Some aspects of establishing and developing remote sensing of the Earth's surface from space

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Abstract. Remote sensing of our planet from space currently provides data for both Earth sciences (geography, geology, volcanology, geoinformatics, cartography, climatology, meteorology, oceanology, seismology, etc.) and applied problems in many areas of human activity. Already the early years of the space age saw the emergence of two areas of spacecraft use that were of great interest to military circles: Earth observation from space and communications. It was the photographic exploration that predetermined the beginning of the interaction between astronautics and Earth sciences. In addition to the obvious need and importance of using space methods, the cartography focused on meteorological tasks. This area of space instrumentation played a decisive role in the subsequent use of space sensing of the Earth's surface for civil purposes and in the creation of special scientific and technical productions.

1. Introduction

Our knowledge of processes on Earth and other planets in the solar system is based on intuition and experience of remote sensing in the optical range. Information in other parts of the electromagnetic wave spectrum, particularly in the infrared and radio bands, became available only in the 20th century. The new means of exploration provided by astronautics have made it possible to assess our planet "from the outside", viewing it on a par with the rest of the solar system. The deployment of research systems in Earth orbit made it possible to view Earth processes on a global scale.

Space sensing is the study of geographical objects using space imagery obtained by recording reflected solar or artificial radiation and the Earth's own radiation from spacecraft. It is also primarily about using new approaches in established areas of the natural sciences, including geography, geology, cartography, meteorology, oceanology, etc. The subject of study is the geographical shell of the Earth, its structure and dynamics, the interaction and spatial distribution of its individual components remains the same.

From this point of view, remote sensing from spacecraft has become a necessary and sufficient condition for scientific and technical breakthroughs in the understanding of complex natural phenomena. In general, the modern genesis of science involves an interdisciplinary synthesis between scientific disciplines and a technological basis. This feature is particularly evident in remote sensing. Based on qualitatively new means of this cognition, remote sensing simultaneously incorporates the methods of their application. Along with the design and application of research equipment, there is also the development of efficient information-analytical systems and algorithms that provide the
required information to the end user.

Remote sensing of the Earth's surface comprises two interrelated fields: natural science (remote sensing proper) and engineering (remote sensing techniques). This branch of science and technology is understood as a functional whole that serves the specific needs of the human community and is ultimately determined by socio-historical practices. From the early 1960s to the mid-1970s, remote sensing from spacecraft finally emerged as an independent scientific and technical field [1]. Thus, one of the most characteristic features in the genesis of science as a system of natural and technical knowledge in recent decades was the emergence of remote sensing. A retrospective analysis shows that remote sensing is at the interface between the sciences and different branches of technology. It combines and interacts with technical research and scientific directions that study global and local planetary processes.

If we consider a remote sensing system as a complex technical complex, it is necessary to include, in addition to the hardware, a theoretical justification of the research method, which largely determines the structure of the construction of the entire device. This view provides a rationale for including the spacecraft, which acts not only as a carrier, but also as a determinant of the feasibility of a range of sensing techniques. The rapid progress of space-based remote sensing, especially in the last decade, is primarily due to its advantages: obtaining quantitative information about objects where contact measurements are not feasible or difficult; covering large areas with measurements without a network of local devices; obtaining data averaged over a line, area or volume.

The identification of ways for interactions and collaborations between space and space technology and remote sensing tools and techniques can also contribute to solving many of the problems associated with predicting future space systems.

The rapid development of computer technology at the end of the 20th and beginning of the 21st century was one of the reasons for the qualitative transformation of the industry. At this time, spacecraft with new instrumental capabilities in hyperspectral and multichannel multispectral modes were created [2]. Apart from the construction of the research instruments themselves, there is the development of effective information systems (based on the results obtained) and the development of a wide range of fundamental earth science problems.

The basis for the interaction between astronautics and earth sciences was photographic exploration. Aircraft became an essential tool in mapping. Reconnaissance satellites have replaced them since the early 1960s. There were certain restrictions on the use of the material obtained for civilian purposes under conditions of secrecy. The range of optical photography was supplemented by infrared. The year 1978 marked the beginning of a new phase of weather-independent radio research on the Earth's surface. In recent decades, hyperspectral remote sensing capabilities have made it possible to determine the characteristics of objects on the ground that are hidden under normal conditions.

In the initial period, the task of photographing the surface determined the design parameters of the spacecraft. The development of electronics has turned it into a platform for the hardware complex. Instead of the historically established principles of visual image processing and recognition, a computer system with appropriate software becomes the main analytical device to produce new derivative images based on raster data values and their geographical location [3, 4, 5].

