Conjunction and synchronization methods of earth satellite images with local cartographic data

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Abstract — **The tools for processing satellite images and orientation objects with maximum accuracy based on local cartographic data are considered. A brief description of the process of obtaining digital images, preliminary procedures for processing images, as well as the process of detection and recognition of objects in the image. The results of working with interactive maps, as well as completed and approved projects based on the services OpenStreetMap, Yandex.Maps and Google Earth, are described. A brief overview of interactive maps of the area and their views, including interactive maps with visualization, is given. The most popular services with interactive maps of the area, their types and applications are also considered. The technique of processing satellite images with their subsequent placement in cartographic services is presented. Fragments of individual projects for editing interactive maps for various types of areas are also presented. Orientation problems with maximum accuracy are described using the services OpenStreetMap, Yandex.Maps and Google Earth, and the features of using interactive maps for various categories of users.**

Keywords* — *Earth remote sensing, satellite image processing, OpenStreetMap, Yandex.Maps, Google Earth.

I. INTRODUCTION

Remote methods for studying the environment is a complex and diverse field of science and technology, undergoing a period of rapid development. The first pictures of hard-to-reach areas were taken from the aircraft back in 1910. After aerial photography of the area, a complex process of deciphering the images follows – each object needs to be recognized and the results recorded.

Now terrestrial and aerial surveys are increasingly being replaced by Earth remote sensing satellites. Satellites can be conditionally divided into ordinary and ultra-high resolution. Naturally, for photographing the taiga or the ocean, very high-quality photographs are not needed, and for certain areas or tasks satellites photographing in ultra-high resolution are simply necessary. Currently, most of the Earth remote sensing data (ERS) are obtained from artificial Earth satellites (AES). Organization of work on the study of the Earth's surface, based on a combination of aerospace methods with a small amount of ground-based research, which are carried out on a limited number of support routes and key sections, can significantly reduce the time of work and reduce their cost.

Remote sensing data is currently aerospace images that are digitally presented as raster images, therefore, the problems of processing and interpretation of remote sensing data are closely related to digital image processing. Satellite imagery data has become available to a wide range of users and is actively used for scientific and industrial purposes. Remote sensing is one of the main sources of relevant and operational data for geographic information systems.

Scientific and technological achievements in the field of creation and development of space systems, technologies for obtaining, processing and interpreting data have greatly expanded the range of tasks solved using remote sensing. The main areas of application of remote sensing data from outer space are the study of the state of the environment, land use, assessment of the consequences of natural disasters, etc.

Remote sensing today – this is a huge variety of methods for acquiring images in virtually all wavelengths of the electromagnetic spectrum from ultraviolet to far infrared and radio range, the most varied visibility – from images from meteorological geostationary satellites, covering almost the entire hemisphere, to detailed surveys of small areas. Spatial resolution can vary from a few kilometers to several centimeters.

II. DIGITAL IMAGING IN REMOTE SENSING

Remote sensing data processing includes preprocessing and image enhancement. In the process of image preprocessing, systematic radiometric and geometric errors are removed from the data. Image enhancement allows you to convert it to the form most convenient for visual or machine analysis and used to emphasize the most important features of the image and further facilitate the task of data interpretation. To improve the image usually use the change in brightness and contrast, as well as spatial filtering and Fourier transform. Remote sensing data processing is a preparatory stage before extracting thematic information from the image.

Currently, there are a number of software tools used for preliminary and thematic processing of remote sensing data. The most common are ERDAS Imagine, ER Mapper, ENVI, IDRISI, etc.

From the moment the image is received from the satellite, to the possibility of analyzing it, a whole cycle of procedures must be taken to bring it into a form convenient for obtaining and subsequent analysis of visual information.

