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UNMASKING THE SOIL COVER'S DISRUPTION BY MODELING THE DYNAMICS OF GROUND VEGETATION PARAMETERS¹

*Vysotska O. V.¹, Doctor of Engineering, Associate Professor;
Zholtkevych G. N.², Doctor of Engineering, Professor; Klochko T. A.³;
Bespalov Yu. G.², M.S.; Nosov K. V.², PhD.*

¹ *National University of Radio Electronics, Kharkiv, Ukraine*

evisotska@mail.ru

² *V. N. Karazin Kharkiv National University, Kharkiv, Ukraine*

³ *National Aerospace University «Kharkiv Aviation Institute», Kharkiv, Ukraine*

ДЕМАСКУВАННЯ ПОРУШЕНЬ ҐРУНТОВОГО ПОКРИВУ ЗА ДОПОМОГОЮ МОДЕЛЮВАННЯ ДИНАМІКИ ПАРАМЕТРІВ НАЗЕМНОЇ РОСЛИННОСТІ

*Висоцька Є. В.¹, д.т.н., доцент; Жолткевич Г. М.², д.т.н., професор; Клочко Т. О.³;
Беспалов Ю. Г.², магістр; Носов К. В.², к.т.н.*

¹ *Харківський національний університет радіоелектроніки, Харків, Україна,*

² *Харківський національний університет імені В. Н. Каразіна, Харків, Україна*

³ *Національний аерокосмічний університет*

«Харківський авіаційний інститут», Харків, Україна

Introduction

A number of areas of human activity needs the estimation of soil disruption. In many cases, such estimation can be carried out very efficiently by remote sensing methods. For example, in this area for nearly a century there have been a fruitful cooperation between the representatives of such quite different professions, as archaeologists and military personnel [1]. One of the factors currently determining an important role of the spectral brightness of the Earth's surface is use of chlorophyll and other pigments measurements of ground vegetation for remote determination of abnormality of the soil cover.

The vegetation may play the role of both unmasking (e.g., due to its different development at walls and ramparts of medieval castles) and masking (as in dense crops of cultivated plants) factors alike. The character of quasi-periodic variations in spectral brightness caused by human factors for cultivated plants may be an unmasking factor [2].

In some cases [3], one can use not spectral, but colorimetric parameters obtained by computer processing the digital photography taken in the RGB color model. For these instances, it's possible to use the digital photography from unmanned aerial vehicles (UAVs). Information arrays of an actual material obtained in this way may be a little incomplete and, in some cases, may not contain the right sequence of phases in the quasi-periodic cycle of colorimetric parameters of vegetation. That can be caused by nonflying weather, poor visibility and

¹ <http://radap.kpi.ua/radiotechnique/article/view/1174>

so on.

Traditional processing of the data related with remote sensing of the Earth for solving similar problems assumes long-term observations [2] and cannot always be applied for quick decision-making or under conditions of insufficient information.

In the paper we suggest a solution based on the use of dynamical models of special kind (Discrete Models of Dynamic Systems, DMDS), and the information technology developed at V.N. Karazin Kharkiv National University and National University of Radio Electronics. The models allowed us to describe a dynamics of systems at the different levels of organization of life [4, 5, 6, 7, 8] and can reveal the structure of intra-system relationships on the base of the interactions (+,-) (-,-), (+,0), (-,0), (0,0), known in theoretical biology and ecology. The structure' identification procedure involves use of observations data of a real natural system.

For clearness, the structure of relationships can be represented both as a matrix or a signed graph; an idealized trajectory of the system (ITS) is calculated with use of the structure and reflects the cyclical nature of the dynamics (in actual practice the nature is often quasi-cyclical).

For building the ITS with use of the DMDS, it is not necessary to have a series of observations during the period compatible with the cycle of the system [4]. The ITS can be obtained for data of simultaneous observations of a set of instances having the same dynamics (since, the same ITSs), but which are at different phases of the trajectories.

