ANALYSIS OF WORLD EXPERIENCE IN SPACE-BASED METHODS APPLICATION FOR AGRICULTURAL MONITORING

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Formulation of the problem

Even though maps are still the main source of information about the surface of our planet, in recent decades space methods involving digital representation of the Earth surface and the dynamics of its changes are intensively implemented [3]. Nowadays, huge amount of heterogeneous data obtained by remote observation using large number of Earth observation satellites are available. These data are widely used by public authorities in different countries to support making decisions in the field of environmental safety, urban and road construction monitoring, creating a unified geographical database, agriculture monitoring etc.

The State land cadastre is the only system of information about the lands, located within the borders of Ukraine, their purpose, restrictions on their use, as well as the numerical and qualitative characteristics of the lands, their valuation and distribution between the owners and users. It requires comprehensive knowledge about all the land, the unified spatial coordinates system and land plots identification, as well as the commonly accepted system of the actual cadastral information.

A necessary condition for effective organization of agricultural production is up-to-date information on the distribution and use of land resources, agricultural land conditions and the dynamics of climatic factors changing.

Crop rotation, unpredictable changes in structure of sown areas, variation of soil characteristics and meteorological conditions within the growing season - all these factors should be operatively tracked in order to carry out agricultural works in proper time and ensure maximal productivity of the land. The need for such comprehensive information became the reason of introduction of the Earth remote sensing (ERS) methods in agricalture. Modern software gives possibility of controlling the size of cultivated areas, erosion sites identifying, state of crops monitoring and harvest forecasting by features of ground objects, which are obtained from the satellite images. These include spectral characteristics, texture parameters and vegetative indexes calculated by mathematical methods. Till now many algorithms for the space images processing have been developed and global satellite systems for agricultural monitoring have been created. Those are presented on the web-sites of the World Agricultural Outlook Board of the United States Department of Agriculture and the MARS project of Joint Research Center of the European Commission [4]. Let us analyze the progress of the application of ERS methods for agricultural monitoring in the leading countries of the world [8].

Presentation of the main material of the problem

Improvment of land cadastral registration using satellite imagery and analysis of international experience in aerospace methods using are important tasks.

The main advantage of using aerospace methods for agricultural monitoring is their availability and commonly accepted approaches to data acquisition and processing.

In Europe actual land use monitoring is being realized within the framework of Common Agricultural Policy (CAP) [7].

The CAP policy is to support farmers in Europe who provide supply for more than 500 million Europeans. Its main objective is stable supporting of agricultural producers, ensuring low prices for consumers and increasing the standards of work for farmers and agricultural workers.

In particular, in the EU, a single Integrated Administration and Control System (IACS) is developed. This system should be maintained and used by all the EU members. The system is intended for management of grants, which can be obtained by specific farmers or agricultural enterprises directly (direct funding) or within the framework of the rural areas development program from the specialized Paying Agencies (PA).

Within IACS system the correctness of funding can be checked by an administrative procedure or by selective field expeditions. Cross-checking in the IACS system is done automatically.

Aero or satellite imagery of the target area, in most cases, allows to minimize the number of field expeditions and estimate the size of parcels and the crops type remotely. For this purpose satellite imagery data from European satellites of Sentinel family and Copernicus program are used [21].

Since in most EU countries remote sensing data are used for control of at least part of farming subsidies, a substantial amount of information can be obtained within a specialized policy CwRS (Control with Remote Sensing) [20].

The European IACS system uses data from various specialized systems. Therefore, certain data structure is used to ensure the integration and consistency of data collected during the growing season from different sources. In particular, for data exchange regulation in therms of reference parcels that corresponds to different classes of land cover and the land use of LPIS system the INSPIRE infrastructure and ISO standards of geospatial data exchange are used [16].

In the United States, in 1992, a number of laws were passed to ensure the leading role of the country in the field

of obtaining and using remote sensing data, in particular the law No. 2297 "Ensuring US leading role in remote sensing and continuous data acquisition within the Landsat program by developing a new national remote sensing policy". These acts have general name Land Remote Sensing Policy.