III. DIGITAL IMAGE AND THE PROCESS OF OBTAINING IT

As you know, a digital image is a matrix of pixels, the value of each of which is obtained by averaging over four

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components: the coordinates of space (x and y), wavelength and time. Each pixel stores information in binary form. The more bits are allocated per pixel, the greater the number of values corresponding to one pixel, the original discrete signal is more accurately approximated and the image can store more information. In CCD scanners, the already mentioned detectors scan the Earth and divide a continuous stream of data into pixels [1].

A lot depends on the type of scanner, it determines the method of obtaining images. So, there are three main types of CCD scanners – linear, transverse and longitudinal (Fig. 1).

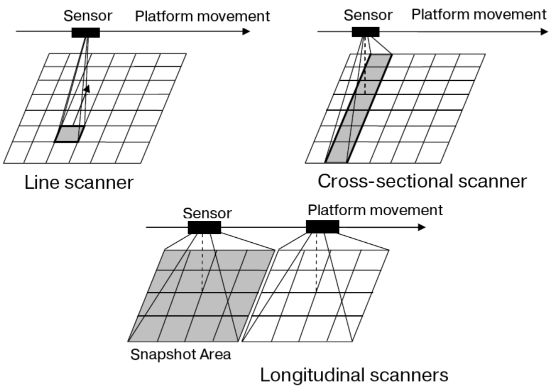

Fig. 1. The main types of CCD scanners [1]

1. Line scanner (for example, AVHRR) – the simplest, it is equipped with only one detector element.

2. Cross-sectional scanner (GOES, MODIS, TM) – uses a line of detectors located along the survey path for scanning. A parallel scan of the Earth is carried out with each cycle of motion of the mirror.

3. Longitudinal scanners (IKONOS, QuickBird, SPOT) have thousands of detectors in the CCD line, therefore, parallel scanning is carried out simply by moving the platform in orbit.

Digital images are displayed using either an 8-bit grayscale or 24-bit scale, which is based on a mixture of different shades of R, G, B. The original range of pixel values is converted into a limited range by combining color values that correspond to any three channels of a multispectral digital image. One pixel is displayed by 256^3 RGB vectors, one vector is one color. There are other options for radiometric resolution. For example, QuickBird has 11 bits/pix, Landsat-8 has 16 bits/pix.

IV. PRELIMINARY IMAGE PROCESSING PROCEDURES

The cycle of preliminary procedures for image processing includes:

1. 1. Radiometric correction – eliminates the variation in pixel brightness values that occurs as a result of improper operation of the detectors, the influence of topography and atmosphere.

2. 2. Atmospheric correction – correction for the influence of the atmosphere, which determines the location of the shooting ranges due to the transparency windows.

3. *Geometric correction* includes the correction of image distortions such as streakiness, line dropping, and geocoding – linking the image in such a way that each image point is assigned the coordinate of the corresponding point on the ground. Mathematically, georeferencing is usually done using power polynomials. The accuracy of the snap is increased when there are reference points. After geocoding, the brightness characteristics of the already transformed image are determined by various methods: the nearest neighbor, bilinear interpolation, bicubic convolution.

4. Orthorectification – Image errors are eliminated due to differences in elevation of the terrain, as a result, many errors of central design are eliminated in the resulting image.

Next, the process of improving image quality, including:

1. Spectral transformations, which are based on work with a spectral diagram – a graph showing the relationship between the number of image pixels and spectral brightness values.

2. Filtering, which enhances the reproduction of objects, eliminates noise, emphasizes structural lines, smooths the image and does much more – depending on the task.

3. The Fourier transform improves the quality of the image by decomposing it into many spatial-frequency components. The distribution of brightness characteristics in space is represented as a linear combination of periodic functions sin and cos with given characteristics in the frequency domain. For example, to remove noise, it is enough to identify the frequency of their occurrence.

V. DECRYPTION

Decryption is the process of detecting and recognizing objects in a picture. It can be manual, based on a visual assessment of the image, and machine (automatic). Machine processing consists of various classification mechanisms. First you need to imagine all the pixels (their spectral brightness) as vectors in the space of spectral features. When analyzing the quantitative relationships of the spectral brightnesses of different objects, pixels are divided into classes. The classification of images is divided into classification with and without training.

