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MAJOR REMOTE SENSING DEVELOPMENT TENDENCIES IN THE COMING DECADE

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Abstract: *Remote sensing of the Earth and space occupies a very important place in the development of modern science and technology and contributes greatly to the expansion and improvement of human knowledge about the Earth planet. Irrespective of its quite juvenile age, remote sensing of the Earth is expected to proceed at vigorous pace during the next decade.*

The paper presents the major remote sensing development tendencies, analyzing the state-of-the-art of all its components, including sensors, platforms and software, classified based on their location – spaceborne, airborne or terrestrial. Some of the most important tasks are identified, which should be solved to accomplish the made forecasts. Based on the performed analysis, the expected development of remote sensing during the next decade has been extrapolated.

ОСНОВНИ ТЕНДЕНЦИИ В РАЗВИТИЕ НА ДИСТАНЦИОННИТЕ ИЗСЛЕДВАНИЯ ПРЕЗ СЛЕДВАЩОТО ДЕСЕТИЛЕТИЕ

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Ключови думи: *дистанционни изследвания, сензори, платформи, предварителна обработка, следващо десетилетие.*

Резюме: *Дистанционните изследвания на Земята и космоса заемат изключително важно място в развитието на съвременната наука и технологии и стремително допринасят за разширяването и подобряването на човешките знания за планетата Земя. Независимо от съвсем младата възраст на дистанционните изследвания на Земята се прогнозират високи темпове на нарастване през следващото десетилетие.*

В работата са представени основните тенденции на развитие на Дистанционните изследвания, като се анализира състоянието на всичките им компоненти, включващи сензори, платформи и софтуер, класифицирани в зависимост от вида.на базиране - космическо, въздушно и наземно. Посочени са някои от най-важните задачи, които следва да бъдат решени, за да придобият тези прогнози реални измерения. На базата на извършения анализ е направена екстраполация на очакваното развитие на дистанционните изследвания през следващото десетилетие.

Introduction

Remote sensing of the Earth and planets marked vigorous development during the recent decades. The applications of remotely sensed data and images cover important areas, such as weather forecasting, climate changes, planet biological, mineral, and water resources, agricultural yield forecasting. This coverage area is expanding continuously to include new fields, such as ecological monitoring of endangered areas, monitoring of global natural resource and environment changes, climate changes, public health care, security and more. Therefore, the conclusion can be made that the further development of remote sensing will take place in the conditions of increasing demands. The other two factors to affect the development of remote sensing in the next decade are technology progress and restricted resources [1-8].

1. Remote sensing development

Irrespective of the quite juvenile age and vigorous development of RS during the last some fifty years, and of spectrometric measurements during the last some thirty years, RS of the Earth using spaceborne, airborne or terrestrial instruments is expected to develop at a vigorous pace during the next decade. The CAGR (compound annual growth rate) of RS products is expected to increase by 6% on an annual base by 2014. A study of BCC Research considers instrumentation increase from the view point of the development prospects of the four available types of platforms: spaceborne, airborne, terrestrial and aquatic. The CAGR of the greatest segment – spaceborne platforms, is expected to increase by 5.7% on an annual basis, of the second-ranking segment, airborne platforms – by 6.4% on an annual basis, and of terrestrial and aquatic platforms – by 5% and 8.7%, accordingly.