2. Materials and methods
This article attempts to analyse the impact of new scientific methodologies and tools on the qualitative changes in individual S&T industries and their transitions from one state to another. The analysis of historical-scientific issues involves the development of a body of historical-scientific sources, primarily specialist literature and data bases.

The methodological and informational basis of the work was the results of research reflected in scientific monographs and publications, as well as materials posted on the websites of the most important centres and organisations for remote sensing (FGDC, USGS, Planet, DigitalGlobe, Airbus Defence and Space, NASA, ESA, JAXA, CNES, Roscosmos, etc.). Thus, the review of the sources that formed the basis of this study enabled us to conclude that the materials used provide objective
coverage of the problem in both scientific and technical as well as socio-historical contexts.

The methodology of the work is based mainly on source studies, historical-comparative and historical-technical methods. The principle of historicism remains fundamental. As this study is at the crossroads of several scientific disciplines, in particular geography, space technology, history of science and source studies, the work uses an integrated approach.

A retrospective review of relevant publications shows that remote sensing is at the interface between the sciences and various branches of technology, harmoniously combining technical research with the branches of science that study global and local planetary processes, and incorporate both basic and applied research. As a synthetic branch of knowledge, satellite remote sensing drives the interaction and cross-fertilisation of a large number of natural and technical sciences and disciplines in the course of its development. Thus, it connects and at the same time enriches with its results not only virtually the entire complex of Earth sciences, but also a number of astronomical disciplines.

The scientific, technical and technological basis for the application of specific space-based remote sensing techniques, as well as the integrated sensing method itself, and the associated hardware, are the components of the system whose development is the subject of this study. Each of the elements separated from the structure of space remote sensing complex itself forms a complex system with its own functional, substantive and historical structure. The degree of detail of the proposed consideration will obviously depend on what is chosen as the criterion for a system element, i.e. a specific complete functional unit. A space-based remote sensing system includes, in addition to the remote sensing hardware itself, a spacecraft with power, orientation, correction, control and management systems, and a radio information system. For this analysis, we find that such a detailed consideration of the spacecraft is unnecessary. The influence of its constituent systems need only be considered in individual cases if their influence on the development of the remote sensing method itself and the remote sensing equipment was decisive. It is useful to consider the spacecraft as a whole, as an integral part of the technical support for space-based remote sensing. This inclusion of the spacecraft itself in the ongoing analysis is justified for two main reasons, which are determined by its functional purpose.

The first is that the spacecraft serves as a transport facility. This role, although supportive, often determines to a large extent the development of technical aspects of space remote sensing. In this case, it is precisely the need to consider the spacecraft as a complex system, and to consider the influence of its constituent functional elements.

The second reason stems from the fact that the spacecraft is in some cases part of the remote sensing research system itself. This refers in this case to the need, for example, for uniform movement of scientific instruments for their normal functioning along the orbit of an artificial Earth satellite or in outer space near another astronomical object under study.

The distinction between these functional parts is very arbitrary. It is necessary to develop a scientific rationale for the research method itself, for the construction of the apparatus and the design of the spacecraft. In turn, hardware, in addition to serving as a remote sensing tool on board of a spacecraft, serves to test scientific theories and has some influence on the development of related space technology.

3. Results
The first satellites, designed to observe the Earth's surface, served military reconnaissance purposes. In 1958, the US adopted the Corona programme to build a photographic reconnaissance satellite using a reentry capsule with captured film. The first one was obtained in 1960. In the Soviet Union, a similar project began with the Zenit-2 (Zenith-2) spacecraft launched into Earth orbit in 1962.

The resulting images, which included images of cloud cover, demonstrated the effectiveness of space tools in monitoring and studying the atmosphere and hydrosphere for meteorological purposes. The first US satellites, Vanguard 2 (1959) and Explorer 6 (1959), could not fully transmit reliable data due to unstable orbital motion. A successful mission was the Explorer 7 space probe (1959), which measured infrared radiation from the Earth's surface. The launch of the more advanced TIROS-1
(Television and Infrared Observational Satellite) in 1960, equipped with two television cameras transmitting both real-time and tape-recorded information, showed the advantage of space technology over other observational tools. Up to 1965, there were 10 launches of this series. In 1978, the first TIROS-N/NOAA was launched with a high-resolution on-board radiometer and special equipment for collecting data from maritime buoys. The first Soviet satellite of this type, Cosmos-122, was put into orbit in 1966.

A milestone was the beginning of surface research and mapping in the radio band, using side-scan systems to capture large areas at any time of day and in any weather.

