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THE WEB APPLICATION FOR PLANNING REMOTE SENSING OF THE EARTH

Abstract. This article describes a web application for constructing the orbit of a remote sensing (RS) satellite and for planning the survey of the specified territory on the Earth's surface. It is important for RS to select an appropriate satellite, taking into account such criteria as optical characteristics and frequency of surveys. The developed application offers a user-friendly interface and efficient calculation of the satellite position. With this application, the user will be able to see the trajectory of any available commercial ERS satellite for a specified period of time, calculate all the possibilities that meet the user's requirements for surveying a point or polygon on the Earth's surface and schedule a survey of the area of interest taking into account all the required restrictions. The algorithm is based on the SGP4 model, which uses public TLE data for Earth remote sensing satellites, formulas of celestial mechanics, analytical geometry, and heuristic methods for reducing computations. The program code is written in JavaScript and PHP programming languages using the Bootstrap, JQuery, and Cesiumjs libraries. JavaScript is the most common means of creating browser interfaces, new features are added to the language. The article contains screenshots of the program itself and the results of speed tests of calculations performance are presented in the article.

Key words: remote sensing of the Earth, survey planning, SGP4, TLE, the motion trajectory, web application.

Satellite methods of studying the Earth's surface have become important in recent decades. This is connected both with the further improvement of space technology, and with the curtailment of aviation and ground-based methods of monitoring. The main applications of satellite remote sensing of the Earth (RS) are obtaining information on the state of the environment and land use, studying plant communities, assessing crop yields and the consequences of natural disasters. Remote sensing tools are effective in studying soil and water pollution, ice on land and water, in oceanology. These facilities allow obtaining information about the state of the atmosphere, including on a global scale.

Whatever is the sphere of use of ERS imagery, there is always a need for operative provision of consumers with up-to-date data. In other words, the speed of the order execution is important for all users. Most of the time in the work to fulfill the order for space images is taken by the survey process itself. The duration of this process depends on the size and location of the ordered territory, the climatic conditions during the survey, as well as the optical characteristics and orbital parameters of the spacecraft itself. All this must be taken into account when forming a request for space imagery by both the supplier and the client, in order to correctly plan their further work.

At the same time, remote sensing services are provided by hundreds of satellites moving in low Earth orbits. In this regard, remote sensing service users have got the problem of choosing a suitable satellite. The selection criteria here are, firstly, optical characteristics, and secondly, the possible frequency of surveys with the desired parameters. If we conditionally allocate a class for the similarity of optical characteristics from a set of all available remote sensing satellites, then it is required for final decision-making to evaluate to what extent it is possible to execute an acquisition order by means of a particular spacecraft from this class. The program described in this article can help in solving these problems.

The software product considered in this paper allows solving the following tasks for any open commercial ERS spacecraft:

1) To construct a motion trajectory for a given time interval.
2) To estimate the frequency of passing in the vicinity of the territory of interest.
3) To see all the possibilities for surveying the ordered part of the Earth's surface for the specified date range, taking into account the customer's requirements.
4) To create a time-optimal plan of the survey of the requested area on the Earth surface.

Thus, a user can select with the help of this application an ERS spacecraft, that is the most suitable for its purposes and requirements, and estimate the time costs in order to take them into account.

The application itself is based on a number of mathematical algorithms, where SGP4 model [1] takes central part. SGP4 determines position and velocity of a satellite at a point in time by appropriate TLE data [2], which is in a free and public access for all commercial ERS spacecrafts. So it is enough to run SGP4 model with some time step in order to construct a motion trajectory for a given time interval.

The task of finding all the possibilities for surveying the ordered territory that satisfy all user's requirements expands previous one and includes next subtasks:

– Coordinate and date transformations [3, 4].
– Calculation of the Sun's angle on the terrain at a given time [5].
– The construction of a minimal convex hull of an arbitrary set of points in the plane [6].
– The determination of the intersection of a point or a convex polygon on the surface of the Earth with some neighborhood of the subsatellite point.

Thus, the algorithm for the second task consists of the solution of these subtasks. Also the formulas of spherical trigonometry [7] are used there.

The last task – planning the time-optimal process of shooting a polygon on the surface of the Earth – extends previous task with next subtasks:

– to cover polygon with shooting strips;
– to arrange the order of surveying strips so that it takes the least time to shoot the entire polygon.