Classification with training

Classification with training implies the existence of a standard with which the brightness of each pixel is compared. As a result, having several standards predefined, we get many objects divided into classes. This classification only works if the objects that are displayed in the image are known in advance, the classes are clearly distinguishable and their number is small.

Here are just a few of the methods that can be used in classifications with training:

1. *The method of minimum distance* – the brightness values of pixels are considered as vectors in the space of spectral features. Between these values and the values of the vectors of the reference sections, the spectral distance is calculated as the root of the sum of the squares of the difference between the vectors of the pixel and the reference

(Euclidean distance between them). All pixels are divided into classes depending on whether the distance between them and the reference exceeds the set or not. If the distance is less, then the class is defined, the pixel can be attributed to the standard.

2. *The Mahalanobis distance method* – is very similar to the first method, only classification does not measure the Euclidean distance between the vectors, but the Mahalanobis distance, which takes into account the variance of the brightness values of the standard. In this method, if the Euclidean distance to two standards from a given pixel is equal, then the class with the variance of the reference sample is greater will win.

3. *Spectral angle method* – initially the maximum value of the spectral angle (the angle between the reference vector and the vector of this pixel) is set. The spectral angle is found, and, as with the Euclidean distance, if the angle is less than the specified one, then the pixel falls into the standard class with which the comparison is being made.

Classification without training

Classification without training is based on a fully automatic distribution of pixels into classes based on statistics on the distribution of brightness values of pixels. This type of classification is used if it is not initially known how many objects are present in the image, the number of objects is large, as a result, the machine itself generates the obtained classes, and we determine which objects to match them with [2].

1. *The ISODATA method (Iterative Self-Organizing Data Analysis Technique Algorithm)* is based on cluster analysis using the method of successive approximations. After considering the brightness of pixels as vectors in the space of spectral features, the nearest ones are determined in one class. For each spectral zone, the statistical parameters of the brightness distribution are calculated. All pixels are divided by some n number of equal ranges, inside each of which is an average value. For each pixel in the range, the spectral distance to the average value is calculated. All pixels with the smallest distance between them are defined in one cluster. This is the first iteration. At the second iteration and subsequent it is already real average values for each cluster are calculated. Each new iteration refines the boundaries of future classes.

2. K-means method – similar to the previous method, but initial averages are set (this is possible only if the objects in the picture are well readable).

All processes of pre-processing, improving the quality of images and decoding represent a huge field for discussion [5,7,8].

VI. Problems of Satellite Images

The modern world is very changeable: cities are growing, new roads, communication networks, engineering structures are being built, new areas of mining are being developed, forests are being cut down, land use patterns are changing, etc. Therefore, the constant challenge of updating topographic maps showing all the visible elements of the area with the same detail. Such maps display terrain, hydrography, vegetation, soils and soils, settlements, road network, socio-cultural and other objects, which allows a comprehensive assessment of the territory [6]. To determine the parameters that cannot be obtained from the images, additional data sources are used.

When updating topographic maps, only contour changes are applied, and when drawing up, it is necessary to accurately determine the position of these elements. Therefore, to compile topographic maps, satellite images of higher spatial resolution are required. When compiling and updating topographic maps of a certain scale, the same images may be suitable or unsuitable for various elements of the map contents.

In theory, in order to create a vector map, a satellite image and a graphic editor or service are enough to use it to draw all objects from the image. But in reality, this is not entirely true: almost always real objects on the surface of the earth do not correspond to digital data of several meters.

The distortion is due to the fact that all the satellites take pictures at an angle to the Earth at high speed. Therefore, recently, to clarify the location of objects began to use photo and video, and even tracking cars. Also, to create accurate maps, it is imperative to convert satellite images taken at an angle to strictly vertical images.

