC + 1}$, obtained under the conditions $PWC = a_3 \cdot WI - a_4$; $C1 = a_1/a_3$ and $PWC = - a_1 R_{1450} + a_2$. Here A_1 is the mass of a wet plant before drying .

Then, the fourth chapter explains the spectroradiometric oblique remote method to determine the structure of the forest cover.

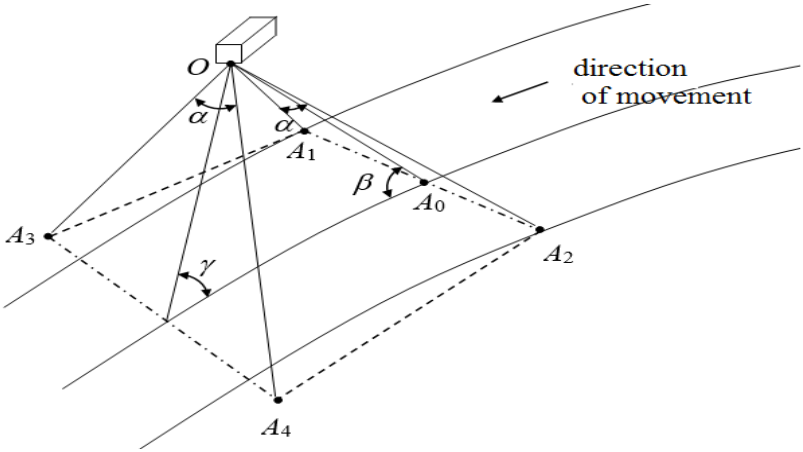

Figure 4. Schematic description of polygon (oblique)remote measurements

Limiting the signal / noise ratio can lead to a decrease in the informativeness of such experiments. This can be accomplished by using electron-regulated liquid-crystal optical filters with a spin-off channel of less than 150 ms.

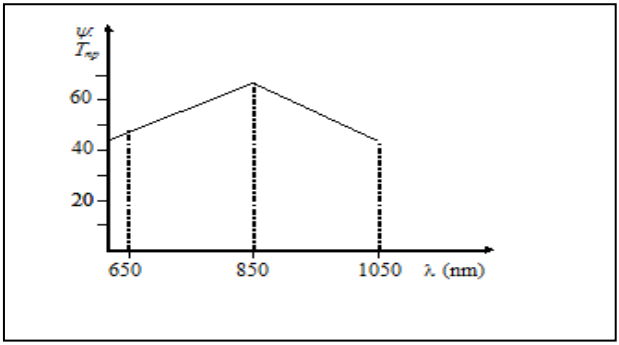

Figure 5.Linear discrete approximation of the spectral transmittance coefficient of the liquid crystal filter

It is known that when the angle of sight is changed, the reflection characteristics of the plant areas also change. Therefore, remote spectroradiometry should provide scanning of the studied forest array at different angles to ensure high informativeness.

It is known that trapezoidal distortions of the rectangular shot of the probe occur during oblique remote sensing.

As can be seen from Figure 4, with the conversion of the angle $\beta = 90^{\circ}$ to the angle $\gamma \approx 45^{\circ}$, the sides of the triangle OA_1A_2 OA_1 and OA_2 increase to value OA_3 and OA_4. Such geometric distortions during the frame reduce the signal/noise ratio (as a result of the transition from the distance OA_1 to the distance OA_3) and provided that the stability of the processing interval of one pixel on the surface leads to an extension of the time of the scan

It is indicated that during the planning of oblique remote sensing it is necessary to take into account the low energy level of the output signal in hyperspectrometers during a high scanning speed corresponding to the stretched lines of the scanning device. ner line.

Approximated penetration amplitude-spectral characteristics of liquid crystal filters is shown in Figure 5.

As can be seen from this graph, the penetration coefficient in the range of 650–850 nm increases linearly, while in the range of 850–1050 nm it decreases .

The research question is formed as follows: during oblique remote measurements taking into account the above distortions in order to obtain information in the maximum amount due to the multitude of {650-850 nm; 850-1050 nm} it is necessary to determine the optimal spectral range.