These subtasks and the last one from the previous task have been solved by authors themselves.

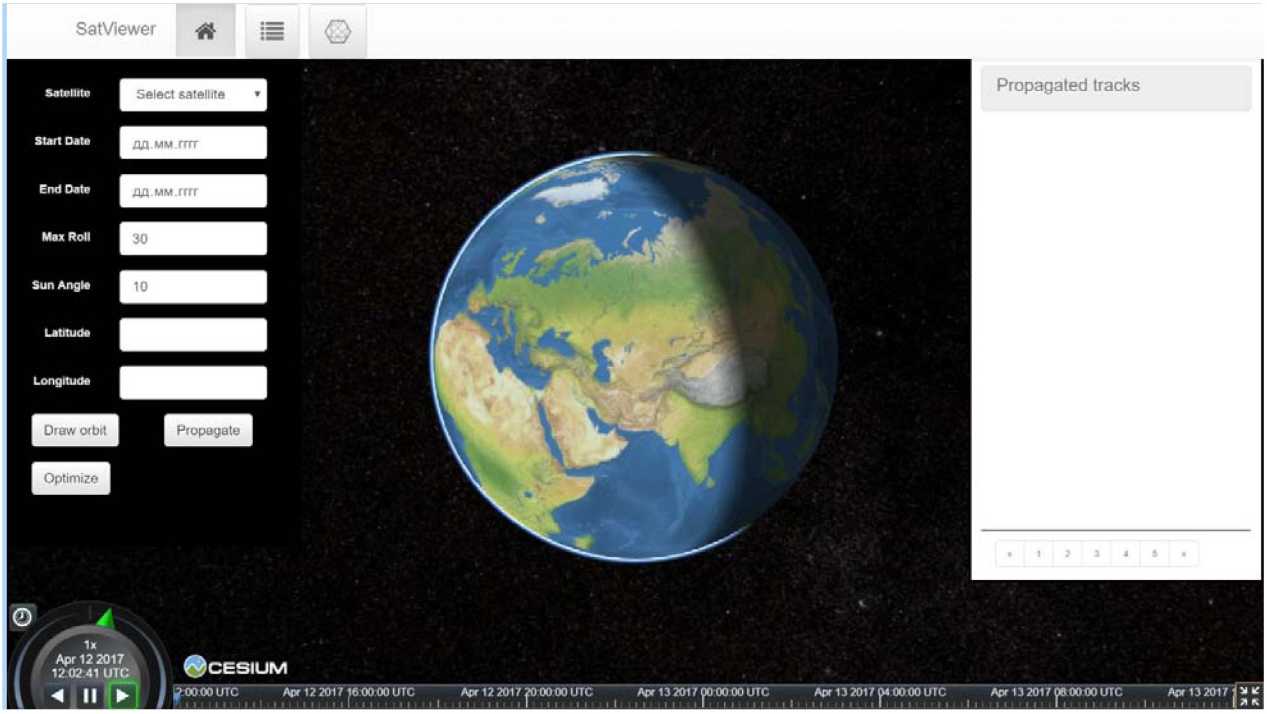
To solve the above tasks, a web application has been created. JavaScript and PHP programming languages, HTML with CSS were used to write its code. jQuery and Bootstrap libraries [8, 9] were involved in the interface; 3D visualization was realized with the help of Cesium library [10]. The application itself is deployed on an Apache server.

The consideration of the application would be started from an interface, which can be conditionally divided into five parts: the main layer, top, left, right and bottom panels.