The crops of cultivated plants is a case to which an approach described above can be applied. The phases of the cycle of plant growth for neighbor areas may be slightly different due to a small, but always existing diversity in varying supply conditions, light, moisture, planting density, quality of the ploughing and sowing material etc.

For earlier studied living systems [4, 5, 6, 7, 8], the cyclicity (quasi-cyclicity) of their parameters was essentially caused by the presence of the relationship (+,-) in the structure.

We can advance a working hypothesis consistent with available literature on the subject [2, 3]. The differences in the nature of quasi-cyclic vegetation, allowing us to detect remotely the terrain areas with different kinds of the soil disrupted by a human, are caused by the relationship (+, -) between colorimetric parameters associated with the content of chlorophyll and other pigments.

This paper aims to model the relationships' structure between pigments for the crops of cultivated plants that reveals the soil cover's disruption.

Brief description of the dynamic model

We briefly describe here the discrete dynamical models used in the research. Full description can be found, for example, in [7, 8].

Assume that some natural system consists of N components to be denoted

by A_1, A_2, \dots, A_N . The quantity of each component takes K discrete values denoted by $1, 2, \dots, K$ that is the initial series of natural numbers. The system develops in discrete time denoted by $t = 0, 1, \dots$. The value of each component A_i in the moment t denoted by $A_i(t)$, and the state of the system at this moment — $(A_1(t), A_2(t), \dots, A_N(t))$.

The trajectory of the system is a matrix

$$\begin{pmatrix} A_1(0) & A_1(1) & A_1(2) & \dots \\ A_2(0) & A_2(1) & A_2(2) & \dots \\ \vdots & \vdots & \vdots & \dots \\ A_N(0) & A_N(1) & A_N(2) & \dots \end{pmatrix}. \quad (1)$$

Since the number of states is finite, the minor presenting the cycle of the system dynamics can be extracted from (1). There exist such natural numbers s and T , that the minor

$$M = \begin{pmatrix} A_1(s) & A_1(s+1) & \dots & A_1(s+T-1) \\ A_2(s) & A_2(s+1) & \dots & A_2(s+T-1) \\ \vdots & \vdots & \ddots & \vdots \\ A_N(s) & A_N(s+1) & \dots & A_N(s+T-1) \end{pmatrix} \quad (2)$$

fully describes the dynamics of the system (after $t = s + T - 1$ the trajectory repeats periodically).

As a model is intended for description of the dynamics of systems based on interactions adopted in biology and ecology, the important issue is the relation between the inter-component relationships and the dynamics. Here we introduce the concept of a relationship between the pair of the components A_i и A_j . The relationship between the A_i and A_j is called a couple (ω_1, ω_2) , where $\omega_1 \in \{-, 0, +\}$, $\omega_2 \in \{-, 0, +\}$. It is also assumed that for $i = j$ the only possible relationships are symmetrical, i.e. $(-, -)$, $(0, 0)$, and $(+, +)$.

The meaning of relationship (ω_1, ω_2) is expressed by the following rule.

If there exists the relationship (ω_1, ω_2) between the components A_i и A_j , this implies:

1. If $\omega_1 = \{-\}$, large values of the component A_j decrease the values of the A_i .
2. If $\omega_1 = \{0\}$, the component A_j does not affect the value of the A_i .
3. If $\omega_1 = \{+\}$, large values of the A_j increase values of the A_i .

It is assumed, that relationships are antisymmetric in the following sense. If there is the relationship (ω_1, ω_2) between the components A_i, A_j , the relationship between the A_j and A_i will be (ω_2, ω_1) .

Two types of dynamics on the base of the system of relationships were suggested. One type uses the weight functions (the additive model), the second — the principles of the law of von Liebig (the law of limiting factor).

