REMOTE SENSING DATA

THERE ARE SEVERAL LEVELS OF REMOTE SENSING DATA PROCESSING WITH DIFFERENT NAMES AND NOMENCLATURE THROUGHOUT THE RS OPERATORS

Despite a big variety of satellite-based remote sensing data systems, of imaging equipment operation modes and data processing formats, some special features and process solutions, typical for the majority of the RS data collection and processing systems, can be tracked down.
As a rule, the RS data processing is divided into preliminary and thematic processing. The first represents a set of actions (processes), converting the input raw data, received by the ground station, into some RS products of standard processing levels suitable for archiving and further use. Preliminary processing includes radiometrical calibration, geolocation and geometric correction of images. Thematic processing is the one used for RS data interpretation for specific tasks with thematic products in the output.

The tasks of preliminary RS data processing at a ground receiving complex are to unpack the downlinked data array, to retrieve images and associated metadata, to process and represent data in storage formats.
There are several levels of remote sensing data processing with different names and nomenclature throughout the RS operators.

RS data receiving ground stations hardware standardization

The existing international standards are voluntary; however the desire to be on the international market of space data makes them de-facto regulations for civil and commercial remote sensing programs

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International standardization of RS satellites parameters and systems became a reality due to the world space data market development and the creation of a great number of RS programs in different countries.
Frequency and radio link structural parameters have been standardized enabling to use one and the same ground receiving station for the acquisition and processing of data from satellites of different RS operators. Despite the fact that the existing international standards are voluntary, the desire to be on the international market of space data makes them de-facto regulations for civil and commercial remote sensing programs.

Radio data transmission links

The idea of data relay links is tied to the communications structure. Based on the functional purpose of space satellites, the following types of communications in space systems can be delineated:

- commands, telemetry and trajectory data transmission;
- data collection (special data or images from sensors);
- data transfer via transponder satellites (both commands, telemetry and sensor images can be used).

Two basic configurations can be identified here depending on the data distribution scheme: from point to point and circular broadcasting (from one point to all).

Frequencies for data downlink

Higher and higher frequency bands of the electromagnetic spectrum were mastered along with the development of radio technology and increase in the volume of data array downlinked from satellites. Currently the following frequencies are used for radio data downlink from the RS and meteo-satellites:

- VHF (135-150 MHz) and UHF (400-470 MHz);
- L-band (1670-1990 MHz);
- S-band (2000-2300 NHz);
- X-band (7450-8400 MHz);
- Ku-band (13,75-15,35 GHz, used for inter-satellite communications);
- Ka-band (25,5-27,0 GHz).

The main frequency bands used for “Space-to-Ground” (S/G) radio links from the RS and meteo-satellites are shown in Table 1. It should be noted that some countries use the bands different from those indicated. For example, the Chinese RS satellites use 180 Mhz band for commanding and telemetry string and 480 MHz – for meteodata downlink.
The VHF/UHF bands were used in the RS systems back in 60s. Currently the application is restricted to automatic low-rate transmissions of meteorological images (APT format), data from automatic sensors for data and emergency signals collection, two-way communications with micro- and mini RS satellites, as well as to relay commands and telemetry data at some ground sites (Russia, China).

Table 1. Main frequency bands used for radio links of RS and meteo-satellites

Bandwidth, MHz	Radio service	Application
VHF band		
137-138	Meteorological satellites, space operations	Automatic image downlink from meteo-satellites on polar orbits in APT format (e.g. the US NOAA satellites). Telemetry and trajectory data downlink.
UHF band		
400,15-406	Meteorological satellites and probes, space operations	Data and images downlink from meteo-satellites
460-470	Meteorological satellites, space operations	Data relay from automatic platforms of the geostationary GOES meteo-satellites (USA)
L-band		
1670-1710	Meteorological satellites and probes	Meteodata downlink from polar-orbiting and geostationary satellites in HRPT format
S-band		
2200-2290	Space research, space operations, RS satellites	Telemetry string (including the US SGLS BBC systems and NASA DSN) and imaging equipment data downlink
2290-2300	Space research	Data downlink from research satellites of the NASA DSN deep space tracking system
X-band		
7450-7550	Meteorological geostationary satellites	Used by the Russian “Elektro” meteo-satellite
7750-7850	Meteorological non-geostationary satellites	There are plans to use at NPP satellite (USA), in the future NPOESS system and on the European MetOp-1 satellite.
8025-8400	RS satellites, meteorological satellites	Imaging equipment data downlink
Ka-band		
25500-27000	RS satellites, meteorological satellites	There are plans to use in the future NPOESS system

L-band radio links are used for transmission of 1 km resolution meteodata from polar and geostationary satellites (NOAA, Meteor (Russia), FY (China), GOES, METEOSAT (ESA), MTSAT (Japan)).