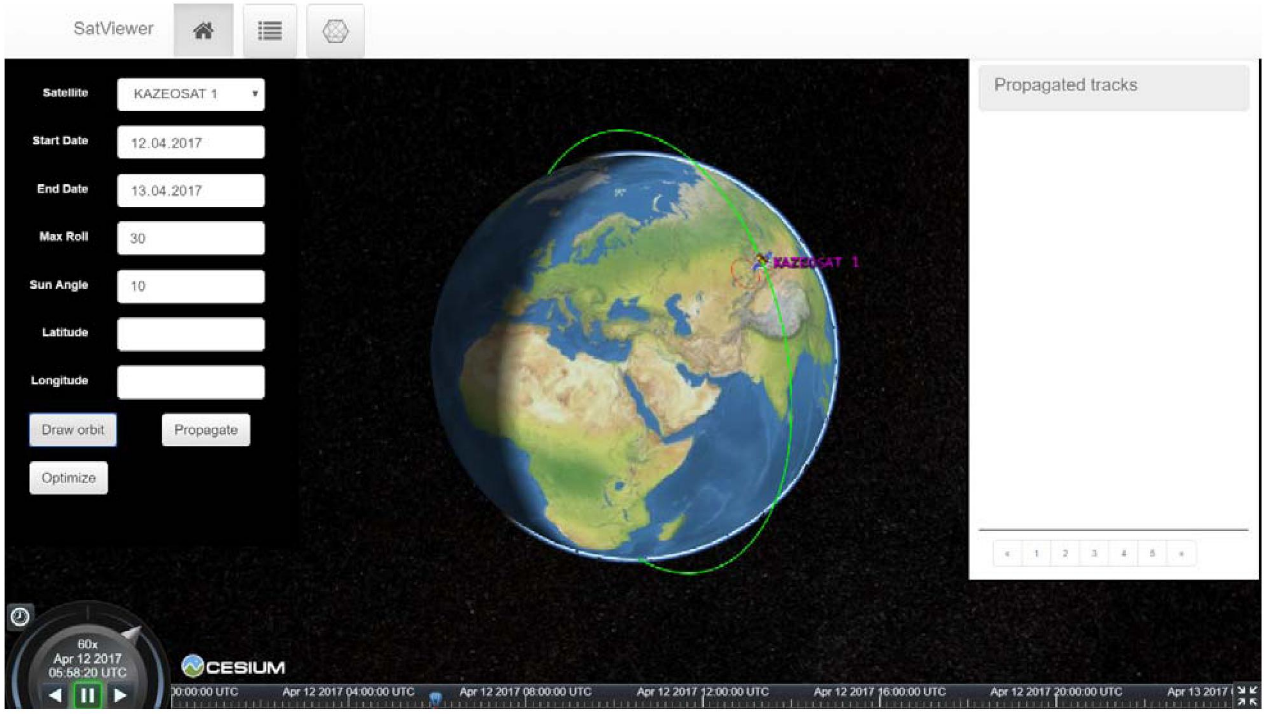
The main layer represents a three-dimensional model of the Earth. Here the user can specify an area of interest and see the satellite motion trajectory as a result of the program execution.

The left panel has two modes: input and output. In the input mode the user must select an ERS spacecraft, start and end dates from the dropdown menus, and enter maximal roll angle, minimal Sun height, latitude and longitude of the area of interest in degrees. If the user is interested in night shooting, he can set negative Sun angle, for example, -90. The territory of interest can either be entered into latitude and longitude fields, or drawn on the map, and then its coordinates will automatically appear in the corresponding fields. Besides, three buttons: “Draw orbit”, “Propagate” and “Optimize” – are available. When you click the "Draw Orbit" button, a satellite trajectory is constructed for the given date range; an area of interest is unnecessary here (pic. 2). The “Propagate” button finds all possible passes that satisfy specified restrictions near the territory of interest in the required date range; the results are displayed in the right panel (pic. 3 and 4). The “Optimize” button creates an optimal plan for surveying a polygon on the Earth's surface beginning from the start date, taking into account the indicated limitations. In this case, the polygon is covered by shooting strips of a spacecraft with overlap. The resulting passes are also output in the right panel. The end date is ignored here (pic. 5).