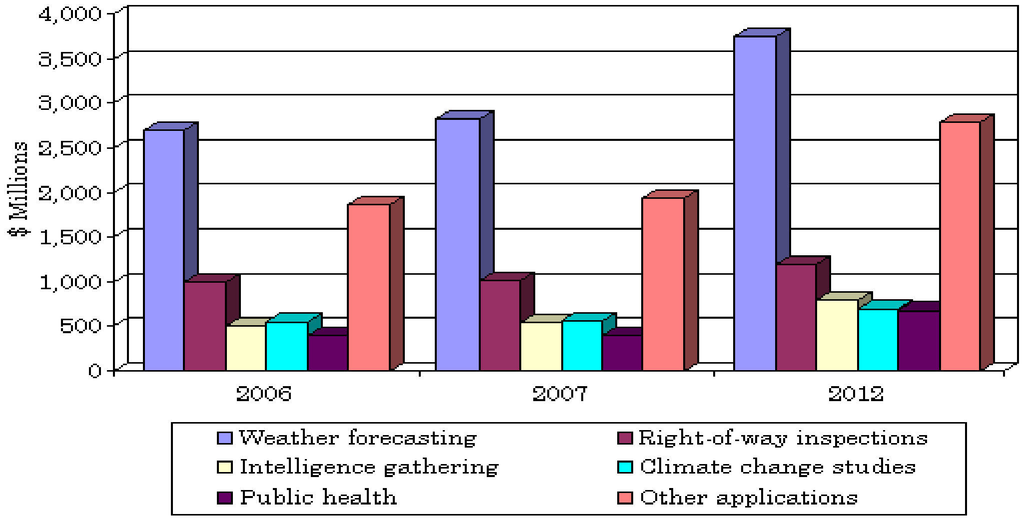
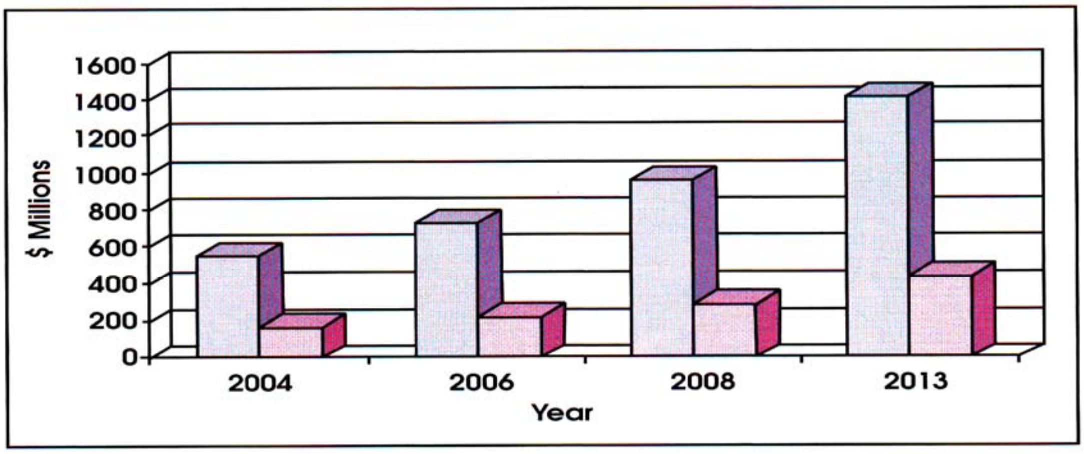


Fig. 1 Increase of the funds allocated for the major RS application lines (Report Code: IAS022A, Published: February 2007, Analyst)

The expected CAGR for the most widely used instruments in RS – the spectrometric ones, as seen from the marketing experts' analysis points to an expected increase of 8.5% on an annual basis by 2013 [9,10].



The growth of the process spectroscopy market in USD millions is shown from 2004 and projected to 2013. The purple bar represents the equipment segment and the pink bar, the applications segment. Courtesy of BCC Research.

Fig. 2. Increase of the finds allocated for spectrometric devices and applications [10].

RS development will make RS data and information from various platforms, together with GIS coordinates of any location on the planet, accessible to common citizens. It is expected that in future, intelligent houses will obtain environment satellite data on a regular basis.

To turn these forecasts into reality, the following tasks should be resolved:

- improvement of the accuracy and resolution of RS data;
- improvement of the performance and access to RS data, which will improve the conditions for quick response;
- improvement of the preprocessing methods and techniques, which will relieve data processing and analysis;
- development of algorithms for joint use of RS data from various sensors to improve the quantity and quality of the information obtained by the users.

Actually, reaching these parameters necessitates development and improvement of RS methods and technologies, including sensors, platforms, and software.

