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DETERMINE COVERAGE CHARACTERISTICS OF EARTH SATELLITE

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Abstract

Threats posed by counterspace capabilities are directed against space systems, their supporting ground infrastructure, and data links between space systems and ground infrastructure. Space countermeasures include direct attack and co-orbital anti-satellite systems, cyber attacks, electronic warfare and directed energy. Earth, as seen from space, is a key visual element in planning operations. This necessitates a careful selection of continuous review of certain areas of operational and strategic interest. Satellite coverage planning covers the entire process, from the idea of a new satellite system to final in-orbit testing. It is a multidisciplinary activity that ranges from defining the areas of interest in the relevant geographic areas, designing the appropriate orbit, and arriving at the determination of the necessary sensors that will meet the mission's need.

Introduction

The modern security environment requires more and more complete interaction between the types of armed forces and the branches of troops, based on a unified information space, which creates conditions for situational awareness and information superiority. This cannot be achieved without adequate infrastructure, mobile and secure logistics, command and control systems, communications, computers, cyber defense, combat systems, and intelligence (the result of surveillance and intelligence combined with other data), surveillance and intelligence (collection of data to solve a specific military issue) {C6ISR}, electronic warfare, drones that are directly dependent on continuous communication with satellites orbiting in outer space.

Depending on their purpose, the missions of some satellites require continuous coverage of a certain area of the Earth or the ability to communicate simultaneously with any point on the Earth. Given the shape of the Earth, it is clear that a single satellite cannot provide simultaneous communication with every point. This requires the satellites to be placed in the same or different orbits to provide the necessary coverage. For this reason, it is very important to correctly determine the coverage of each individual satellite. The most famous example is the Global Positioning System (GPS), whose mission requires that every point on Earth be visible to at least four GPS satellites at any given time. To ensure the mission, the GPS constellation contains 24 satellites working together to provide continuous coverage of the world. Placing satellites in a higher orbit requires a larger launch vehicle and greater cost. However, the height of the orbit essentially depends on how much of the earth's surface the satellite's sensors can cover. Logically, the higher the orbit, the larger the total area the corresponding satellite can cover. A satellite's field of view is defined as the cone of visibility for a particular sensor. Depending on the field of view of the satellite and the height of its orbit, the total area of the earth's surface that is constantly covered is determined as the corresponding linear width or diameter of this area is called coverage width (Fig. 1) [1–2].

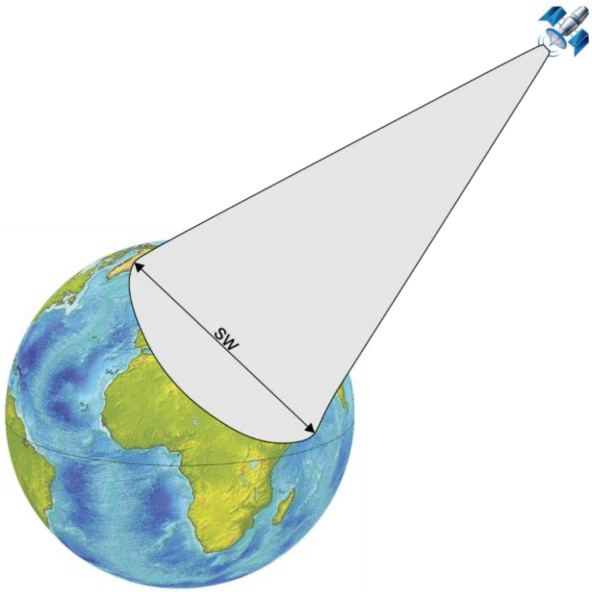

Fig. 1. Coverage on Earth's surface (swath width)

Depending on the desired coverage of the Earth, necessary for the implementation of the set mission of the satellite, the main elements of the orbit in which it will be placed are determined. For example, if the satellite is to survey the entire surface during the mission, it needs a near-polar inclination of about 90°.

Geometry of satellite coverage

Satellite coverage depends on and can be calculated from the following satellite orbital parameters (Fig. 2) [3]:

- perigee;
- apogee;
- extreme northern latitude (for Bulgaria - the mouth of Timok in the Danube River, Vidin region, coordinates 44.214555°N and 22.67459°E);
- extreme southern latitude (for Bulgaria – Veikata mountain, Kardzhali region, 41.236022°N and 25.288167°E);
- true anomaly;
- latitude of the satellite;
- nadir (na) (Nadir is a term used to designate a point on the celestial sphere opposite the zenith, or more precisely, the point with a slope of −90°, located in the direction "down" from the observer);
- central angle of the Earth (ca);
- elevation angle (ea);
- slope range (sr);
- geocentric radius of the satellite $(\mathrm{R_s} = R_E + H_s)$.