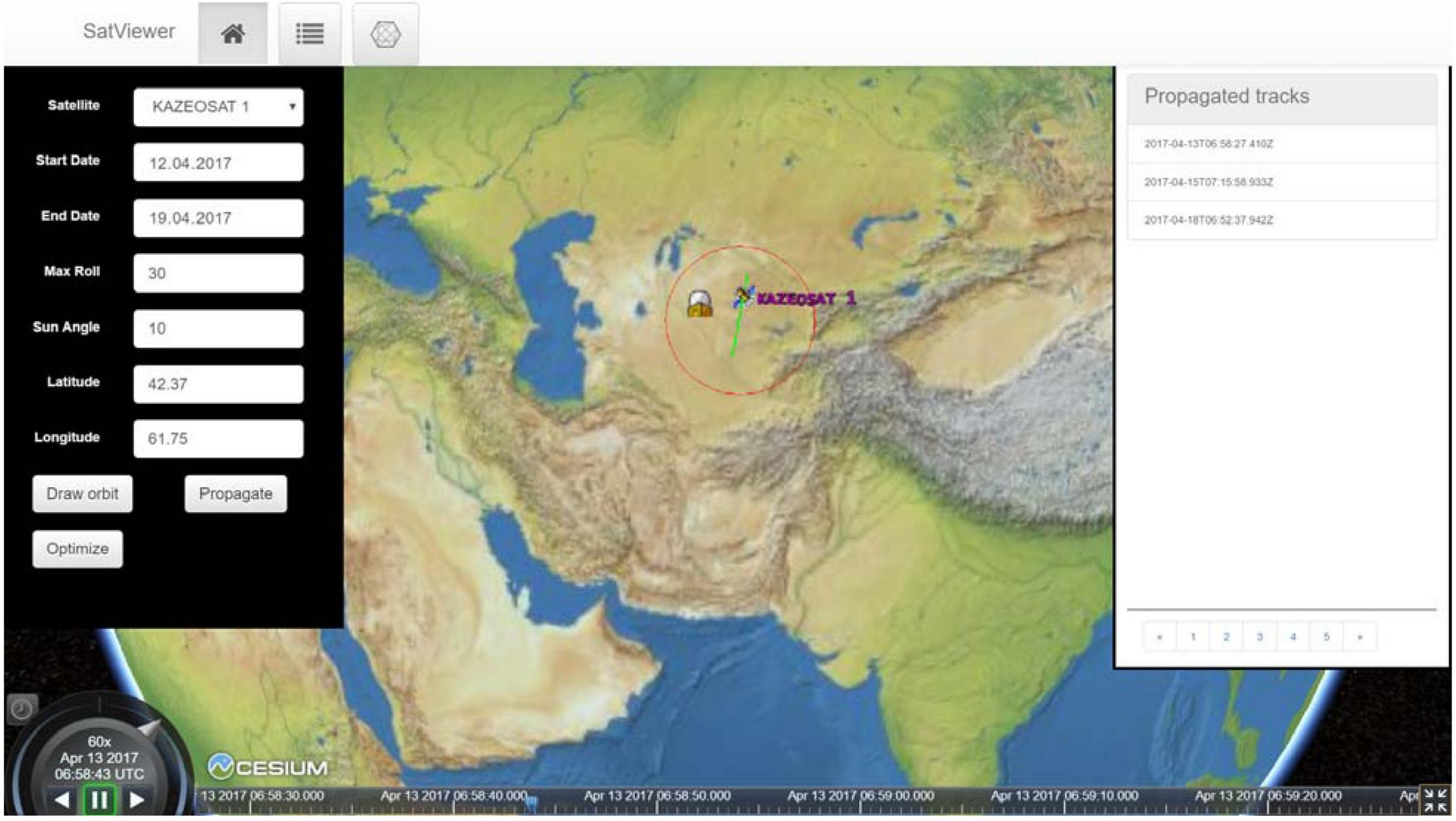
In the output mode the left panel is used for displaying and is unavailable for editing. The name of the ERS spacecraft, the start and end dates, a number of strips covering the area of interest and a necessary number of passes are output here. To draw the orbit, the last two fields are always zero, the start and end dates are the same as the input values. For “Propagate”, the start and end dates indicate the dates of the first and last pass, the last two fields are also zero. For “Optimize”, the start and end dates have the similar to “Propagate” meaning, strips and passes are shown in the amount that is necessary to cover the polygon.