The future development of RS on a national scale will depend on the adequate involvement in the process of three main sectors: academic community, government, and private sector (Fig. 3). Each of these sectors plays a specific role in supporting RS progress [3]. Their adequate future representation in the joint activity in the field may provide for a next, higher development level.

Remote Sensing		
Government	**Academy**	**Private Sector**
Public interests Long-term planning Public infrastructure	Fundamental studies Innovations Independent views	User orientation Risk assessment – target groups Product efficiency

Fig. 3. The mutually supplementing role of the governmental, academic and private sector

On a global scale, RS development will depend on the adequate participation of State coalitions in the process, such as the GEOSS (Global Earth Observation System of Systems) initiative – (NOAA) in which 66 states are participating.

2. Sensor development

During the recent decades, observation of the Earth’s surface using instruments in the visible range developed greatly. Nowadays, the global network provides access to satellite images and data to a wide user circle. Moreover, the quality of these images has improved greatly – for instance, the images obtained from *Ikonos* feature 1m resolution for the panchromatic and 4m resolution for the multispectral devices. Data may be combined in a coloured image featuring 1m resolution. Currently, images featuring 0.1m resolution may be obtained, which creates difficulties for data receiving, storage, and processing. The development of a 14-bit CCD with 14000x9000 pixels for panchromatic image is planned. Since the development of such a matrix at nowadays technology level would not be efficient from the economical point of view, some companies, such as Vexcel, plan to develop a camera with 13 CCD – 9 for panchromatic images and 4 for spectral images [11]. Apart from the increased sensor size, such developments involve improvement of the devices’ technical parameters, such as increase of the devices’ quantum efficiency, increase of reading speed, increase of the signal-to-noise ratio and more [1,2,12,13]. Achievement of high spectral and spatial homogeneity and high measurement accuracy requires modern optical design using high-efficiency optic components. Optomechanical design will be improved to provide for achievement of spectral and radiometric stability, which in its turn will facilitate the devices’ spectral, spatial, and radiometric calibration.

The use of the invisible spectrum range is expected to expand, especially the use of the infrared and microwave part of it, and the number of active sensors is expected to increase to provide for improvement of spectral and spatial resolution.

The development of micro- and nano-technologies will provide to create small, inexpensive, autonomous sensors of the MEMS (microelectromechanical systems) type, but sized less than a blood cell. Millions of these devices are expected to form in future an expanding network related with digital data transfer networks which will provide to retrieve as much “information from unit volume”, as possible.

Development of intelligent sensor networks. These networks will be proactive and will be able to meet and reflect the changes in the physical, chemical, and biophysical parameters of the environment.

Development of a global intelligent sensor network.

3. Platform development

3.1. Spaceborne RS systems (satellite systems).

They established themselves as a major Earth study source. They are financed mainly by the governmental space agencies. Their main advantage is provision of high-quality global coverage, quick response and frequent revisiting periods. Table 1 contains an excerpt for the existing RS satellite systems [3].

Table 1. An excerpt for the existing RS satellite systems

TYPE	NATION	SATELLITE OR PROGRAM	DESCRIPTION/PURPOSE
Geostationary Meteorology	USA ESA Japan India China	GOES METEOSAT MTSAT INSAT Feng Yun	2 active SC with imager and sounder 3 active spacecraft with imager 1 active spacecraft with imager 1 active spacecraft with imager 1 active spacecraft with imager
Polar Meteorology	USA Europe Russia China	POES/DMSP METOP Meteor Feng Yun	3 active spacecraft, mult instruments 1 active spacecraft, mult instruments 1 active spacecraft, mult instruments 1 active spacecraft, mult instruments
Earth System Science	USA Europe	EOS ERS/Envisat	20+ satellites, variety of science Multi-instrument sats, variety of science
Earth Surface Resources, Oceans, Ice, and Disaster Monitoring	USA Japan India Italy Korea Taiwan China /Brazil USA/Fr	Landsat ALOS IRS/ResourceSat COSMO-Skymed KOMPSAT FormoSat CBERS Jason	Med-res multi-spectral, global coverage Multi-instr sat, land/disaster monitoring Mod-high res multi-spectral imager 4 spacecraft, imagers for mil/civ use Mod-high res multi-spectral imager Mod-high res multi-spectral imager Mod-high res multi-spectral imager Radar altimeter for ocean topography