Taking into account the fact that the land area is obtained in a trapezoidal shape during oblique remote measurements, in all lines of the frame the total amount of information can be calculated as follows:

$$M_1 = \int_{T_{min}}^{T_{max}} T\, log_2 \psi(\lambda) dT .$$

Here, T is the scanner's line length, T_{min}, T_{max} -maximum and minimum values of T .To formulate the optimization problem, the function X = Y, which determines the change in the functional dependence between the wavelength and the line length was considered.

It was shown that the optimal function $\lambda(T)$, which is sought in positive values of ψ'_λ under certain constraint conditions, is a linearly increasing function of T .The optimal function $\lambda(T)$ becomes a linearly decreasing function of T, at a negative values of ψ'_λ .

If the working lower band is selected in the range of 650-850 nm, where ψ'_λ receives positive values, and if the condition for a linear increase of wavelength λ in the time T interval is carried out, the optimal mode of operation of the system is ensured. This mode of remote measurements provides the study of various homogeneous of the forest at different wavelengths as a result it becomes possible to obtain maximum information in the calculation of vegetation indices of the forest area.

Chapter 4 further discusses the issues of improving the calibration method using values of remote measurements of the FAO-56 environmental model.

It is known that the evapotranspiration rate of plants is calculated as

$$K_{cb} = 1.07\left[1 - \left(\frac{NDVI_{\max} - NDVI}{NDVI_{\max} - NDVI_{\min}}\right)\right]^{0.84a_1}.$$

At the same time, using the dependence $NDVI = NDVI_{\max} - (NDVI_{\max} - NDVI_{\min}) \cdot \exp(\alpha_1 \cdot LAI)$ between $NDVI$ and LAI plant indices, we can use the proposed graphoanalytical method to calculate the $NDVI_{\max} - NDVI_{\min}$ difference.

In this case the coefficient K_{cb} can be written as follows:

$$K_{cb} = 1.07\left\{1 - \left[\exp\frac{\overline{NDVI}}{\exp(OC)}\right]^{0.84a_1}\right\}.$$

Here $\overline{NDVI} = NDVI_{\max} - NDVI$ is defined as such.

Thus, if the proposed graphoanalytical method is used to calculate the coefficient K_{cb}, it is not necessary to determine the minimum value of $NDVI$, which reduces the number of computations required.

At the end of Chapter 4, multispectral measurements of mixed objects in a subpixel scale are considered.

A new method based on linear programming has been proposed to calculate the signal / noise ratio during remote measurements of subpixel objects.

IN RESULTS

1. It was determined that the sensitivity of the solar photometer inside which a liquid crystal filter is imbedded in the operating mode of the wavelength has a typical maximum, it was also shown that this should be taken into account during selection of the regime parameters in solar photometric measurements.

2. Problems of increasing the accuracy of triple distance measurements in a narrow spectral range of 685-705 nm, as well as 400-700 nm wide spectrum, taking into account the negative effects of water vapor and O2 continual absorption, atmospheric aerosol moistening and drying, were formed and solved.

3. An adaptive measuring method for studying color components was proposed with which it is possible to eliminate distortions in determining the color of water that are the result of fluctuations of different degrees of the sea surface due to changes in wind speed

4. The problem of optimization information of water color measurements at several points in the maritime area was solved, as a result, it was shown that the parameters such as wavelength and number of measurements in the optimal mode are inversely proportional to each other, that is, the need for more measurements at shorter waves was shown.

5. On the basis of photometric methods of spectral measurements of the plant area, was determined that the actual measured value of the water index due to the effects of aerosol moistening and drying has bipolar errors.

6. A generalized model of optical thickness of the atmospheric aerosol, suitable for the formation of the objective function during optimization of working mode of the color signal correlation calculator was developed , the optimal mode of correlation calculations with consideration of atmospheric factors was synthesized.

7. During frame formation in the mode of continuous change of the spectral transmittance strip of filters using the increasing shoulder

of the amplitude-spectral characteristic of liquid crystal filters, the possibility of optimization by the information criterion of the spectrometric system, which studies the forest cover structure along sloping trajectory was shown.

8. An improved method of calibration of indicators of the environmental model FAO-56 using remote spectral measurements was developed, since there is no need to determine the minimum *NDVI* value in the proposed method, the volume of calculations decreased, also the possibility of determining the exact value of the empirical coefficient of the correlation between *LAI* and *NDVI* indices was shown.

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