The following fundamental result was proved for the dynamic of the system. Let the dynamics of the system is completely described by the minor (2). Suppose that we cannot observe the dynamics at each moments, i. e. at the moments of continuous series $s, s + 1, \dots, s + \sigma$, where σ is natural. But we have the table of observations

$$\tilde{M} = \begin{pmatrix} C_{11} & C_{12} & \dots & C_{1B} \\ C_{21} & C_{22} & \dots & C_{2B} \\ \vdots & \vdots & \ddots & \vdots \\ C_{N1} & C_{N2} & \dots & C_{NB} \end{pmatrix},$$

obtained by equiprobable choice of columns from (2) (B columns were chosen).

Let

$$P = \begin{pmatrix} 1 & r_{12} & \dots & r_{1N} \\ r_{21} & 1 & \dots & r_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ r_{N1} & r_{N2} & \dots & 1 \end{pmatrix}, \tilde{P} = \begin{pmatrix} 1 & \rho_{12} & \dots & \rho_{1N} \\ \rho_{21} & 1 & \dots & \rho_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{N1} & \rho_{N2} & \dots & 1 \end{pmatrix},$$

are to be correlation matrices (Pearson or Spearman) of rows of M и \tilde{M} respectively. Then $\tilde{P} \rightarrow P$ in probability if $B \rightarrow \infty$ (it is assumed entry-wise convergence here).

This fundamental result is a basis for the identification of the models by observations data. If we have the table of observations \tilde{M} , the relationships and initial conditions of the model should be chosen from condition

$$D(P, \tilde{P}) = \sum_{j=1}^{N-1} \sum_{i=j+1}^N (r_{ij} - \rho_{ij})^2 \rightarrow \min,$$

where the minimum is taken over all initial conditions and all admissible relationships.

Materials and Methods

For modeling the structure of relationships between the pigments we used the measure of proximity based on the Spearman correlation, the Liebig's type of dynamics and three levels of component values ($K = 3$).

The test satellite images of agro-landscapes were taken as initial data and processed with use of Image Processing Toolbox of MATLAB. The essence of image processing was calculation of color composites from three spectral channels of the RGB color model.

This method is based on a property of eye retina to form a signal of any color by three types of receptors (*coni*) responsible for color vision.

A part of *coni* of the retina captures the long-wave part of the visible spectrum (red), second part — medium-wave (green) and third part — short-wave part (blue). Therefore, any visible color retrieves from different combinations of three long-wave, medium-wave and short-wave visible spectra or, equivalently, three colors: red, green, and blue. Combining color from the components "R", "G", "B", it's possible to obtain the image that represents the situation at the ground.

The model was built in the following way. Preliminary, we specified so called reference plot as a plowed chernozemic soil, not covered with vegetation. For this plot, we calculated RGB component values of its image. Next, the RGB component values R, G, B and the sum $G + R$ for the plots with vegetation were taken and divided by the corresponding values (R, G, B, $G + R$) of the reference plot and quotients were taken as the components of the dynamical model. The values of the components calculated in such a way were obtained for four fields, from each of which 12 plots of the size of 10 x 10 m allocated in large squares of 50 x 50 m were taken (to be explained later). It is conceivable that colorimetric parameters under consideration for large squares have the same cycle, but for separate plots 10 x 10 m they may be at different phases the cycle.

Results

On the base of simulation with use of images of maize crop (Fig. 1) taken from the satellite Quick Bird (resolution about 1 m/pixel), the signed graphs demonstrating the structure of the relationships between the colorimetric parameters were obtained.



Fig. 1. Satellite image of the test area.

Recultivated (red square on the right) and not-recultivated areas (green square on the top left).

The above mentioned large squares of 50 x 50 m were selected according to the following principle: first square was taken from immediate neighborhood (10 - 50 m) of recultivated area of a former gas-oil well, the second is situated at large distance (500 - 1000 m) from the well on a virgin soil. Denote these squares as the near field (NF) and the far field (FF).

For four images 8 signed graphs were built, 4 graphs for NFs and 4 graphs for FFs (Fig. 2). On the figure the rectangles correspond to the system components, the arrows reflect relationships

between components: solid arrow means negative influence, dashed arrow —

positive. The graphs for the same field are allocated side by side horizontally: NFs — on the left, FFs — on the right.