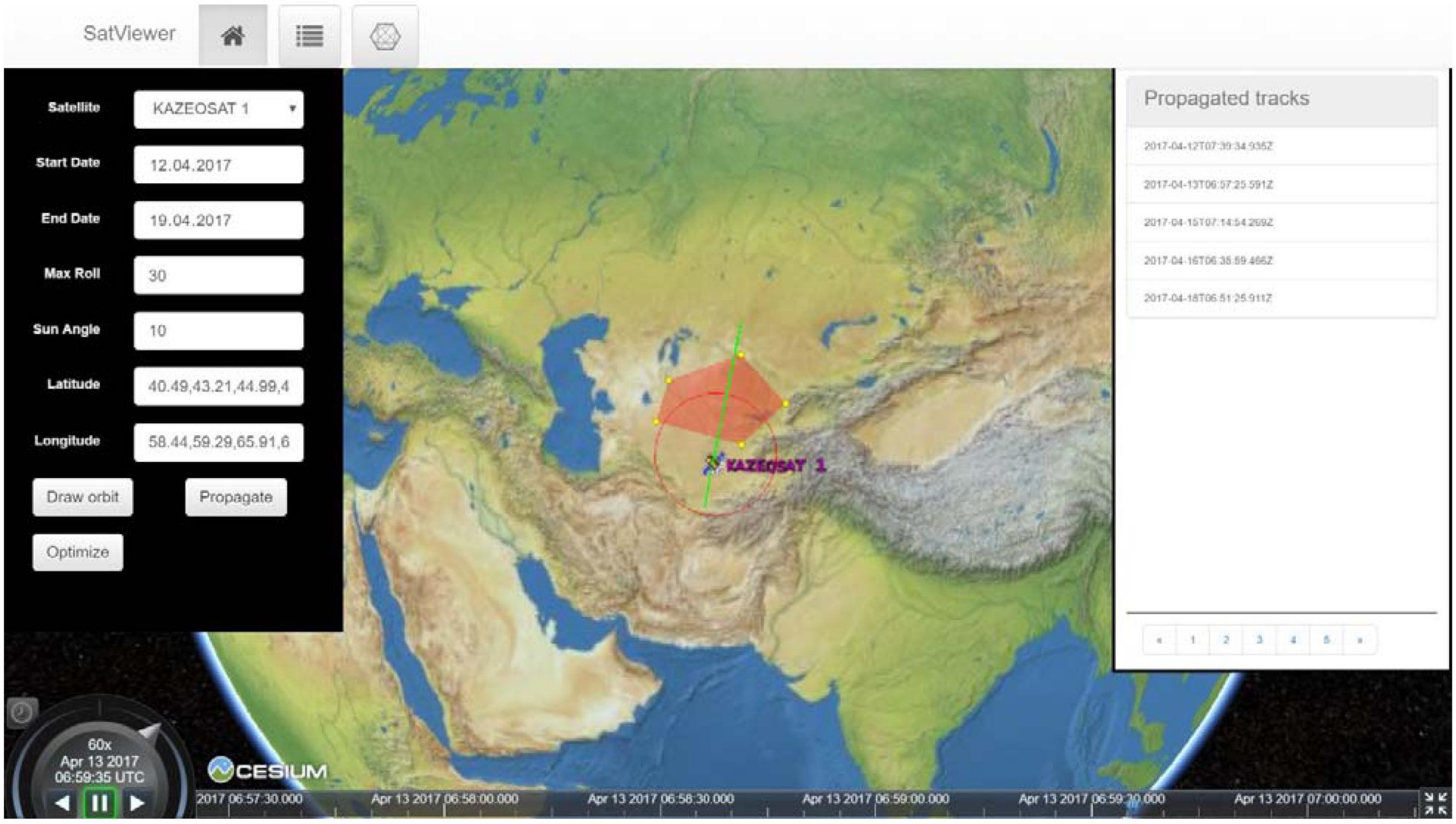
Pic. 1 – The application interface



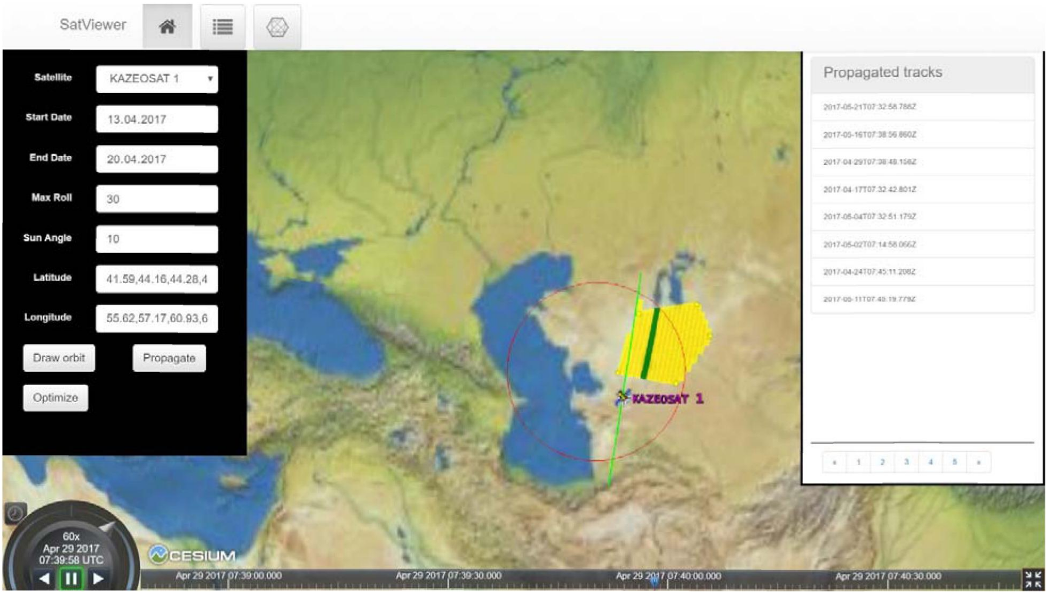
Pic. 2 – Satellite orbit



Pic. 3 – The pass near the point



Pic. 4 – The pass near the polygon



Pic. 5 – The surveying plan

The top panel consists of two buttons. The first one, with a “list” icon, is used to toggle the left panel between input and output modes. The other, with a “hexagon” icon, turn on the polygon drawing mode, which works as follows:

1. Switch on the polygon drawing mode by clicking the “hexagon” button. The old polygon will be erased, if there was one.
2. Place the dots on the Earth surface with the left mouse click.
3. After placing all required dots, right-click. The minimal convex hull of these dots will be drawn on the Earth model, and the latitudes and longitudes of its vertices will be listed by commas in the corresponding fields of the left panel.
4. Switch off the polygon drawing mode by clicking the “hexagon” button.

The single point can be placed on the Earth surface by double-clicking with the inactive polygon drawing mode. Its latitude and longitude values also appear in the left panel.

In the right panel the list of passes near the territory of interest appears after clicking the button “Propagate” or “Optimize”. Each item of this list indicates the beginning of the span. Clicking on any item of the list part of the spacecraft trajectory, with which it is possible to survey a given territory, will be drawn. For “Optimize” the strip, which will be shot from the selected pass, will be colored green (pic. 5). There is a pagination switch in the bottom of the right panel. The length of the list that can fit into the panel does not exceed 10 elements, so that the appropriate multi-page output is provided for demonstrating more passes. The pagination switch itself initially has next elements: “left” arrow, page numbers from 1 to 5, “right” arrow. By clicking on the “right” page numbers in the switch increase by 5, provided that the current five pages are not enough to show all results. For example, if you have received no more than 50 passes as a result of computations, nothing will happen after clicking on the “right”, otherwise page numbers will change as follows:

$$\{1,2,3,4,5\} \rightarrow \{6,7,8,9,10\},$$

and they will grow this way after every click on the “right” until the next five pages reach the end of the list. Clicking on the “left” decreases page numbers by 5, if there are not first five $\{1,2,3,4,5\}$ in the switch, otherwise nothing happens.

The bottom panel consists of a multimedia control unit and a slider. Multimedia control unit allows you to pause the animation, adjust its speed and direction. The slider is used to rewind the animation back and forth.

The inner part of the application is based on solutions to the problems described in the beginning. The corresponding algorithms can be found in the references [1-8]. Some specific programmatical issues will be described here.

TLE data acquisition. Upon entering the application, a client sends the GET-request to the server for the list of ERS satellites and corresponding TLE. After receiving the request from a client, the server reads the contents of the file at http://www.celestrak.com/NORAD/elements/resource.txt, processes it and returns an ordered list of satellite names and TLE data. The server stores a copy of this file on its side in case it is unavailable, and the server can successfully process the request by reading data from this copy. The above URL contains actual ephemeris of all available ERS satellites, and they update every day.

The visualization of a satellite's trajectory. The Cesium library, written in JavaScript, is actively applied in 3D-visualization in the considered web-application. But it works with data of a certain kind, so the calculation results must be transferred to this kind. Thus the visualization of a trajectory occurs according to the following scheme:

1. The calculation results are sent to the server with a POST-request with the following data fields: the satellite name, the start and end time, the time step in seconds, the radius of visibility in meters, the array of time points and Cartesian coordinates.
2. After receiving the data from a POST-request, the server writes it to the czml file [11], and returns a link to this file.
3. The client downloads the contents of the czml-file from the received link using Cesium, thereby triggering a 3D-visualization of the satellite's motion.