And this is just the small tip of the iceberg. A new building was built, a ford appeared on the river, and part of the forest was cut down – all this is almost impossible to quickly and accurately detect using satellite imagery. In such cases, the OpenStreetMap project and the like come to the rescue, working on a similar principle.

OpenStreetMap is a non-profit project created in 2004, which is an open platform for creating a global geographic map. Anyone can contribute to improving the accuracy of maps, whether it be photographs, GPS-tracks, videos or simple knowledge of local residents. Combining this information and satellite images, maps are created as close as possible to reality. To some extent, the OSM project is similar to Wikipedia, where people from all over the world work to create a free knowledge base (Fig. 2).

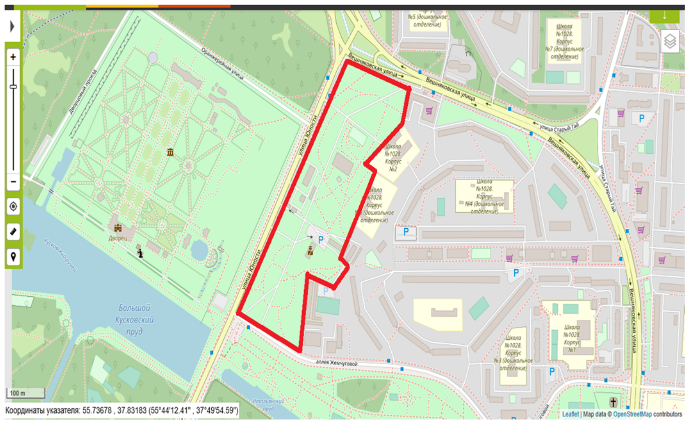

Fig. 2.An example of work in OpenStreetMap (Moscow)

Any user can edit the maps on their own, and after checking and approving these changes by the project staff, the updated map becomes available to everyone. GPS tracks and satellite images of Bing, Mapbox, DigitalGlobe are used as the basis for creating maps. Due to commercial restrictions, Google and Yandex maps cannot be used.

Progress does not stand still and cartography was no exception. Services are already being created on the basis of machine learning and neural networks, which are able to independently add objects, determine densely populated territories and do map analysis. While this trend is still not very visible, but in the near future, people may not have to edit maps in OSM at all. Cartographers believe that the future lies in the automatic creation of maps, where machine vision will be used to model objects to the nearest centimeter.

VII. Interactive maps and their types

Let's take a closer look at what interactive maps are and which of them are the most popular today.

An interactive map is an electronic map operating in the mode of interaction between a user and a computer and is a visual information system. For example, you can select the category of objects that you want to see on the map, and only they will be displayed. By clicking on an object, you can get additional information on it.

Information about the objects is presented in text and graphic form. For visual presentation, we used both traditional photographs taken at different times of the year in different conditions, including aerial photography, as well as modern interactive virtual 3D tours, where you can inspect the mouse in any direction by controlling the mouse.

When viewing an interactive map based on the technology of geographic information systems (GIS), the user sees only that part of it that is of interest to him at the moment. If desired, he can move around the map in any direction, zoom in or delete the fragment in question.

Recently, interactive maps with visualization have appeared, in which the map is combined with satellite images that are geographically attached to the map, and the user does not see symbols, but real landscapes taken from the satellite (Fig. 3).