The synthetic-aperture radar developed by NASA's Jet Propulsion Laboratory (JPL) pioneered on the Seasat oceanographic satellite in 1978, providing images of the Earth's surface with a spatial resolution of 25m. This spacecraft was also equipped with a radio altimeter and a scatterometer.

The successful experience of the onboard equipment led to the use of SIR-A (Shuttle Imaging Radar) synthetic aperture radar on the Space Shuttle during the second STS-2 mission in 1981 and SIR-B on the STS-41-G mission in 1984. The result was clearer and more distortion-free data than that transmitted from Seasat. For example, it has uncovered long-drained riverbeds hidden beneath the surface of the Sahara Desert in Sudan and Egypt, demonstrating that L-band radar (with a 23.5 cm wavelength) can penetrate ultra-dry sand layers to a depth of several metres. More recently, there were special Earth surface radiosonde missions as part of the Space Shuttle programme: the Shuttle Radar Laboratory (SRL-1) in 1994 and the Shuttle Radar Topography Mission (SRTM) in 2000. [6]

The Soviet Union was developing the manned Almaz-A station, which was scheduled to enter orbit in 1978. It was equipped with a Mech-K (Sword-K) radar with a resolution of 25 m. There was also a powerful Agat-1 (Agate-1) space imaging telescope on board, which could study the area in both the infrared and visible wavelengths. Unfortunately, the USSR economy could not support such a large-scale project in light of the considerable expenses involved in preparing for the 1980 Moscow Olympics. The launch failed. It was only in 1987 that Cosmos-1870 (Space-1870) was launched into orbit in an unmanned, automatic version. In 1991, a modified version of the station with significantly improved on-board instrumentation was launched into orbit as Almaz-1A. The spacecraft carried out unique experiments on sounding the sea surface, observing currents, surface manifestations of internal waves.

Positive results of the first applications of space radars with synthetic aperture radar (synthetic-aperture radar) enabled in 1982-1983 to use such instrumentation on the Venus-15 and Venus-16 interplanetary probes and to obtain a detailed surface map of Venus, hidden by a permanent thick cloud cover from observations in the optical and infrared bands. In 1989, The Venus Surface Atlas was produced [7].

The Magellan interplanetary probe for mapping Venus was to have been launched by the US back in 1976. But it was delayed by three and a half years due to a delay in the Space Shuttle programme associated with the Challenger shuttle accident (1976), which extended the flight time to the planet by almost a year. Magellan orbited Venus from 1989 to 1994. Its on-board radar has produced a detailed map of the surface with a resolution of up to 150 m. In 1997 The United States Geological Survey has published a detailed map of Venus. The first map of the planet's surface obtained with data from the radar altimeter of the "Pioneer-Venus-1" space probe [8] (launched into orbit around Venus in 1978, operated till 1992) was presented in 1980.

The role of the individual space probe in exploring the planets of the solar system remains extremely important today. However, the situation changed somewhat with the study of the Earth by orbiting means.

In the initial period from the late 1950s to the early 1970s, it was the country's budget for space exploration that funded space experiments. This process involved research into fundamental possibilities, frontier areas of knowledge and technology, the development of empirical experience and the implementation of the first major projects and theoretical work.

The period from the early 1970s to the early 1980s marks a decade of government initiatives in geographic information systems. It was state support at this stage that stimulated the development of
experimental work in geo-information systems, and the creation of automated navigation systems and vehicle traffic control systems in emergencies. It was the time of the first personal computers and graphics tablets. The development of formal methods of spatial analysis also belongs to this period.

A new stage in the development of astronautics began in the late 1980s and continues to the present day. During these years, there was a removal of one main impetus for the space industry, which was primarily due to ideological and military confrontation between the two societal systems. This set of circumstances led to a fundamental change in the pace, direction and very motivation of space progress. The commercial development of geographic information systems began. This became the time of launching a wide variety of software tools, the development of desktop geographic information systems, the expansion of their application area through integration with non-spatial databases, the emergence of networked applications, and systems supporting databases on personal computers, and distributed geodatabases. Geo-information systems for non-professional users emerged. There is a trend towards commercialisation of existing remote sensing systems and their transfer to private companies. This was most evident in the United States, where, for example, the operation of Landsat satellites was put on a commercial basis in 1985.

The role of the individual space probe in exploring the planets of the solar system remains extremely important today. However, the situation changed somewhat with the study of the Earth by orbiting means. The major trend in the remote development of the Earth is the creation of satellite constellations, i.e. the work of single spacecraft is becoming a thing of the past. Satellite constellations include spacecraft that are identical or similar in their characteristics, operate in an adjusted manner, and the resulting data are collected in a single common repository. These constellations operate in a coordinated manner and share a common data repository. The emergence of new spacecraft constellations and the expansion of existing ones, driven by the need for higher productivity and shorter re-imaging intervals, result in a dramatic increase in the amount of data transmitted. This situation calls for new technical solutions for receiving, processing and storing vast amounts of information.