Within these documents, the importance of the Landsat Operational Program as well as the satellite data collected by it, and the core competencies of the various departments [10] are stated at the highest legislative level.

The primary purpose of the legislative acts No. 2297, 3614 and 6133 is the following:

- ensuring the US leading role in the field of remote sensing, guaranteeing national security and fulfilling of international obligations;
- legislative support of civil research programs development and demonstration of remote sensing technologies capabilities;
- development of technologies for providing high quality remote sensing data;
- support the permanent global satellite data archive for long-term monitoring of environmental changes.

Other document regulating the activities of the US space agencies are the law No. 111—314 passed on 2010. This law regulates the responsibilities of the NASA space agency, the principles of space programs formulation, licensing access to satellite data and terrestrial segment (long-term storage, free provision), risk assessment of such programs, responsibilities of profile ministries, etc.

In Chapter VI, "Earth Observation" [11], information on satellite information using is provided. In particular, within the activities of the Departments of Agriculture and Internal Affairs of the United States is recorded that for constant improvement in the capabilities of the United States regarding the management and use of renewable and non-renewable resources these agencies are authorized and should initiate research and innovation programs of remote sensing data application by use of appropriate funds. Departments and agencies should initiate research in the universities as well as integration activities between different departments and international organizations.

In recent years, the National Agriculture Statistics Service (NASS) of the United States Department of Agriculture (USDA) annually updates the CDL information product (Cropland Data Layer), which is raster, geographically linked data on individual crops and land surface classes. As input information, the CDL software uses satellite data of medium spatial resolution, land-based and other historical data collected by USDA, such as the National Land Cover Data. Different classification methods are used to obtain open classification results at the level of individual states. Land-based data is collected by land expeditions, organized annually in June, within the framework of supporting the CDL system and the NASS agency. The general classification accuracy ranges from 85% to 95% for the main crops.

The main task of USDA and the US Statistics Department is to provide up-to date, accurate statistics on the dynamics of agricultural production. Since 2009 the CDL program plays an important role in the functioning of US government authorities by providing operational information on crop area estimation for the Agricultural Statistics Board and land information offices for 15 main crops in 27 states. The CDL Program monitors different crops such as corn, soybeans, wheat, rice, cotton and provides estimation of crop area during the current growing season after farmers' reports and satellite data are available. [Fisette T., 2014 6]. For the states with leading agriculture production CDL service updates this information up to 6 times per season.

CDL information products are comprehensive, raster and geographically linked data on individual agricultural crops and other classes of land surface of spatial resolution 56 m. Since 2010 48 land surface classification products for the individual states were openly distributed in the form of data layers for further use in GIS systems.

CDL information products allows to obtain many geospatial data in the United States, including in conjunction with MODIS (geospatial resolution 500 m). These data are used for estimating areas of maize and soybeans, monitoring of agricultural land in North and South Dakota [Pal M. 2003 42], automatic assessment of land condition, harvest forecasting, landscape changes assessing, crop rotation, and solving other problems in various areas [M. Lavreniuk M., 2015 45].

Design of many products implies application of land surveys data, which are collected annually at June under the JAS (June Agricultural Survey) policy. For land surveys, about 11,000 segments of size 1 x 1 miles are being selected in accordance with the national strategy for constructing statistically stratified samples [15].

The main sources of input information for the CDL software are the AWiFS data (spatial resolution in nadir 56 m), Landsat TM and ETM+ (30 m), MODIS satellite data (250-500 m), retrospective and up-to-date terrestrial data, national data sets of land surface classes for non-agricultural areas, historical data and relief model of the US Geological Survey (USGS) agency [Kussul N., 2011 53].

The accuracy of data provide by CDL products for agriculture is assessed by comparing them with an independent validation sample, which is formed using part of the data obtained by land surveys. These data are used exclusively to validate the obtained models on the level of individual pixels [15, Song C, 2001 10]. As a rule, for the main classes of crops, the accuracy of PA and UA is from 85% to 95%. This information is included as metadata in all CDL products [15].