S-band radio links have been widely used starting from the 70s for commanding, telemetry downlink and for RS data collection via medium data rate channels (1-15 Mbps), such as MSS sensor of Landsat-4, -5 (USA), DMC and DMSP sensors (USA).

X-band frequency is widely and commonly used as the main bandwidth for medium and high data rate transmissions (up to 320 Mbps) from board of almost all the RS satellites to the ground stations. Data downlink parameters of the major RS systems are shown in Table 2, where RT stands for real-time and SD – storing device.

S-band (2-2,3 GHz), Ku-band (13-15 GHz) and Ka-band (23-28 GHz) are used in the inter-satellite data relay systems.

Table 2. Radio transmitter parameters of RS systems

Satellites (launch year)	Company (country)	Transmitter frequencies, MHz	Data rate (Mbps), modulation (mode)
QuickBird-2 (2001)	DigitalGlobe (USA)	8185	320; OQPSK
IKONOS-2 (1999)	GeoEye (USA)	8185 8346	320; QPSK
Terra (1999)	NASA (USA)	8212,5 8212,5	150; QPSK (SD) 13; UOQPSK (RT)
Aqua (2002)	NASA (USA)	8160 8160	150; QPSK (SD) 15; SQPSK (RT)
Landsat-7 (1999)	USGS (USA)	8082,5 8212,5 8342,5	150; AQPSK
SPOT-4 (1998)	SPOT Image (France)	8253 8153 1704	50; QPSK 3,4; — 0,51; —
SPOT-5 (2002)	SPOT Image (France)	8253 8365 8153	50; QPSK 50; QPSK 6,8; QPSK
RADARSAT-1 (1995)	MDA (Canada)	8105 8230	105; QPSK (RT) 85; QPSK (SD)
ENVISAT-1 (2002)	ESA (Europe)	8100 8200 8300	100; QPSK (RT) 100; QPSK (RT) 50; QPSK (SD)
TopSat-1	Infoterra (Great Britain)	8127	11; QPSK
«Monitor-E» (2005)	Federal Space Agency (FSA), Khrunichev Space Center (Russia)	8192	15,36; BPSK 61,44; BPSK 122,88; QPSK
«Meteor-3M»-1 (2000)	FSA (Russia)	8192	15,36; BPSK
IRS-1C (1995), -1D (1997)	NRSA, Antrix (India)	8150 8350	85; QPSK 42,45; QPSK
IRS-P6 (2003) ResourceSat-1	NRSA, Antrix (India)	8125 8300	105; QPSK 105; QPSK

Due to an increase in the resolution of the remote sensing data, the International Telecommunications Union (ITU) made a decision to allocate the Ka-band (25,5-27.0 GHz) for the high data rate S/G radio links. For the first time in the RS practice Ka-band data relay radio links will be used in the future American meteorological NPOESS system.

Commanding, telemetry and data handling standards

Usually, the national command and measurement complexes (ground sites) are used for trajectory measurements, commanding and telemetry downlink. Equipment to receive commands and create a telemetry package is installed onboard a satellite, compatible with national standards and ground site firmware. Most of the currently operating satellites use S-band for commanding, telemetry and trajectory data downlink.

Commanding and telemetry equipment of several standards is being used in the USA:

- NASA USB (Unified S-band) – for all the civil NASA satellites and many commercial ones;
- BBC SGLS (Space Ground Link System) – for most of the military and experimental satellites of the US Department of Defense;
- TDRS (NASA) – for all the NASA civil satellites, serviced by the tracking and data relay satellite system (TDRSS);
- CDLS (Common Data Link System) – in support of the reconnaissance satellites.

Standards for commanding and telemetry equipment of the US satellites in S-band are shown in Table 3.

UniScan-36 ground station with the 3.6 m antenna installed in the Moscow Center for data reception and processing of ScanEx R&D Center. Nowadays it is the most universal domestic complex, providing for the data reception from 11 satellites of the leading RS operators in the USA, India, Israel, France, European space agency, Russia and Canada.