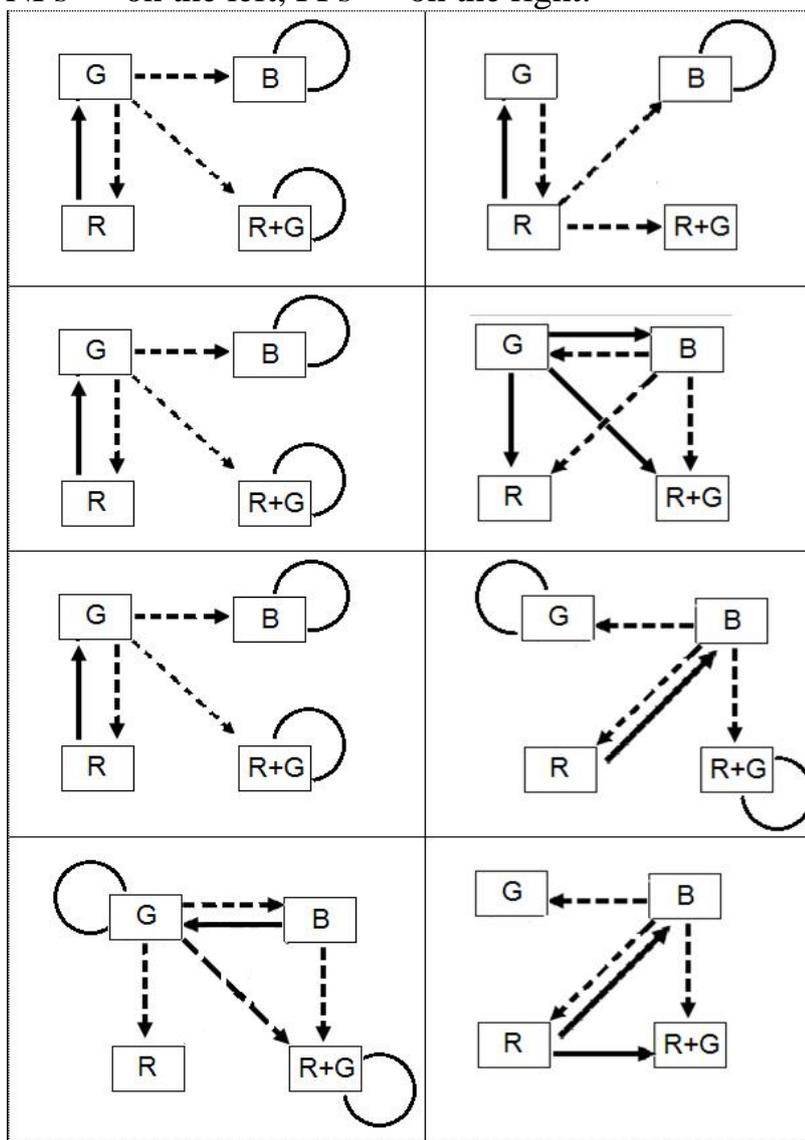


Fig. 2 Signed graphs constructed for various reclaimed and remediated sites crop cultivation.

positive impact of R on G.

In the graphs for the 4th NF and the other three FFs, there doesn't exist feedback of type (+, -) between G and R. Besides, any pair of graphs for the NF and FF of the same image doesn't have a CWD of the same type coinciding on both the FF and NF. Also, there are no similar types of relationships between R and G.

Conclusions

The results obtained for cultivated plants developing in similar conditions show an appropriateness of use of the DMDS model, relatively simple and inexpensive methods of digital photography, and promising application of the effects described above for development of new methods for remote assessment of hu-

The paths weakening the deviation (PWD), that work according to a feedback mechanism of the type (+, -) between the components R and G, are present in four graphs both for FFs and for NFs.

Additionally, such CWDs with the positive impact of G on R and the negative impact of R on G are present in 3 of 4 graphs for NFs and absent in the graphs for FFs. These CWDs reflect the relationships between chlorophyll and the yellow and orange plant pigments often observed in the period of growth and development of crops.