One of the comprehensive satellite programmes is the NASA Earth Observing System (EOS) developed during the 80-ies of the last century. Currently, a series of satellites are operating within the EOS (Figure 5) [3] whose main objective is study of the Earth system in a number of important fields, such as climate change, geology, oceanography. This system comprises satellites intended for long-term monitoring, such as Landsat, providing medium-resolution images of the Earth's surface, as well as satellites intended to study the physics of Earth processes, such as the Terra satellites which provide 16 out of 24 climate-determining parameters, such as aerosols, clouds, temperature, vegetation and radiation.

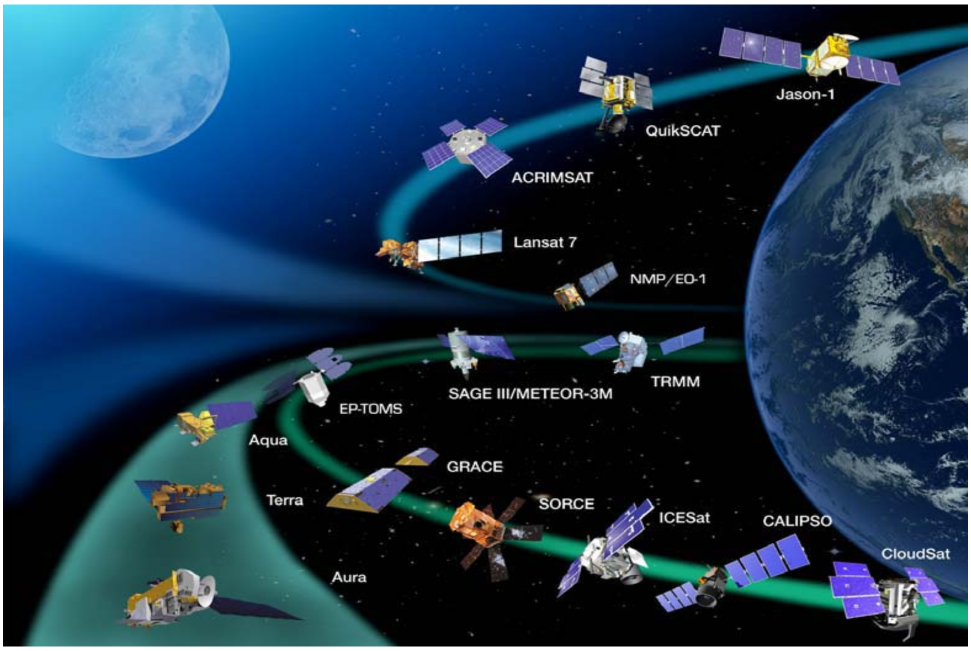


Fig. 5. The NASA Earth Observing System (EOS) as of 2006, consisting of a number of satellites performing a diverse range of Earth science (courtesy NASA) [3].

The USA National Research Council has scheduled 17 new Earth observation space missions during the next decade [14].

Table 2. Launch, orbit, and instrument specifications for missions recommended to NASA 2010–2013

Decadal Survey Mission	Mission Description	Orbit[a]	Instruments	Rough Cost Estimate (FY 06 $million)
CLARREO (NASA portion)	Solar and Earth radiation; spectrally resolved forcing and response of the climate system	LEO, Processing	Absolute, spectrally resolved interferometer	200
SMAP	Soil moisture and freeze-thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	300
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	300

During the recent years, **small satellites** (weight under 500kg) feature particularly intensive development. Their philosophy which is characterized by the words “quicker, better, lesser, cheaper” presents their greatest advantages. The development of these platforms shows that RS within the optical range will be performed mostly on board small satellites.