In 1987, a unified international protocol for commanding and telemetry data transmission was introduced – CCSDS (Consultative Committee for Space Data Systems). For the first time it was used on the ERS-1 satellite of the European space agency in 1991.

Basically all the RS satellites are currently equipped with the data relay devices using the radio links meeting the CCSDS protocol requirements: RADARSAT-1 (Canada), RocSat-1 (Taiwan), American Landsat-7, Terra, Aqua, MTI, EO-1, KOMPSAT-1 (Korea), ADEOS-2 (Japan), as well as the would-be COSMO (Italy), Pleiades (France), TerraSAR-X (Germany), MetOp-1 satellites and others. Thanks to CCSDS the equipment of a stand-alone station can be easily upgraded to receive and process the data from different RS satellites. TDM and SLE, used in some national projects, can be regarded as alternative protocols.
Quite a new way of data transfer is the IP format (internet protocol), increasing the rate of data processing and presentation. For the first time in the RS practice such a format was successfully tested during the radio traffic with the British UoSat-12 mini-satellite.

RS data ground receiving stations

Technology development, especially over the past 10-15 years, had a serious impact on the looks of the ground receiving complexes. Expensive and bulky installations with large-diameter antennas of 10-15 m were replaced with small-size cost-efficient systems with only ∅2-3 m antennas.
Remote sensing data market developments and democratization of the access to space data had a positive influence on the receiving stations market. With growing number of remote sensing programs, the demand on the **universal receiving complexes** operating in **X-band** has also increased. Operators of the relevant remote sensing centers are upgrading their ground receiving stations to support the new satellites radio link formats.

Table 3. S-band command and telemetry hardware standards of US satellites

Standard	Command forward link		Telemetry		Comments
	Frequency, MHz	Data rate, Kbps	Frequency, MHz	Data rate, Kbps	
SGLS BBC USA	763,721–1839,795	1; 2	2202,500–2297,500	0,125–2048	20 channels 256/205
NASA USB standard	2025–2120	0,0078–2	2200–2300	0,0056–500	20 channels 240/221
TDRS (NASA)	MA 2106,4; SA 2025–2120	Up to 10; Up to 300	MA 2287,5; SA 2200–2300	1–1500; 1–12000	20 objects in MA mode and two objects in SA mode

Due to high applicability of MODIS data (Moderate-resolution Imaging Spectroradiometer) of EOS series satellites the biggest international network of 110 simplified small-size receiving complexes operating in X-band has been created providing for the MODIS data collection in real-time mode. One fourth of these ground receiving stations have been developed and manufactured in Russia by the ScanEx R&D Center.
In some countries broadcasting technology is used for the real-time distribution of the Earth observing space data. After being processed in the remote sensing centers, the space data are broadcast via geostationary satellites to the network of customer’s stations, equipped with small-size antennas for the TV programs reception. For example, such networks have been created in Europe to broadcast the MSG meteo-satellite data and in China to distribute the MODIS sensor images through the country.

There is still another trend. RS operators of high-resolution systems are extending distribution networks by offering expensive **special-purpose stations with processing terminals** to the customers together with space data reception contracts, thus relaying part of the space segment development costs to the firmware of ground complexes. Former US Space Imaging company's terminals for the IKONOS-2 data reception may serve as an example, as well as ELS terminals (Easy Link to SPOT), created by the European Astrium concern for SPOT-5 data reception with the total cost exceeding 2 million euros.

Ground stations development in 70-90s followed the course of standardization of large special-purpose ground receiving stations. The THA-57 complex with the 12 m antenna (Priozersk, Republic of Kazakhstan) has been used in the Soviet period for field tests and target tracking in S-band. As a result of the modifications, performed by the ScanEx R&D Center in 2004, it became possible to receive space data from IRS-1C, -D and "Meteor-3M"-1 satellites in X-band.

Inside the Iranian Remote Sensing Center, where the UniScan-36 ground station is installed

At the same time, thanks to a flexible approach of the SPOT Image, MDA (Canada), ImageSat (Israel) and Antrix (India) companies, the existing ground stations can be upgraded to support X-band radio links for SPOT-2, -4, RADARSAT-1, EROS A, IRS-1C, -D, -P6 satellites data reception for a reasonable price.