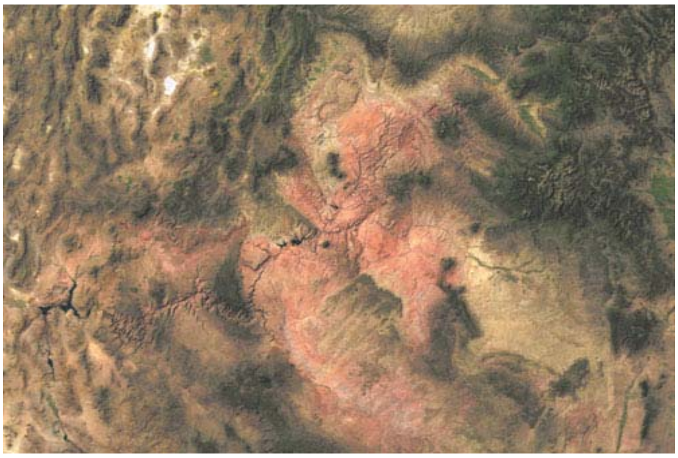

Fig. 3. Travel on the Great Canyon in the environment of an interactive map with a three-dimensional visualization

VIII. The scope of interactive maps application

Electronic maps are indispensable in all cases when you need to find something, or visually show the location of some object (for example, the plan of your office or the country's position on the political map of the world). Now electronic cards should be considered not only as a cartographic reference, but as a source of a wide variety of information related to a specific territory. Examples of such interactive maps can be maps of the metro and urban land transport, maps of roads and railways, locations of gas stations and shops, tourist attractions and architectural monuments, weather maps, etc.

For comparison, it is worth looking at the interactive map of the Borodino Military History Museum, where the object is just the territory of the Battle of Borodino field, and interactivity consists in obtaining a brief reference on the location of troops during the battle, which allows you to clearly imagine the battle (Fig. 4).

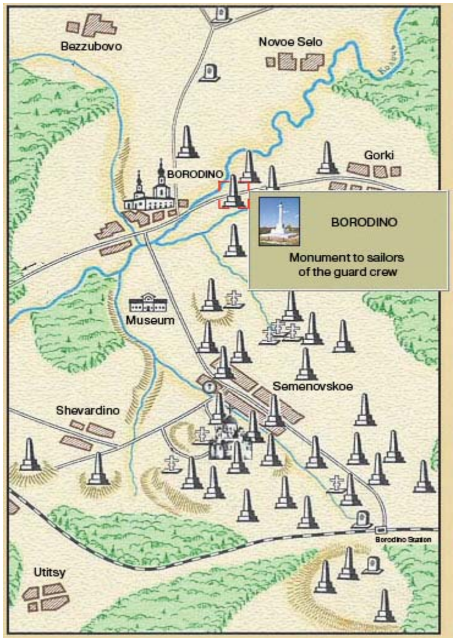

Fig. 4. Interactive map of the Borodino battle

Being a source of various information, modern interactive maps are indispensable as a navigation tool. They will be useful not only when preparing for a long trip, but also if the user needs to visit an unfamiliar area of his hometown, especially since finding detailed interactive maps of many cities with house numbers is not a problem today. As a rule, on these maps the routes of urban land transport are displayed, and therefore it is not difficult to choose the optimal route. All possible directions to the destination are displayed automatically, for example, this is what happens on the interactive map of Moscow.

No less useful is the possibility of forming the optimal route when moving on the subway. An example of a card with the support of this service is an online map of the Moscow metro. To form the optimal route, just select the start and end stations and click on the "Search" button – you will be shown the location of transfers and their number, as well as the travel time.

IX. Interactive maps with visualization

Interactive maps are even more interesting, in which it is possible to visualize the fragment in question. Such a map is a virtual globe (or a fragment of a globe), so you can look at any place on the earth’s surface and see mountains and rivers, cities and fields, forests and lakes there – and not symbols, but photographs.

The most famous and recognized among online projects of this type were Google Maps (http://maps.google.com), Google Earth (http://earth.google.com) and NASA WorldWind (http: //worldwind.arc. nasa.gov) containing information on the entire earth's surface. The Google Maps service displays information directly in the browser, and Google Earth and NASA WorldWind work with data using a navigator program that must be downloaded and installed on a computer beforehand (Fig. 5).

