FROM IMAGERY TO DIGITAL REALITY:

Earth Remote Sensing & Photogrammetry

17th International Scientific and Technical Conference

Conference Proceedings

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Dear colleagues!

The geographical map is one of the major advancements that man has developed over thousands of years. We have come a long way from Ptolemy's maps to have our modern-day, precise, digital maps. Over time, scientists have created and developed many ways of obtaining of spatial information.

More than 150 years have passed since the day French inventor Gaspard-Félix Tournachon took a photograph of Paris from an air balloon. This photograph started the phenomenon of remote sensing, which rapidly developed in the twentieth century and has continued to evolve in the twenty-first century.

The appearance of the Earth's satellite imagery, new technologies of aerial survey, laser scanning, and the use of digital methods of data collecting and processing in real time have significantly changed our attitude to spatial information.

These advancements, in turn, have led us to understand the necessity of development and to bring our annual conference, "From imagery to map: digital photogrammetric technologies," to a new level.

This year, the name of our annual conference was changed to "FROM IMAGERY TO DIGITAL REALITY: ERS & Photogrammetry" in order to reflect current trends in visualization and use of spatial information.

Digital reality is measured spatial information that is used in almost all directions of society's technological developments, be it land management, navigation, autonomous transport systems, smart cities, robotic technologies, and much more. Digital reality provides cartographic basis for the Internet of Things, and it allows building space-time models for sustainable development of society.

This new conference name significantly widens the theme of the conference. We are sure that it will contribute to the growth of interest in Earth remote sensing and photogrammetry technologies, attracting new participants to the conference. We are hopeful that this year's conference will allow us to be more interesting and fruitful.

Sincerely yours,
the Organizing Committee

17th International Scientific and Technical Conference
"FROM IMAGERY TO DIGITAL REALITY: ERS & Photogrammetry"
October 16-19, 2017, Hadera, Israel.

RACURS

2017

CONTENT

GEOIndustry 4.0

M.A. Bolsunovsky, Sovzond Company, Moscow, Russia

The modern world lives in the era of the third industrial (digital) revolution, started with active use of electronics and information technologies in 1969. Nowadays we can see a gradual transition towards the fourth industrial revolution which is characterized by a merger of technologies and blurring of the boundaries between physical, digital and biological spheres. Geoinformation technologies and the Earth Observation is undergoing the same transformation, possibly named GEOIndustry. What kind of changes can occur in the industry of geoinformation technologies and the Earth Observation in 15 years? Let's try to predict the distinctive features of GEOIndustry 4.0.

Satellite imagery will be conducted in a continuous mode. In the field of unmanned aerial vehicles, there will appear a system of fully automated docking stations with UAV which are integrated into the existing infrastructure components. In the sphere of aerial photography and airborne laser scanning, there will take place a transition from manned survey systems to UAVs. Revolutionary changes will occur in the field of data processing, software development, geoinformation systems. The very concept of "map" will be a subject to review. Transition to the spatiotemporal model, information analysis will be done automatically (starting from the collection of necessary data), transition to systems with informal and intuitive perception of tasks will be carried out, providing the users with optimal solutions on the base of the dynamic spatiotemporal model. The user's request to receive necessary analytical information will be met online.

In 15 years when GEOIndustry 4.0 gains full strength, the spatiotemporal terrain model and intelligent analytical services will become basic concepts. In general, the industry will be characterized by: BigData technologies, cloud computing, full automation of processes, neurologics, convergence of all spatial data sources.