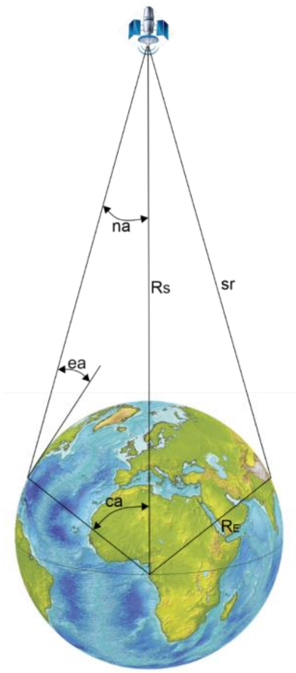

Fig. 2. Coverage geometry of a satellite orbiting a spherical planet with a nadir-pointing conical sensor

The relationship between the nadir, central angle, and elevation angle can be written as follows:

(1) $na + ca + ea = 90^o;$

(2) $sr.\cos(ea) = R_s \sin(ca);$

(3) $sr.\sin(na) = R_E \sin(ca);$

Therefore:

(4) $na_s = \arcsin\left(\frac{R_E}{R_s}\right);$

The nadir, central angle, and elevation angle can also be represented as a function of slope range sr:

(5) $na = \arccos\left(\frac{R_s^2 - R_E^2}{2.sr.R_s} + \frac{sr}{2R_s}\right);$

(6) $ca = \arccos\frac{R_s^2 + R_E^2 - sr}{2.sr.R_E};$

(7) $ea = \arcsin\left(\frac{R_s^2 - R_E^2}{2.sr.R_E} + \frac{sr}{2R_E}\right).$

The nadir, the central angle, and the slope range can also be represented as a function of the elevation angle:

(8) $na = \arcsin\left(\frac{R_E}{R_s}\cos(ea)\right);$

(9) $ca = \arccos\left(\frac{R_E}{R_s}\cos(ea)\right) - ea;$

(10) $sr = \sqrt{R_s^2 - R_E^2 \cos^2(ea)} - R_E \sin(ea);$

The relationship between the central angle, the elevation angle, and the slope range can be represented as a function of the nadir:

(11) $ca = \arcsin\left(\frac{R_s}{R_E}\sin(na)\right) - na;$

(12) $ea = \arccos\left(\frac{R_s}{R_E}\sin(na)\right);$

(13) $sr = R_s\cos(na) - \sqrt{R_E^2 - R_s^2\sin^2(na)}.$

The relationship between the nadir, elevation angle, and slope range as a function of the central angle can be represented as follows:

(14) $na = \arcsin\left(\frac{R_E\sin(ca)}{sr}\right);$

(15) $ea = \arctan\left(\frac{R_s\cos(ca) - R_E}{R_s\sin(ca)}\right);$

(16) $sr = \sqrt{R_s^2 - R_E^2 - 2R_sR_E\cos(ca)}.$

The width of coverage (sw) can be calculated as follows:

(17) $sw = 2R_E.ca;$

The observed land surface percentage under these conditions is $50(1-\cos(ca)),$ and the covered surface (SA):

(18) $SA = 2\pi R_E^2(1-\cos(ca)).$

Results

The calculation sequence is presented in Fig. 3, and the results are in Tables 1, 2, 3 and 4.