Fig. 5. Viewing a map fragment in Satellite mode (Google maps)

The main difference between Google Earth and NASA WorldWind from Google Maps is the presence of three-dimensionality, due to which the entire surface of the Earth is also voluminous, as well as individual objects, such as buildings (Fig. 6).

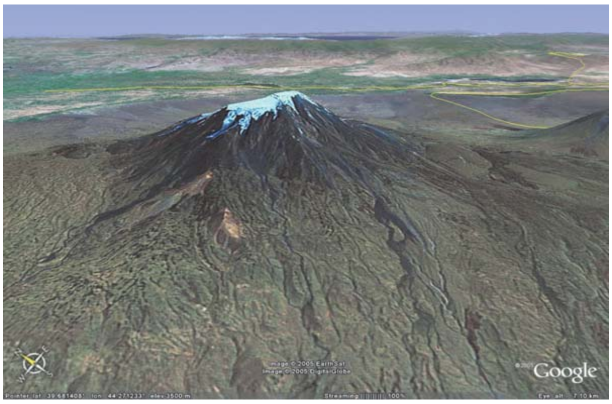

Fig. 6. Three-dimensional reproduction of earthsurfaces (Google Earth)

In addition, Google Earth has additional interesting features – for example, you can fly around the territory at a given height and speed, measure distance, work with GPS and create your own maps by superimposing your objects on the original Google Earth map. The NASA WorldWind service contains a daily updated database of natural disasters: typhoons, floods, forest fires, volcanic eruptions, etc., and the dynamics of changes in the areas of the Earth where natural disasters occurred can be traced.

The concept of a geographic information system is also used in a narrower sense – as a software product that allows users to search, analyze and edit a digital map of the area and additional information about objects.

In this article, the author proposes a technique for processing satellite images with their subsequent placement in cartographic services and fragments of individual projects for editing interactive maps for various types of terrain. Having examined various services and online platforms that allow the user to edit individual objects on maps or create their own maps by superimposing their objects on the original map, it becomes obvious that at the moment there are no automation methods available even for partial preparation of images for analysis. Software products closest to such an analysis are highly specialized and practically inaccessible.

This is especially noticeable when analyzing changes in one territory for some time, when they are being prepared for analysis, large numbers of satellite images are analyzed and their thematic processing is performed. The relevance and practical aspect of these problems are related to the fact that currently there are no available methods for automating such preparation and thematic processing of satellite images.

The author of the article has proposed an image processing technique that can be applied locally for critical infrastructures, using cartographic online services.

Compare the three most popular services used today:

a) Yandex.Maps;

b) Google Maps;

c) OpenStreetMap.

The presented methodology is applicable for any of the above services (Fig. 7). The main advantage is the processing speed and universality of use for a specific task.

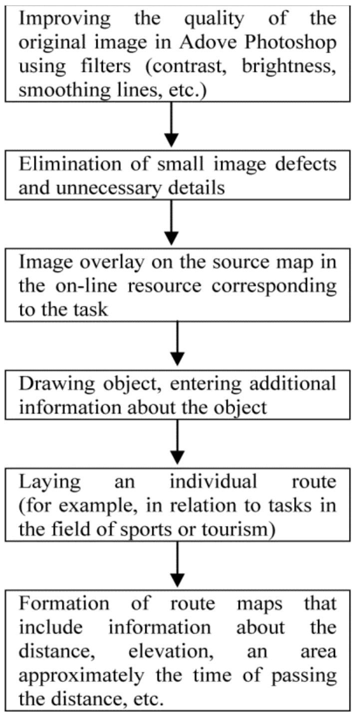

Fig. 7. Image processing technique overlayed on an interactive on-line map

Yandex.Maps – Yandex search and information mapping service (Fig. 8). Opened in 2004. It contains a map search, information about traffic jams, laying out routes and panoramas of streets of large and other cities. The route is laid even when the departure point and the final point are in the territories of different countries.

Fig. 8. Specially equipped car for shooting street panoramas

By mid-2019, the Russian audience of the resource reached 25 million users.