Due to the current world standardization and globalization trends, an international network of X-band data ground receiving stations has been established, simplifying the space data access and making it much cheaper for the end-customer, who is interested only in an end-product, rather than how this access was achieved hardware-wise. Notably, Russia is by far not the last operator in this network.

REMOTE SENSING DATA PRELIMINARY PROCESSING TECHNOLOGY: EXPERTISE OF SCANEX R&D CENTER IN SETTING UP A COMPLETE CYCLE OF DATA PROCESSING FOR GROUND RECEIVING STATIONS

The most important features during the development and introduction of preliminary remote sensing data processing systems are: processing and data formats standardization, automation and efficiency improvements.

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Despite the great variety of remote sensing satellite systems, of imaging equipment operation modes and data formats, there are characteristics and technological solutions inherent in most of the world systems of RS data acquisition and processing.

As a rule, the **remote sensing data processing** is divided into **preliminary** and **thematic**. The first one usually implies a set of operations (processes), conversion of the source data, acquired by a ground station, into certain RS products of the standard processing levels, suitable for archiving and further use. Preliminary processing covers radiometrical calibration, georeferencing, geometrical correction and so on. Thematic processing implies data processing for remotely sensed data interpretation within the frames of a specific task, with thematic output products (maps, cloud masks, elevation models, etc.)

The source data (raw data array), registered by the ground receiving center, is downlinked as a signal from the satellite as a bit chain, containing both the Earth imaging results, and the service information about the trajectory and attitude of the spacecraft, imaging equipment operation modes, etc. The data signal passes several processing stages (demodulation, synchronization, decoding, etc.), part of which is performed by the hardware, and the other part – using software tools straight after the loss of signal with the satellite. Knowing the architecture (format) of the data array, one can retrieve the delivered images out of it.

If the sensor complement includes several imagers and several imaging modes, then data arrays are downlinked separately to the ground stations. As a rule, one array contains the data acquired using one frequency band. For example, the Indian IRS-1C, -1D, -P6 series satellites are broadcasting the captured data via two radio channels.
The ground station tasks of RS data preliminary processing are as follows: decode the acquired data array, retrieve the images and auxiliary data, process and present the data in storage formats.

There are several RS data processing levels, which can have different names and nomenclature among RS operators. The most frequently used are the following levels of preliminary data processing:
0 – raw (primary) data of the imaging equipment;
1A – radiometrically corrected and calibrated data;
1B – rediometrically corrected and geo-located data;
2A – rediometrically and geometrically corrected data, represented in a map projection;

They are followed by products of a higher processing level, when additional data is used to get such output products (ground control points, DEM for orthocorrection, etc.), usually generated for further thematic processing.
Remote sensing products of higher than 2A processing levels are usually distributed in popular archive formats (e.g. GeoTIFF or image processing formats – ERDAS, ENVI, PCI, etc.), because in most cases they are georeferenced images and no more specific information about satellite orbital parameters and attitude at the time of imaging is required for their further use. The only requirement is that the format must contain raster georeference parameters (for example, in form of map projection description).

Lower processing level products are supposed to contain (and in most cases it is secured) auxiliary information which is used further on to generate higher level products. Unfortunately, there are no general formats to archive and distribute the lower processing level products, which can be explained by the uniqueness of satellites, their imager instruments, imaging modes, etc. Probably, in future the RS operators will come to an agreement and offer unified formats to their customers. Meanwhile, each operator uses its own storage formats (e.g. RADARSAT, CEOS, IRS Super Structured, etc.). In most cases the structure of such formats is open and the companies try to come up with compromise solutions. Thus for example, EOS NASA program (Terra, Aqua US satellites) implies data products storing and transfer in EOS-HDF format, which a modification of the more popular HDF (hierarchical Data Format) format to represent the scientific research data of different type and structure. There are software tools available, allowing the user to handle this format, and many modern remote sensing data processing systems support hdf-files. Another example is SPOT-5 data (France), distributed in DIMAP format, which contains a raster in (Geo) TIFF format and metadata (auxiliary information) in XML format, making it much easier to user the products further on. Similar solutions are used by other RS operators; in particular, the domestic Monitor-E satellite data will be available in RSML format, which metadata are represented in XML-based files.