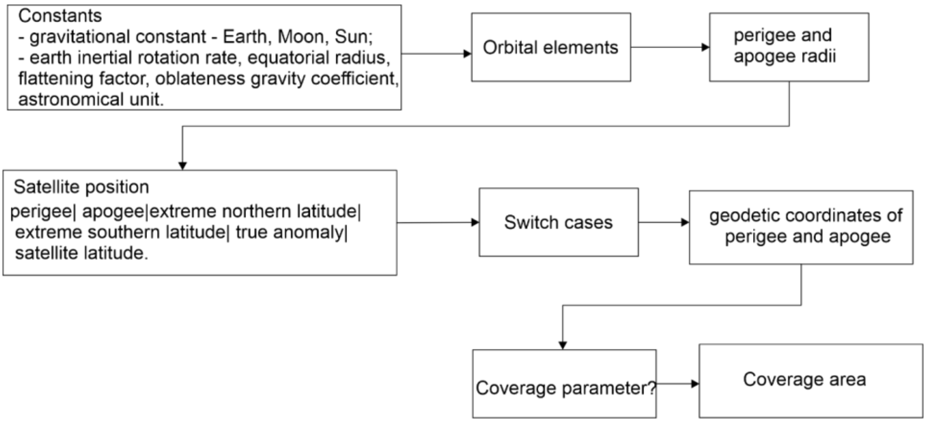

Fig.3. Calculation sequence

Table 1. Calculation results -1

Input data	***Output data***
✓ semimajor axis -10000 km; ✓ inclination – 0°; ✓ satellite's position - extreme northern latitude; ✓ coverage constraint - elevation angle = 7°.	• satellite altitude - 3621.8637 km; • nadir - 39.2762°; • central angle - 43.7238°; • slant range - 6963.7324 km; • coverage area - 70884025.0530 km^2 = 13.8660 %; • view latitude 1 – (- 43.7238°); • view latitude 2 – (43.7238°); • distance of arc - 4867.3099 km; • true anomaly – 0°.

Table 2. Calculation results -2

Input data	***Output data***
✓ semimajor axis -10000 km; ✓ inclination – 30°; ✓ satellite's position - extreme northern latitude; ✓ coverage constraint - elevation angle = 7°.	• satellite altitude - 3627.2203km; • nadir - 39.2762°; • central angle - 43.7238°; • slant range - 6963.7324 km; • coverage area - 70884025.0530 km^2 = 13.8660 %; • view latitude 1 – (-13.7238°); • view latitude 2 – (73.7238°); • distance of arc - 4867.3099 km; • true anomaly – 90°.

Table 3. Calculation results -3

Input data	***Output data***
✓ semimajor axis -10000 km; ✓ inclination – 60°; ✓ satellite's position - extreme northern latitude; ✓ coverage constraint - elevation angle = 7°.	• satellite altitude - 3637.9127 km; • nadir - 39.2762°; • central angle - 43.7238°; • slant range - 6963.7324 km; • coverage area - 70884025.0530 km^2 = 13.8660 %; • view latitude 1 – (16.2762°); • view latitude 2 – (76.2762°); • distance of arc - 4867.3099 km; • true anomaly – 90°; • view latitude is over the pole.

Table 4. Calculation results -4

Input data	***Output data***
✓ semimajor axis -17893 km; ✓ inclination – 0°; ✓ satellite's position - extreme northern latitude; ✓ coverage constraint - elevation angle = 7°.	• satellite altitude - 11514.8637 km; • nadir - 20.7201°; • central angle - 62.2799°; • slant range - 15958.3818 km; • coverage area - 136709100.0687 km^2 = 26.7424 %; • view latitude 1 – (-62.2799°); • view latitude 2 – (62.2799°); • distance of arc - 6932.9668 km; • true anomaly – 0°.

Conclusions

There are many factors that influence the coverage of a satellite or constellation of satellites. Of primary importance is the ability to steadily collect images depending on the elements of the orbit. Most moderate and low-resolution sensors possess an intelligence plan that covers the globe in a regular and repeating pattern of activity. Information assurance for military operations requires constellations of satellites to achieve global coverage at moderately high resolution. Current orbital plan requirements for individual satellites provide high-resolution coverage that does not affect active imaging. Even if the sensors are constantly switched on and transmit data, it is possible that the optical images are unusable over areas with dense clouds covering them. Unlike commercial targets, where there is less interest in much of the global south, for military targets, all parts of the earth's surface are of real interest. This places various increased demands on the sensor's ability to collect imagery over a given area. A satellite can carry a suite of sensors and collect images from space, just like drones, aerostats, and aircraft, but they do it from a much lower altitude. Satellites provide high temporal resolution over large areas of the Earth's surface, periodically collecting information over a specific area, depending on orbit and satellite coverage over a very long period of time, which sets the stage for large-scale reconnaissance. At the same time, airborne vehicles provide images with very high resolution - up to 1 cm per pixel. This makes them suitable when a specific task is to be performed.

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ОПРЕДЕЛЯНЕ ХАРАКТЕРИСТИКИТЕ НА ПОКРИТИЕТО НА САТЕЛИТ В ОКОЛОЗЕМНА ОРБИТА

А. Маринов

Резюме

В зависимост от предназначението си, мисиите на някои спътници изискват непрекъснато покритие на определен район от Земята или възможност за едновременна комуникация с всяка точка на Земята. Предвид формата на Земята е ясно, че един сателит не може да осигури едновременна комуникация с всяка точка. Това налага спътниците да бъдат разположени на еднакви или различни орбити, за да осигурят необходимото покритие. Поради тази причина е много важно да се определи правилно покритието на всеки отделен спътник. В настоящата статия е определено покритието на сателит в околоземна орбита, като е взета предвид крайна северна ширина и ъгъла на издигане, на базата на което са определени и характеристиките на покритието.