In Canada, on the base of radar data, a layout-scheme of crops is being built annually. Responsible organization is Agriculture and Agri-Food Canada (AAFC), one of the departments of the Government of Canada, which collects information on agricultural production, develops and introduces agriculture monitoring technologies and implements state monitoring policies.

The effectiveness of Canadian agricultural management depends on information that is available for the decision-making process. Because of the scale and complexity of the Canadian agricultural landscape the space imagery and satellite data are used as the main source of up-to-date information on agricultural production. In 2007 AAFC made the first steps to implement this information by developing software for crops mapping by satellite observations. This system is based on the research and software for remote sensing, which were developed in the AAFC department and other organizations for two decades, and is used for crops mapping on individual fields in the provinces of Alberta, Saskatchewan and Manitoba in 2009

and 2010, and in 2011 and 2012 in all the other provinces of Canada (except Newfoundland, which was added to the system in 2013).

In 2009 and 2010, the methodology for the classification and fusion of optical (Landsat 5, AWiFS, DMC, SPOT) and radar (Radarsat 2) satellite imagery were used in the pilot regions of the provinces of Manitoba, Saskatchewan, Alberta. Since 2011, with the support of the National Cadastre of Canada, this methodology is being applied in other provinces. Nowadays the proposed approach allows to perform inventory of crops with an accuracy of not less than 85% by using satellite data with a spatial resolution of 30 m.

Currently, crop maps of the entire territory of Canada are provided 8 months after the end of the growing season [12].

The most needed are two types of cartographic products: Preliminary assessment during growing season and final assessment made soon after the end of vegetation. With this purpose the Earth Observation Service (EOS) introduces a new fully automatic classifier of agricultural crops, which will significantly reduce the time of crops maping. In 2012 the lack of available optical data forced AAFC to rely mainly on RADARSAT 2 satellite radar data, which made the process of crop maping more complicated. It is expected that data from new satellites (Landsat 8, Radarsat Constellation Mission, Sentinel 2) will significantly improve the quality of the crop maps developed by the AAFC.

Inventory of crops allowed to get the fundamental information about the state of agricultural land in Canada. For example, in 2011, the inventory included evaluation of areas too moist for agricultural crops. The obtained results differ by only 3% of the information provided directly by provinces.

For the operative assessment of crop state AAFC develops a crop classification system [23], which allows processing of large amounts of data. The classification process for digital crop maping consists of the following steps:

1) Planning and acquisition the required data.

2) Data preprocessing: atmospheric correction, geometric correction.

3) Definition the regions for classification.

4) Classification [14]. An information system used by AAFC, allows automatic management of the classification processes. A two-tier hierarchical scheme is used, when, at first, agricultural land is divided into generalized classes, which in its turn is divided into subclasses. Classification is carried out in three stages. Firstly, the NLWI map of the Earth's surface is updated. Next, a map of agricultural land and pastures is created. And only after that, the mapping of agricultural crops and the estimation of their are are carried out.

5) Post-processing of classification results (filtering). This step increases the overall classification accuracy by about 5%.

6) Data distribution. The data is distributed in raster format in appropriate UTM projection for the individual provinces. They can be downloaded from the FTP server of the Ministry of Agriculture and Food of Canada AAFC [12].

Taking into account the use of multispectral data (Landsat, SPOT, DMC, AWiFS, etc.), it is possible to classify crops if the data is available at the right time points. If there are clouds on photos, the accuracy of the classification can be significantly reduced. To reduce this risk as well as the cost of obtaining reliable optical data, the Ministry of Agriculture and Food of Canada is working on crop classification algorithms which are only using radar data. For instance, for basic crops such as spring wheat and peas, the accuracy of more than 85% can be achieved at the beginning of growing season (early July) using RADARSAT 2 or RADARSAT Constellation with a larger coverage area [8]. In this case the optical data for classification may not be used.

Each year, the AAFC Department provides tens of thousands of points to identify crops throughout the country. These points are used as training or reference data, and should be linked to the contours of the fields. Digitizing high-resolution images requires a lot of time. In order to reduce this time, an automatic method based on cadastral data and segmentation of a picture is developed [12].