One of the graphs for the FFs has a CWD with the negative impact of G on R and the

man influence on a soil cover. The methods use remote detection of changes in the structure of relationships between pigments of cultivated plants unmasking the tracks of human influence.

In order to identify the structure of relationships between colorimetric parameters, there is no need for long-term remote sensing of test sites and receiving the data arrays like in time series analysis. The case study shows that for identification the differences between the NF and FF one digital satellite imagery is sufficient. Information on the structure of the relationships was identified by splitting an image and applying the identification in framework of the DMDS model.

The study shows that it is possible to select elementary plots on the image with a certain type of graphs of relationships. Later, the analysis of the elementary plots on the image allows us to identify areas having different types of soil cover's disruption.

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Висоцька Є. В., Жолткевич Г. М., Клочко Т. О., Беспалов Ю. Г., Носов К. В. Демаскування порушень ґрунтового покриву за допомогою моделювання динаміки параметрів наземної рослинності. Стаття присвячена проблематиці виявлення незначних змін у характері ґрунтового покриву за допомогою динамічної моделі, що описує взаємодію колориметричних параметрів. На наведеному прикладі цифрового космічного знімка ділянки поверхні показано використання системних ефектів для цілей демаскування порушення ґрунтового покриву.

Ключові слова: дистанційне зондування, демаскування порушень ґрунтового покриву, колориметрія, динамічні системи.

Высоцкая Е. В., Жолткевич Г. Н., Клочко Т. А., Беспалов Ю. Г., Носов К. В. Демаскировка нарушений почвенного покрова с помощью моделирования динамики параметров наземной растительности. Статья посвящена проблематике выявления незначительных изменений в характере почвенного покрова с помощью динамической модели, описывающей взаимодействие колориметрических параметров. На приведенном примере цифрового космического снимка участка поверхности показано использование системных эффектов для целей демаскировки нарушение почвенного покрова.

Ключевые слова: дистанционное зондирование; демаскировка нарушений почвенного покрова; колориметрия; динамические системы

Vysotskaya E. V., Zholtkevych G. N., Klochko T. A., Bespalov Yu. G., Nosov K. V. **Unmasking the soil cover's disruption by modeling the dynamics of ground vegetation parameters.**

The "Introduction" describes topicality and importance of revealing the soil cover's disruption for a wide range of fields. It was shown that spectral brightness and colorimetric parameters of ground vegetation can be used for this task. However, a traditional scheme of data processing for remote sensing requires a long-term observations and cannot always be applied, if quick decision-making is necessary or there is lack of information. Such cases require the use of special methods, one of which is a dynamic model developed with authors' participation based on the following basic relationships: (+,-) (-, -) (+, 0), (-, 0) (0,0).

The section "Brief description of a dynamic model" describes the basic principles of dynamic systems used to solve the problem. Using above-mentioned relationships, the dynamics of a system consisting of several components is constructed and its main properties are listed. The main feature of this model is that the identification of structure and parameters of the dynamic system does not required sequential order of observations (as for models based on time series). This feature of the model enables for identifying the system's parameters of dynamics of the natural system to use information from a single picture taken from the spacecraft rather than long-term observations.

The section "Materials and Methods" describes specific colorimetric parameters used to analyze the vegetation cover.

The section "obtained results" contains an example of the model's application to a satellite image for detecting the differences in two sites of a field with vegetation. One site is a recultivated area near the liquidated gas-oil well, another site is non-recultivated area at a considerable distance from the well (500-1000 m). The simulation results are described by eight signed graphs (4 graphs for each sites), whose structure allows to identify the system differences between the two cases.

The section "Conclusions" summarizes the results of previous sections. The prospects of the use of proposed methodology for soil cover's disruption are shown. Advantages of this methodology over other approaches are highlighted.

Keywords: remote sensing, unmasking soil cover's disruption, colorimetry, dynamical systems.