Leading international RS operators usually recommend (or sometimes require) the compliance with their output products assortment and data storage formats, thus providing for the standardization of remote sensing data storing and distribution among the users. For example, the MDA company (Canada) introduced strict requirements to the ground receiving stations, operating within its network of RADARSAT-1 data reception centers, including the quality of the generated products and output formats structure. Certification of each and every new reception center is a must (three centers, equipped with UniScan firmware, have been validated in Russia and Kazakhstan; the RADARSAT-1 data preliminary processing software package was created by the ScanEx R&D Center specialists based on the submitted Canadian specifications).

The data acquired from satellites is usually stored in the archives for further use (except for real-time monitoring, when only the most updated images have value). There are two basic options: storing, i.e. data distribution in archives on certain media (DLT, HDD, CD, DVD, etc.) and cataloguing – creation of metadata (attributes) catalogues, describing the images being stored. Cataloguing enables to arrange for further search and selection from the archives of the required data, for example, images based on geographic coordinates.

The ScanEx Center experience shows that the following provisions are the most important for decision-making with respect to the processing level of data to be stored:

1. The lower is the processing level, the less possible is to have a mistake; the processing algorithms can be changed, if required; maximum automation and processing time decrease is possible, as well as space saving since the low processing level data are concise.
2. An important requirement – integrity of the stored data, i.e. it is highly preferable not to cut them into small scenes; however, it is required for cataloguing, the scenes can be cut virtually. This will enable to avoid redundant manipulations and reduce the risks of mistakes. Besides, storing a long image (e.g. the one corresponding to one downlink) enables to easily retrieve the required scenes for products generation. Let's have a closer look at this operation.

The data array is a long image usually corresponding to the imagery session (a few thousand kilometers). During the remote sensing products distribution the concept of a "scene" is often used, describing a part of the data array (as a rule, in form of squares). The scenes are retrieved from the data flow, using a certain rule to comply with the spots of the surface. Generally the scheme of the data flow cutting into scenes is called WRS (World Reference System – an international system of references). WRS is used in such RS systems, as Landsat (USA) and IRS. The SPOT program terminology has a GRS abbreviation (Grille de Reference SPOT). The schemes have differences, depending on the satellite orbital parameters and on the imagery mode, however, there is only one core principle. WRS – is a grid of "paths" (satellite passes) and "rows" (parallels), covering the Earth's surface. Intersection of paths and rows creates a number of nominal scene centers. WRS allows the users to position, to put in the catalogue and to request the images of any part of the planet by indicating the nominal center of the scene, set by the Path and Row parameters (Fig.1).

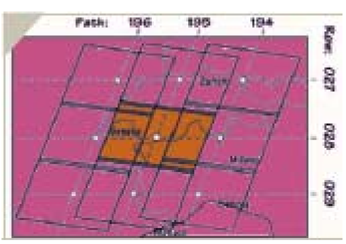

Fig. 1. Landsat-7, scene 195/028

At such a cutting, separate scenes are partially overlapped. What should the user do, if the interested territory is on the cut point between two scenes? To prevent the user from buying excessive information, many RS operators (for example, SPOT Image) allow the scenes with along-path displacement to be cut out of the data flow. In this way the storage of intact (uncut) data arrays enables to easily retrieve random scenes and to generate the output products.

ScanEx Center is experienced in both integrating the end products of foreign preliminary data processing software packages from the operators (EROS A, Israel; ORS-P6 and so on) and creating own preliminary processing software tools based on the existing specifications (RADARSAT-1, SPOT-4, etc.). As a rule, the ScanEx preliminary data processing packages include the software components that make it possible to do the following:

- transfer the data into formats suitable for further processing;
- separate and retrieve data of different sensors and imagery modes;
- select data based on its quality (e.g. clear-day scene);
- cut the data flow into scenes virtually and generate metadata files and quick-looks for each of them for further cataloguing;
- generate products of standard processing levels in preset formats.

Although package composition and destination of separate software components can differ depending on the type of received and processed RS data, the overall flow chart of the preliminary data processing, used by ScanEx R&D Center, can be presented as follows (Fig. 2).