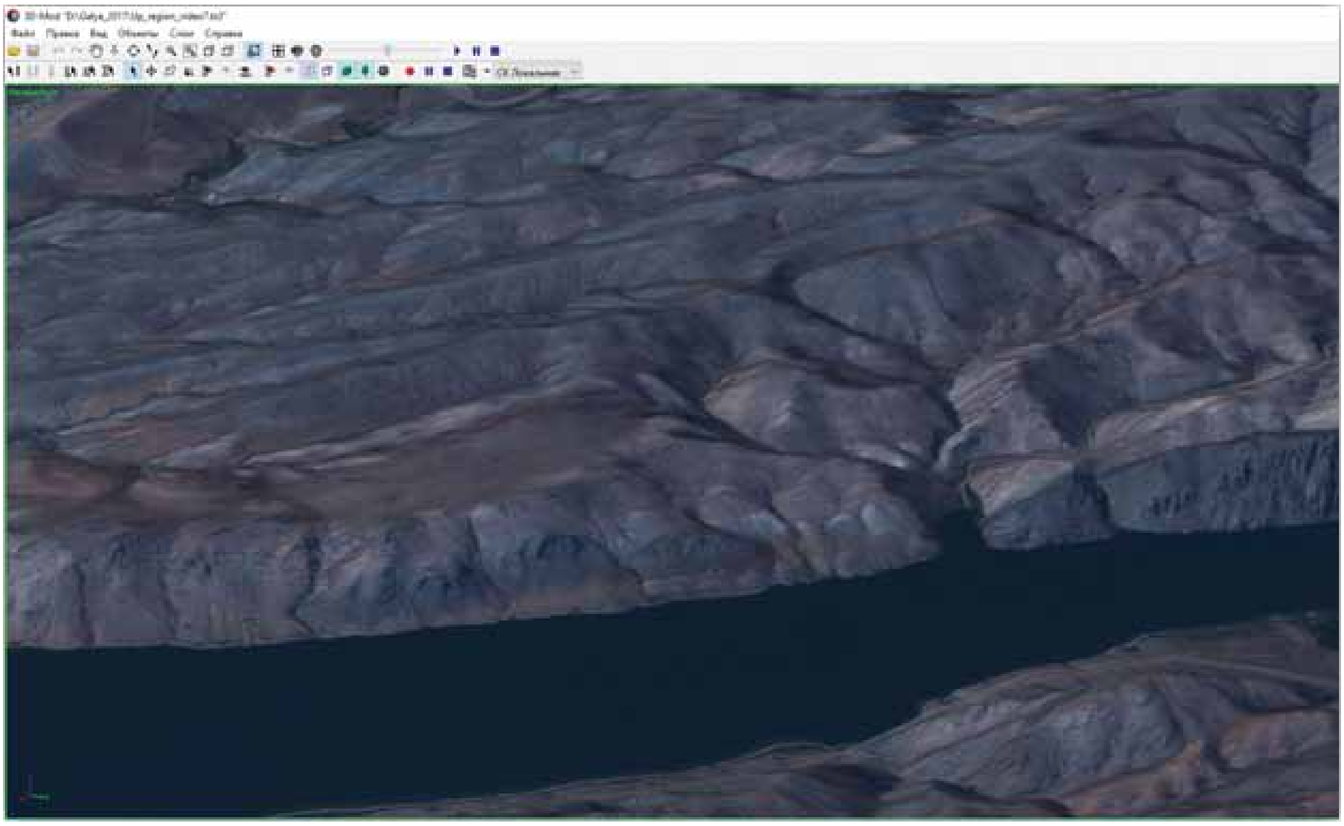
New trends in Photogrammety

A. Chekurin, Racurs, Moscow, Russia

Geospatial technology has entered a period of rapid development. Present day is characterized by the growth of base spatial information, primarily satellite images, spatial and radiometric resolution increase, data acquisition rates speedup. There are new platforms and types of remote sensing systems: UAV, cameras with several lenses for oblique survey and new three-dimensional modeling algorithms.

Technologies of raw data processing as well as data formats and hardware are intensively developing.

The report will give an outlook of todays factors which effect the photogrammetric technologies: the automation level of the main photogrammetric operations, cloud technologies, efficiency of hardware solutions to process, save and share data.



Digital terrain model created on 30 archived multi-temporal images acquired by GeoEye-1, WorldView-2,3. Image courtesy of DigitalGlobe

Innovation in mapping and photogrammetry at the Survey of Israel

Y. Felus, Survey of Israel, Israel

Smart cities, autonomous transportation, modern infrastructure management and real estate market analysis all require high quality geospatial data.

These applications require high spatial accuracy, high resolution and large amount of attribution and contextual information.

Moreover, users of the applications require that the data be frequently updated and that the update processes are cheap.

The presentation reviews the current activities of the Survey of Israel in meeting the demands of these advanced technologies including:

1. Setting directives and regulations for mapping and surveying
2. Defining methodologies to certify digital sensors and cameras for mapping
3. Publishing standards for map format (layers, attributes, cartography)
4. Designing advanced procedures for automatic mapping and updating of national topographical layers (building, land cover, etc.)
5. Developing an on-line quality control system for mapping files
6. Improving the capabilities of the national geospatial portal to present and disseminate the data.

EXCELSIOR: a European Horizon 2020 Teaming project for the establishment of a Centre of Excellence in the Eastern Mediterranean for Earth surveillance and space-based monitoring of the Environment

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Keywords: Center of Excellence, earth observation, remote sensing, natural hazards, natural & built environment, cultural heritage, water resources, atmosphere, land, Cyprus, MENA

1. Introduction

Earth Observation technologies are vital for providing reliable up-to-date information to better observe, understand, protect, monitor and predict environmental parameters that regard land, water and air. Such valuable inputs are crucial for more informed decision-making oriented towards the protection and management of environment and resources. Earth observation includes, among others, technological solutions including satellite observation, navigation and positioning systems. To date, conventional methods are employed for the detection of threats/risks related to pollution events in air, land and water, including the use of physicochemical sampling campaigns and site visits. These techniques are time consuming and require extensive use of manpower and, the same time, create additional environmental issues.