The use of small and very small satellites will provide testing innovative research and engineering space application technologies in extreme radiation, temperature, vacuum and other conditions. NASA nano-satellites are designed for a wide spectrum of space missions including biology experiments, testing advanced propulsion and communications technologies.

In Bulgaria, development of the BalkanSat Programme is underway for the launching of a small regional scale RS satellite [16-18].

Table 3. An excerpt for the existing small satellites

Satellite	Launch	Orbit	Sensor	GSD	swath/ pixels	Spectral bands
OSCAR-18	1990	800km	Array CCD			Mechanical shutter
UoSAT-5	1991	800km	Array CCD	2km	592x592	
KitSat-1	1992	1300km	Array CCD	4km 400m	592x592	Pan
KitSat-2	1993	800km	Array CCD	2km 200m	592x592	RGB
PoSAT-1	1993	800km	Array CCD	2km 200m	592x592	Pan
FASAT-Alfa	1995		Array CCD		592x592	
Inspector	1997					
Techsat-1b	1998	821km SSO, 21:37h	Linear CCD	12m		multispectral
FASAT-Bravo	1998	821km SSO, 21:37h	Array CCD	100m	592x592	
Thai-Phutt	1998	821km SSO, 21:37h	Array CCD	80m	1024x1024	3-band Multispectral
Sedsat-1	1998	547x1079km, 31.4 deg				
SAC-A	1998	400km, 51.6deg	CCD			
Sunsat	1999		Linear CCD			live video
UoSAT-12	1999	650km, 65deg	Array CCD	32.5m 8m	1024x2048 1024x1024	6-band Multispectral Pan
TUBSAT-DLR	1999	727km, SSO, 12am-12pm		370m 120m 6m		Pan/Multispectral/live video
KITSAT-3	1999	727km, SSO, 12am-12pm	Linear CCD	15m		
Tsinghua-1	2000		Array CCD	39m	1024x1024	3-band multispectral
SimpleSAT	2001					
PROBA	2001	CHRIS HRC WAC		18/36m 8m	768x768	19/62 bands panchromatic panchromatic

GSD = Ground Sampling Distance

An example illustrating the effect of small satellite development is shown in Fig. 6 [3].

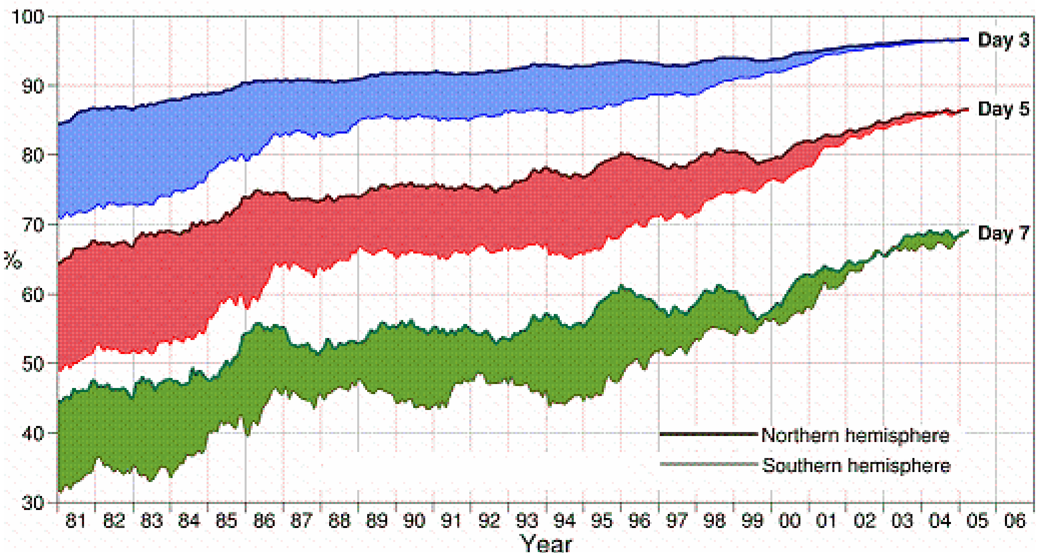


Fig. 6. The progression in prediction skill for weather, showing percent accuracy of 3, 5, and 7 day forecasts over time for Northern and Southern hemispheres (adapted from A.J. Simmons and A. Hollingsworth, 2002, "Some Aspects of the Improvement in Skill of Numerical Weather Prediction," *Q. J. R. Meteorol. Soc.* 128: 647-678).