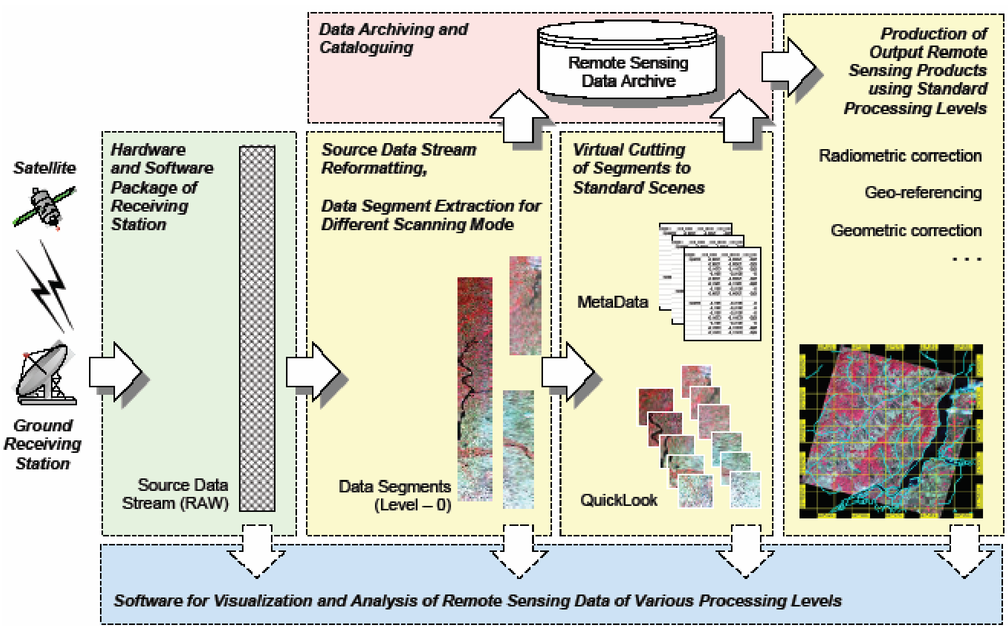

Fig. 2. General flow chart of the preliminary data processing, ScanEx R&D Center

The input raw data received at a ground station is converted into a certain storage format (level 0) and is divided into segments, each corresponding to one operation mode of the satellite imager instrument. Then the data is virtually cut into scenes in compliance with the selected processing technology. Segments are archived, whereas the corresponding virtual scenes are catalogued with quick-looks and metadata of separate scenes being stored. A required scene can be fished out of the catalogue upon request; part of data is cut out of the relevant segment and is then used to generate the output products of the required processing level.

Data preliminary processing software packages, supplied by the ScanEx R&D Center together with UniScan ground stations, are presented in Table below.

Date type	Software package	Features
Terra, Aqua	IMAPP	Preliminary processing and generation of standard MODIS EOS-HDF products of Levels 0, 1A, 1B.
EROS A	EROS Tools*	Preliminary processing and generation of standard EROS products of Levels 0, 1A, 1B
RADARSAT-1	RADARSAT Tools	Preliminary processing and generation of standard RADARSAT CEOS products of Levels 0, 1
IRS-1C, -1D	IRS Tools	Preliminary processing and generation of Level 1A and 1B products
SPOT-2, -4	SPOT Tools	Preliminary processing and generation of standard SPOT DIMAP products of Levels 0, 1A
IRS-P6	IRS-P6 Tools*	Preliminary processing and generation of standard Level 0, 1A, 1B products

* The software package includes components of the RS operators

The Table shows that the enlisted software packages enable to generate initial processing level products (0, 1A, 1B). Creation of the Level-2A products, i.e. images, converted into map projections, does no longer depend on the processed data type and is basically universal. This operation is done in the ScanMagic software application, which is part of the station delivery set.

In addition, ScanEx has been developing and supplying thematic processing software packages (e.g. ScanEx Inage Processor), enabling to generate products of higher than 2A processing levels. ScanEx Catalog Manager is used to catalog the RS data, received by UniScan ground stations.

Notably, the software console versions (without GUI) enable to set up a package mode data processing within stand-alone RS data preliminary processing systems. This boils down to minimum the participation of receiving station operators in data preliminary processing, providing for partial or complete automation of the process. At the same time, the software versions with GUI’s make the operators work much easier, especially when generating standard output products as a result of setting up multiple processing parameters. Therefore, ScanEx’s software packages have console and GUI program versions as a rule. All the software packages run under Windows 2000, XP and higher operating systems.

To sum it all up, the most important moments during the development and introduction of the RS data preliminary processing systems are as follows: standardization of processing and data representation formats, increase of software applications’ processing speed and processing automation.

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