Demand for remote sensing data, products and services will continue to grow worldwide. Remote sensing satellites are already surveying in different spectral channels and at different resolutions, with high accuracy, periodicity and productivity. Technical capabilities continue to improve. We can expect soon that data will be available for any area of the Earth at any time. [9] However, the challenge is not only to acquire more and more remote sensing data, but also to process and analyse the results in near real time. This is driving a trend that will only increase over time - an enormous increase in the volume of data received per unit of time which needs to be processed and analysed in a timely manner. The market for spatial data and geo-analyses shows that users do not just want data as a thing in itself. In reality, the use of data from remote sensing satellites is less than 1%. The development of geo-informatics tools and technologies aims to collect and process data from different information sources jointly. Users should have access to available analysis tools and finished products. Such giants as Google and Apple are actively creating geo-services. The progress of remote sensing from space shows that within a single year there will be complete multi-resolution coverage of the entire world. [10]

By 2025, the National Centre for Earth Remote Sensing will be responsible for the entire operation of the Russian orbital constellation of remote sensing satellites, as well as the storage and processing of the resulting information. The centre will be a geographically distributed organisational unit with a head office in Moscow and elements will be located in the town of Kalyazin, at the Long Range Space Communications Centre.

Another trend in the development of remote sensing is the active development, launch and operation of small remote sensing satellites. In 2017, Planet (USA) proposed a revolutionary new approach to spatial data acquisition. Modern data collection and processing systems allow for a continuous survey of the entire Earth using a large number of small satellites, which is more cost-effective. A constellation of more than 200 spacecraft ensures this approach. The high speed and repeatability of the survey make it possible to create topical, high-resolution orthomosaics over large
areas. The daily acquisition of images of the entire surface of the Earth with a resolution of at least 5 m allows for global surveillance in real-time. An integral part of the system is the terrestrial infrastructure, which includes 36 receiving antennas on three continents. According to Euroconsult, just a few companies (Planet, BlackSky Global and Satellogic S.A., among others) will launch more than 1,400 small satellites by 2025.

Remotely sensed data are the most important and perhaps the only possible source of up-to-date and timely information on the natural environment for thematic layers in geographic information systems, for keeping data up-to-date and for other purposes.

4. Conclusion
Today, there is a clear trend towards reducing the cost of information obtained directly from spacecraft. It is far less than the cost of the space assets themselves. The data collected by orbiting systems can create geospatial products worth millions of dollars. Space monitoring is now one of the most successful and dynamic industries in terms of innovation.

The worldwide orbital constellation of remote sensing satellites numbers over 400. The last two decades show a significant increase in the number of countries using remote sensing systems on their own.

References
[1] Calver K, Elachi Ch, Ulaby F 1985 Microwave remote sensing from space Proc. IEEE 73 970-996
[2] Camacho-Lara S, Madry S, Pelton J N 2017 Handbook of Satellite Applications (Switzerland: Springer International Publishing)
[3] Richards J A, Jia X 2006 Remote Sensing Digital Image Analysis An Introduction (Berlin Heidelberg: Springer-Verlag)
[4] Woodhouse I 2005 Introduction to Microwave Remote Sensing (CRC Press) 400 p
[5] Calver K, Elachi Ch, Ulaby F 1985 Microwave remote sensing from space Proc. IEEE 73(6) 970-996
[6] Elachi C, Brown W E, Cimino J B, Dixon T, Evans D L, Ford J P, Saunders R S, Breed C, Masursky H, McCauley J F, Schaber G, Dellwig L, England A, MacDonald H, Martin-Kaye P, Sabins F 1982 Shuttle Imaging Radar Experiment Science 218(4576) 996-1003
[7] 1989 Atlas of the surface of Venus (Moscow: General Directorate of Geodesy and Cartography)
[8] Pettengill G, Eliason E, Ford P, Loriot G, Masursky H, McGill G 1980 Pioneer Venus radar results: altimetry and surface properties J. Geophys. Res. 85(A13) 8261-70
[9] Ouchi K 2013 Recent Trend and Advance of Synthetic Aperture Radar with Selected Topics Remote Sensing 5(2) 716-807
[10] Dvorkin B A, Natarova E V 2017 Space Monitoring of the Earth: Yesterday, Today, Tomorrow Connect. Information Technology World 11-12 60-64