Maps are available in four versions: schemes, satellite images, satellite images with inscriptions and symbols (hybrid) and People's map. On the maps there is the ability to measure distance, lay routes and view street panoramas [3, 9]. It is possible to view images from web cameras in real time, installed, as a rule, along the largest highways and near junctions (Fig. 9).

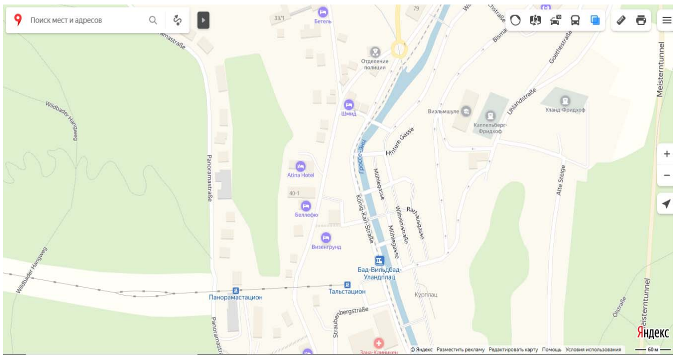

Fig. 9. An example of a project in Yandex maps (Germany), approved by moderators

Google Maps is a collection of applications built on the basis of the free mapping service and technology provided by Google. Created in 2005. The service is a map and satellite images of the planet Earth. Additionally, images of Mercury, Venus, the ISS, the Moon, Mars, etc. are offered. A business guide and a road map with route search are integrated with the service. In July 2015, the "Timeline" function appeared in the service, which records the history of routes and places that the user visited on a certain day.

The *Google Earth* mapping application is also gaining popularity today for professional athletes and travel enthusiasts in hard-to-reach and, especially, mountainous areas. Below are the works of the author of the article in this program. In this case, the Google Earth application was used to develop and fix mountain bike routes (Fig. 10 a-c).