Several global solutions and initiatives related to using satellite information for agricultural land monitoring at global or regional levels should be mentioned. The European Union uses the MARS system [19]. Within MARS, a CGMS system was developed to assess the state of crops and harvest prediction.

Within GEO GLAM program masks construction for major crops around the world, assessment the vegetation state and a forecast for crops growth is realizing. Satellite data and MODIS products are used for this. The management of this system is carried out by University of Maryland (USA). This program is closely linked to the AMIS inter-ministerial initiative, designed to monitor global markets of agricultural products. AMIS uses input data from the GEO GLAM system [14].

In Haifa University of Technology (Israel) scientists have developed a multi-satellite earth scanning system based on small space devices. The GURVIN microsatellite (TechSAT-2) weighing 48 kg and equipped with three-dimensional stabilization system are intended for wide-spectral exploration of the Earth surface in a 27 km radius and resolution of 4.5 m from the height of 600 km. In addition, this satellite performs the X-ray observation. Estimated term of functioning of the divice is three years.

In Italy, the leading developer, Alenia Aerospaz is developing small space divice based imagery system COSMO-SKyMed for implementation of the SAR-2000 program. The Italian company is collaborating with the US in manufacturing X-SAR radars that were used on board the Shuttle spacecraft. At present, this company is developing space platform Prima for prospective Canadian small space device Radarsat.

It is also planned to deploy the RapidEye group of 5-6 small satellites for agriculture and cartography purposes [2].

Ukraine has qualified professionals and advanced industrial and technological base in the field of space research. Interdisciplinary interaction and technology transfer from one sphere to another is implemented for remote sensing developement for solving agricultural problems [4].

Okean-O satellite is intended for the prompt reception of information about the Earth in optical, infrared and

microwave range, as well as for collecting and transmitting information from ground platforms, which allows:

1. Operative reception and transferring remote sensing data to users for studying the Earth natural resources and the World ocean.
2. Solution of economic tasks of nature resources use.

To solve the urgent problems of rational nature resources use it is necessary to create modern means for obtaining operative information about the state of geosystems in Ukraine.

The experience of exploitation of natural resources showed the prospect and efficiency of the remote sensing methods. Therefore, according to the State Space Program of Ukraine, the Ukrainian satellite Sich-1 (1995) and the Ukrainian-Russian satellite Ocean-O (1999) were launched.

Practice shows that the best results are achieved by complex, synchronous conduction of space and ground investigations, when the results of ground measurements are superimposed on the maps obtained by space imagery [6].

On the edge of XX – XXI centuries the Hydrometeorological Institute of the NAS of Ukraine got involved to development of methods for automated processing and interpretation of multispectral satellite data of crops (mainly from NOAA and Resource-01 satellites), as well as the use of remotely determined crop parameters in the dynamic model of crop productivity [Antonenko V., 2002]. At that time, with the support of TACIS, STARS international project was implemented in Ukraine, combining French experience in crops monitoring, on the base of information technologies and space data (mainly SPOT satellite images), and a long-term Ukrainian experience of remote sensing and its ground support. One of the directions of the STARS project is collecting information on natural conditions of crops growth.

At the present stage, scientific and methodological bases for remote sensing methods application in agriculture of Ukraine are being developed by scientific teams of different departments. Within the National Academy of Agrarian Sciences of Ukraine (NAASU) several organizations are working on this task. In particular, in the sector of soil remote sensing of the National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky» [http://www.issar.kharkov.ua/], on the basis of multispectral space scanning materials and GIS technologies, various soil characteristics are monitored and electronic soil maps are created.

The Laboratory for Water Resources and Monitoring of the Institute of Water Problems and Land Reclamation of the NAASU [http://igim.igim.org.ua/] performs research on the water resources transformation processes and reclaimed territories, land condition and stability forecasting using modern technologies, including remote sensing data.

In the Institute of Agroecology of NAASU there is a laboratory of aerospace sensing of the agrosphere, the tasks of which is fundamental research and applied solutions in the field of remote sensing of agricultural objects [http://agroeco.at.ua/]. The main idea is to create a selective network for observation of agricultural areas, condition and productivity of grain crops using space data [7].