Note that when drawing an orbit, one request is sent and one czml-file is generated accordingly. A bunch of POST-request are sent to visualize passes near the territory of interest and a separate czml-file, describing a certain part of the trajectory, is created for each pass.

Output of passes. As mentioned above, the list of passes is displayed in the right panel. Each element of this list is implemented through the HTML tag <a>. Its markup as a JavaScript string looks like

```
"<a href = \"#\" class = \"list-group-item track\"
id = \"track-"+id+"\">" + tracks[id].date + "</a>"
```

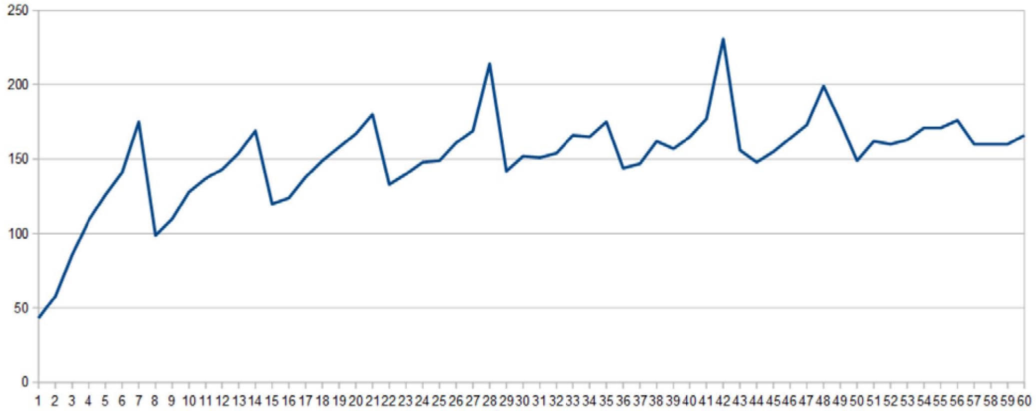
where id is a serial number of the pass in the array, tracks[id].date is a time of id pass start. In addition, the callback function, which loads czml-file associated with the selected id, and launches the animation, is attached to each element by means of JQuery. This function is invoked by clicking on any pass.

Further, the result of numerical experiments are presented. All tests was run on the computer with following features:

CPU	Intel Core(TM) i7-4500U CPU @ 1.80GHz 2.40 GHz
RAM	8GB
Video card	NVIDIA GeForce GT 750M, 2GB
OS	Windows 10, 64 bit

KazEOSat-1 ERS satellite was used in all tests.

The visual result of orbit construction is always as in the pic. 2. Below it as a graph of the computation time versus the planning horizon. The ordinates are in milliseconds, the abscissa is the days. The results are given for up to 60 days.



The table below shows the number of passes and the computation time, depending on the end date of planning for the search for passes near the coordinates point (47.24° N, 66.99° E). As the startting date is taken on 14/04/2017, the maximum roll angle is 30° and the minimum Sun height is 10°.

The end date	The number of passes	The computation time, ms
21/04/2017	3	19
28/04/2017	5	28
05/05/2017	8	47
12/05/2017	11	25
19/05/2017	14	70
26/05/2017	17	68
02/06/2017	20	71
09/06/2017	23	84
16/06/2017	26	77

The table below shows the number of passes and the computation time, depending on the end date of planning for the search for passes near the polygon. As the startting date is taken on 14/04/2017, the maximum roll angle is 30° and the minimum Sun height is 10°.

The end date	The number of passes	The computation time, ms
21/04/2017	4	12
28/04/2017	8	22
05/05/2017	12	40
12/05/2017	16	33
19/05/2017	20	42
26/05/2017	24	106
02/06/2017	28	122
09/06/2017	33	208
16/06/2017	27	158

The following table shows the results of planning the survey of the same territory by different ERS satellites with the same restrictions on roll at 30° and the Sun altitude at 10°. The start date is 14/04/2017. The computation time is in milliseconds.

Satellite	The end date	Strips	Passes	Comp. time
KazEOSat-1	13/06/2017	32	32	489
KazEOSat-2	31/05/2017	30	30	541
LANDSAT-7	16/06/2017	32	32	297
SENTINEL-3A	13/06/2017	32	32	416
WORLDVIEW-4	22/06/2017	32	32	732
RAPIDEYE 5	15/06/2017	31	31	377
PLEIADES-1B	11/06/2017	32	32	489
KANOPUS-V 1	09/06/2017	30	31	517
YAOGAN 29	02/06/2017	30	30	564

The presented results of numerical experiments demonstrate that the developed software product perfectly solves the task in a very short time at the rates of computing power, which any average computer can provide today.