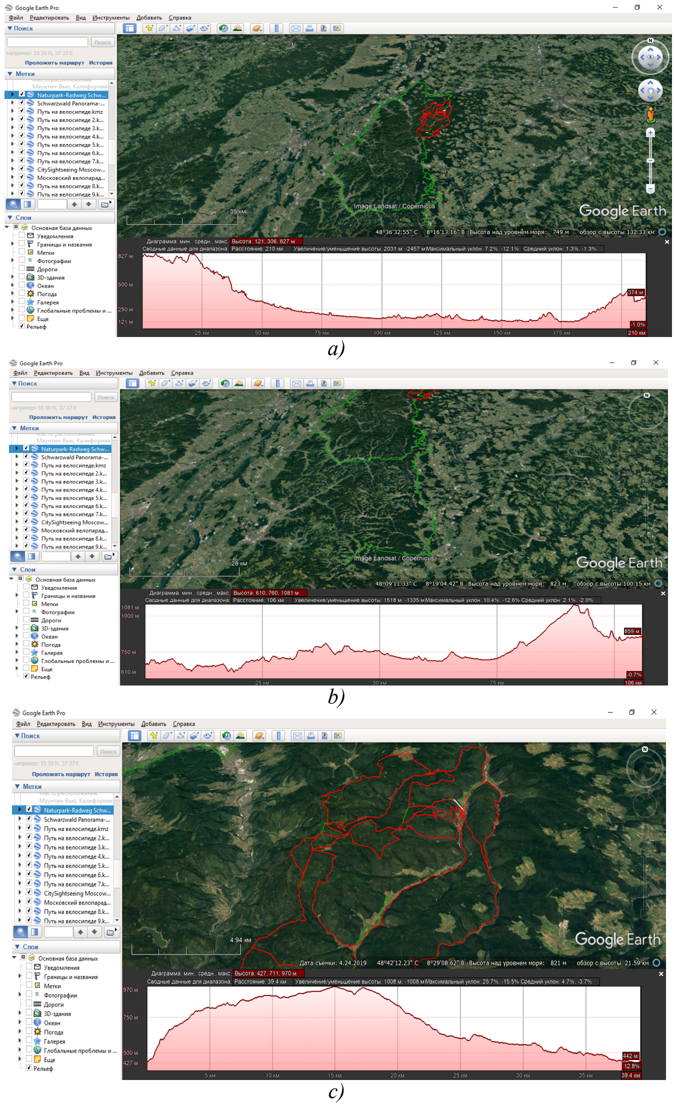

Fig. 10. Laying of cycling routes in mountainous terrain using Google Earth application

The figures show the results of the passage of routes with indications of elevations and the exact distances at different stages of the path. In hard-to-reach mountainous areas, this is especially true, since bike riders can get into adverse weather conditions, get injured, make a mistake with the balance of power. In this case, each kilometer of the way and the terrain are important to them, and not just the approximate distance on the map to the point of arrival.

These calculations also help to draw conclusions about the route traveled: the total length in kilometers, elevations, difficulty of the distance, etc.

Google Street View allows users of Google Maps to "wander around" on a three-dimensional projection of the city or some of its streets via the Internet. This functionality is achieved using circular photography of real terrain with special equipment.

OpenStreetMap (OSM) is a non-profit cartographic project aimed at creating a detailed free and free geographical map of the world by the community of participants – Internet users.

To create maps, data from personal GPS trackers, aerial photographs, video recordings, satellite images and street panoramas provided by some companies, as well as the knowledge of the person who draws the map, are used. Each registered user can make changes to the map.

Steve Coast was inspired by the success of Wikipedia and decided that the principle underlying Wikipedia can be applied to web mapping. To implement his ideas in the UK in July 2004, he created the OpenStreetMap project.

This happened even before the advent of Google Maps, and the goal of OpenStreetMap – to get a free map of the world, relying on volunteers with GPS devices, seemed difficult to implement (Fig. 11).

Fig. 11. Sample project in OpenStreetMap (residential and industrial facilities in the Moscow region)

In January 2007, Cambridge became the first completely "rendered" city. On January 5, 2010, the 200,000th participant was registered. In January of the same year, when a catastrophic earthquake occurred in Haiti, thousands of project participants took part in compiling and updating the map of Haiti. This raised the popularity of OpenStreetMap, many media wrote about the project, and by April 2010 the number of participants exceeded 250 thousand [4]. Today there are more than a million of them (Fig. 12).

Fig. 12. Statistics of OpenStreetMap use

Currently, remote sensing is a source of relevant and timely information and is widely used to solve various thematic problems. A large archive of remote sensing data has been accumulated, which is regularly updated. A potential consumer has ample opportunity to choose images by type of survey, spatial and radiometric resolution, as well as by time of shooting.

X. Conclusion

Despite the great achievements in the field of remote sensing of the Earth, there are a number of problems associated with the processing of the obtained data. For example, decryption, a different approach to generating metadata for different satellites, long and costly processing of images for specific tasks. In the process of analyzing satellite imagery, a lot of similar actions are performed. The time taken to prepare the images takes much more time than the analysis itself. This is especially noticeable when analyzing changes in one territory for some time, when they are being prepared for analysis, large numbers of satellite images are analyzed and their thematic processing is performed. The relevance and practical aspect of these problems are related to the fact that currently there are no available methods for automating such preparation and thematic processing of satellite images.

At the moment, there are no automation methods available even for partial preparation of images for analysis. Software products closest to such an analysis are highly specialized and practically inaccessible. Automatic recognition of satellite or aerial photographs is the most promising way to obtain information about the location of various objects on the ground. The rejection of manual image segmentation is especially relevant when it comes to processing large areas of the earth's surface in a short time. The technique proposed in this article is effective for use in the preparation of individual projects in interactive cartographic applications.

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