In 2007 by the specialists of NAASU the concept of scientific and technical program "Monitoring of agrarian resources and their condition forecasting using remote sensing data" (short name "Agrokosmos") was developed, which should become the first step for creation a state monitoring system of agrarian resources. The system is intended for development and implementation of the latest information technologies of control and management of agrarian resources using remote sensing data.

In November 2008 Institute of Forecasting and Testing of Equipment and Technologies named after. L. Pogorilii [http://ndipvt.org.ua/] was appointed by the Ministry of Agrarian Policy of Ukraine as a responsible contractor of obtaining access to the European system of remote sensing techniques MARS and together with the Institute for the Protection and Security of the Citizen (Ispra, Italy) signed an agreement on the use of this system in Ukraine. It was planned to use EUR 3 million for MARS satellite harvest forecasting system purchase, as well as new equipment for six laboratories. The first positive results of this cooperation have already been achieved.

Conclusions

Having considered the most prospective solutions that can be implemented in Ukraine, it can be noted that world practice shows that the most effective sources of information for agricultural land monitoring are the space remote sensing systems due to the fact that the world is on the edge of a revolution in space imagery technologies. The newest high-resolution space devices will be commercially available in the nearest future. By the end of 2017 there will be about 200 high resolution commercial satellites on orbit, including up to 60 of them intended for radar imagery, which will be possible regardless of weather conditions in 24 hours mode. Their resolution will be not less than 70 cm, and three satellites will guarantee even higher (40-50 cm) resolution. The group of satellites should be equipped with appropriate communication system to receive and transmit to users constantly updating information of agricultural land monitoring.

In Ukraine the remote space sensing methods for agricultural implementation is being developed by scientific teams of different departments.

Our state has qualified specialists and advanced industrial and scientific background of space research. On the other hand, Ukraine possesses powerful reserves of fertile black earth, which determine the priority of domestic agriculture development. Okean-O spacecraft provides operative information about the Earth in optical, infra-red and microwave range. The experience of satellite imagery use for natural resource assessing showed promising effectiveness of remote sensing methods. In this regard, according to the State Space Program of Ukraine, Ukrainian satellite Sich-1 was launched. With the support of TACIS, STARS international project was implemented in Ukraine, combining French experience in crops monitoring, on the base of information technologies and space data (mainly SPOT satellite images), and a long-term Ukrainian experience of remote sensing and its ground support. Within the framework of Interdepartmental Meeting on the Issues of Development of the State Scientific and Technical Program “Monitoring of agricultural resources: forecast and assessment” it is planned in cooperation with international corporation“Rapid Eye” to carry out the pilot project “Agro-UA” in order to ensure the competitiveness of agriculture

and food safety of Ukraine. The participants of the project are Agrokosmos, the Space Agency of Ukraine and the National Academy of Agrarian Sciences of Ukraine. Thus, specialists from different institutions in Ukraine already have valuable experience in working with satellite imagery for agricultural production tasks. However, because of a number of problems, a unified system of space monitoring for at least the most important sectors of agriculture is still not created in Ukraine.

At the same time, Ukraine has established close relationships with world leading organizations such as JRC center of European Commission and has experience in developing and adapting of methods and technologies of land monitoring, which are being implemented in Europe and other countries. In particular, the above-mentioned Integrated Administration and Control System (IACS), which should be supported and used by all EU Members, as well as Ukraine. But the task of implementation of satellite monitoring technologies in state departments of Ukraine is complicated due to the lack of legislative framework.

For effective implementation of land monitoring, the network of stations and observation posts with modern special equipment should be created. No less important task is organization of proper functioning of the environment monitoring system, its financial and technological support.

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Analysis of world experience in space-based methods application for agricultural monitoring

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The solutions and experience in space imagery methods application for agricultural land monitoring worldwide and in Ukraine are analyzed. The prospective and the problems of remote sensing methods implamentation for solving various tasks of agricaltur monitoring are indicated.