Satellites will help us change our attitude towards the world we are living in and small satellites are the flagships of this revolution covering various fields, such as remote sensing, communications, navigation and high-technology scientific research.

3.2. Airborne systems

In contrast to satellite systems, these systems are more commercially oriented. They are intended to provide high- and superhigh-resolution data on a local and regional scale. Another essential advantage of these systems is that they may provide nearly on-line data. These advantages presume joint development, operation and use of satellite and airplane systems and establishment of the so-called integrated RS systems.

Airborne systems are also used as a rule to calibrate replicas of satellite instruments or validate satellite RS methodology.

The next step for airborne sensors is the use of unmanned aircraft carriers. So far, these carriers have been widely used for military purposes, but their use in RS for scientific and commercial purposes will extend further [19-21]. Currently, great emphasis is placed on the use of unmanned aircraft to study and monitor endangered areas, fires, volcanic activities and the like. There is such a program operating in the country [22-24].

3.3. Ground-based (terrestrial) systems

Ground-based RS systems, notwithstanding of not being the largest or most expensive ones, play essential role in Earth observation. In many cases, the detailed information from these sensors cannot be provided by the other systems. In other cases, remotely sensed data cannot be validated without using additionally acquired data by ground-based systems. The data from these systems have an increasing impact on general databases and are processed for various applications with other remotely sensed data. In future, they are going to have an increasing impact on the global database system.

For instance, the use of common, inexpensive cameras allows in many cases to portray the overall picture of the observed scenes. In the same way, data from a number of sensors for observation of physical and chemical parameters, such as temperature, humidity, pressure, atmosphere, soil and water composition [25,26] are used.

The next step in the development of ground-based systems is to construct networks of intelligent sensors using the new technologies – wireless communications and available ones. These networks will be self-regulating, proactive, and capable to meet and reflect the changes in the physical, chemical, and biophysical parameters of the environment. In the near future these networks will be united in a global network of intelligent sensors, whereas the information will be presented in a form appropriate for taking quick decisions in complex situations. For instance, one of these options is providing farmers with information about crop status, diseases, soil status, humidity and more [27-30].

RS development will make remotely sensed data and information from various platforms, together with the GIS coordinates of each location on the planet, accessible to common citizens. It is expected that in future, the so-called “smart homes” will receive satellite data about the environment on a regular basis, thus providing not only an image of this environment, but showing its physical status as well.

3. Development of methods and instrumentation for preprocessing, processing of remotely sensed data, storage and dissemination of information

In parallel with instrumentation development and improvement, data preprocessing methods and techniques are going to develop and improve as well, whereas part of the processing will be made on-board, thus providing to reduce the amount of transferred data and the size of data storage devices and facilitate further data processing and data use procedures [31-32].

Improvement of preprocessing of RS data will render these data relatively independent on acquisition conditions. This will allow performing measurements of the same object in various times and places using various instruments, and still obtain comparable results [15|. It will allow obtaining results of entirely new quality, i.e. to create and use multisensory images in RS.

- apart from development of data acquisition and preprocessing techniques, development of information retrieval algorithms.

Conclusions

Expansion of the used spectral range coverage and improvement of RS instrumentation resolution, implementation of interactive sensors.

Establishment of network of intelligent sensors, which will be proactive and respond adequately to the changes of the observed parameters, establishment of global network.

Providing data with “information from unit volume”, increasing the operability and facilitating the receiving of RS information by end users in nearly on-line regime and in custom-tailored form.

Transition from delivery of multispectral to multisensor images.

Significant intensification of the effect of RS information on the observation and monitoring, planning and forecasting stages, and as a result, supporting managerial decision taking in complex situations.

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