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ЖЕРДІ ҚАШЫҚТЫҚТАН ЗОНДТАУҒА АРНАЛҒАН WEB ҚОЛДАНБА

Аннотация. Мақалада жерді қашықтықтан зондтау спутнигінің (ҚЗС) орбитасын салу және Жер бетінінің қажетті аумағын түсіруді жоспарлау веб-бағдарламасын құру қарастырылған. Қашықтан зондтау үшін, оптикалық сипаттамалар мен зерттеу жиілігі сияқты критерийлерді ескере отырып, қолайлы спутникті таңдау мәселесін шешу маңызды. Осы қолданба арқылы пайдаланушы кез-келген коммерциялық ҚЗС спутнигінің белгілі бір уақыт кезеңі үшін траекториясын көре алады, Жер бетіндегі нүкте немесе полигонды зерттеу үшін пайдаланушының талаптарын қанағаттандыратын барлық мүмкіндіктерді есептейді және барлық қажетті шектеулерді ескере отырып, қызығушылық аймағын шолуды жоспарлайды.

Әзірленген бағдарлама пайдаланушыға ыңғайлы интерфейсті және спутниктік орнын тиімді есептеуді ұсынады. Осы қосымшаның көмегімен пайдаланушы Жер бетіндегі зерттеу нүктесі немесе полигоны үшін қанағаттандыратын пайдаланушы барлық талаптар мүмкіндіктерін есептеуге және назарға барлық қажетті шектеулерді ескере отырып, қызығушылық аймақты түсіру үшін жоспарлау, алдын ала белгілі бір мерзімге кез келген қолда бар коммерциялық серігін траекториясы қашықтықтан зондтау көре аласыз. Алгоритм аспан механикасы формулаларын, аналитикалық геометрия және есептеуді азайтудың эвристикалық әдістерін, қоғамдық TLE деректерді пайдалана отырып SGP4 үлгісіне негізделген. Бағдарлама коды JQuery және Cesiumjs кітапханаларын пайдаланып JavaScript және PHP бағдарламалау тілдерінде жазылған. JavaScript – браузер интерфейстерін жасаудың ең кең таралған құралы, тілге жаңа мүмкіндіктер қосылады. Мақалада бағдарламаның скриншоты және есептерді орындау жылдамдығын тексеру нәтижелері келтірілген.

Түйін сөздер: жерді қашықтықтан зондтау, түсірілімді жоспарлау, SGP4, TLE, траектория, веб-қосымшалар.

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ВЕБ ПРИЛОЖЕНИЕ ДЛЯ ДИСТАНЦИОННОГО ЗОНДИРОВАНИЯ ЗЕМЛИ

Аннотация. В статье описывается веб-приложение для построения орбиты спутника дистанционного зондирования Земли (ДЗЗ) и планирования съемки указанной территории на поверхности Земли. Для ДЗЗ важно решение проблемы выбора подходящего спутника, с учетом таких критериев как оптические характеристики и частота съемок. Разработанное приложение предлагает удобный интерфейс для пользователя и эффективный расчет положения спутника. С помощью этого приложения пользователь сможет увидеть траекторию движения любого доступного коммерческого спутника ДЗЗ на заданный период времени, рассчитать все возможности, удовлетворяющие требованиям пользователя, для съемки точки или полигона на поверхности Земли и запланировать съемку области интереса с учетом всех требуемых ограничений. Алгоритм основан на модели SGP4, использующей общедоступные данные TLE для спутников ДЗЗ, формулах небесной механики, аналитической геометрии и эвристических методах сокращения вычислений. Код программы написан на языках программирования JavaScript и PHP с применением библиотек Bootstrap, JQuery и Cesiumjs. JavaScript является самым распространённым средством создания браузерных интерфейсов, в язык добавляются новые возможности. В статье приведены скриншоты самой программы и результаты тестов скорости выполнения расчетов.

Ключевые слова: дистанционное зондирование Земли, планирование съемки, SGP4, TLE, траектория движения, веб приложение.