The aim of this paper is to present the envisioned upgrade the existing Remote Sensing & Geo-Environment Group-ERATOSTHENES Research Centre (ERC) established within the School of the Engineering and Technology, Department of Civil Engineering and geomatics, Cyprus University of Technology (CUT) into a sustainable, viable and autonomous Centre of Excellence (CoE) for Earth Surveillance and Space-Based Monitoring of the Environment (EXCELSIOR), which will provide the highest quality of related services on the National, European, Eastern Mediterranean and Middle East (EMME) and Middle East and North Africa (MENA)levels.

The above vision will be addressed through the implementation of a robust plan that will be developed during the current one-year phaseof EXCELSIOR project and will establish the foundations for the development of a competitive and high competence profile to expand the Centre's visibility beyond the national level and develop transnational and transregional cooperation. The long-term aim of the upgraded Centre is to create new opportunities for conducting basic and applied research and innovation (R&I) in the areas of the integrated use of remote sensing and space-based techniques for monitoring the environment with applications in several areas, including (but not limted to) the built environment, natural hazards and cultural heritage.

Five partners that have already strong collaborations between each other have united within EXCELSIOR project with the common vision to upgrade the existing ERC to become a world-class innovation, research and education center, actively contributing to the European Research Area (ERA). These five partners include the Cyprus University of Technology (CUT, acting as the coordinator), the German Aerospace Centre (DLR), the National Observatory of Athens (NOA), the German Leibniz Institute for Tropospheric Research (TROPOS) and the Cyprus Department of Electronic Communications of the Ministry of Transport, Communications and Works (DEC-MTCW).

The existing ERATOSTHENES Research Center (ERC)conducts state-of-the-art research, integrating novel technologies in the areas of Remote Sensing and space-based earth observation techniques, along with the use of Geographic Information Systems (GIS), to develop sustainable and systematic monitoring of areas of interest and the on-time detection of risks. The ultimate goal of the CoE will be the protection of the environment, providing critical information, through end user products, not only to policy makers but also to other local, national and regional authorities.

The ERC has demonstrated its innovation and dynamics in the field of Earth Observation over the past 10 years of its existence and is now focused on upgrading the existing ERC into a Centre of Excellence (CoE), which will address the national, regional and international needs regarding remote sensing and Earth Observation. The ERC has received funding for over 60 competitive research programs and funded projects since 2007, with funding Sources from the European Union (EU), the Cyprus Research Promotion Foundation (RPF) and industry.The EXCELSIOR project is built upon the vision for the upgrading of the existing Remote Sensing and Geo-Environment Group (Eratosthenes Research Centre) ERC to a sustainable CoE. The upgrade will regard the expansion of this vision to systematic monitoring of environment using Earth observation, space and ground based integrated technologies focusing on natural and built environment (e.g. land, air and water) related applications. The main pillar will be on conducting basic and applied research to bring innovation in the areas of the integrated use of remote sensing and space-based techniques for monitoring the environment.

The EXCELSIOR's project vision of the significant upgrade of the ERC into a CoE in Earth Surveillance and Space-Based Monitoring of the Environment, is fully aligned with the Smart Specialization Strategy (S3Cy) for Cyprus. The S3Cy has been esteblished by the Government of Cyprus (Government of Cyprus, 2015), based on priority sectors that have been selected for future sustainable economic growth in Cyprus.

Through the H2020 "Spreading Excellence and Widening Participation", the Centre coordinates the 'ATHENA' TWINNING Project (www.athena2020.eu) with the main aim to establish a Centre of Excellence in the field of Remote Sensing for Cultural Heritage in the areas of Archaeology and Cultural Heritage. This enable the Group to move to the next step of upgrading the existing Centre into a sustainable and viable Centre of Excellence (CoE) for Earth Surveillance and Space-Based Monitoring of the Environment through the 'EXCELSIOR' Teaming Project (H2020-WIDESPREAD-04-2017) (www.excelsior2020.eu).

The strong background and individual experience of the ERC in the area of remote sensing and space technologies, combined with the synergy that will be established with the partners of the project, can result in the implementation of a sustainable CoE, which will address crucial research and innovation (R&I) problems of great societal benefit. The research fields of Earth Observations and space technology have matured to the point that many challenges lie in the capitalisation of existing knowledge and technologies to enable advances in many diverse application areas stated in the S3Cy, such as health, tourism, agriculture, cultural heritage, transport, blue growth, natural hazards, natural & built environment etc. The R&I activities of the upgraded ERATOSTHENES CoE are planned to be directly linked with the thematic areas of the horizontal priorities of Environment and Information & Communication Technologies of S3Cy, through future collaboration with the industry not only within Cyprus but also with countries in the Eastern Mediterranean and Middle East (EMME) and Middle East and North Africa (MENA).

2. Areas of expertise of theERATOSTHENES Research Center

In relation to the Copernicus trend, which provides products and services on Land, Marine and Atmosphere monitoring as well as on Emergency management, Security and Climate Change, ERATOSTHENES CoE is organised in 3 main research thematic areas, i.e. Land, Water and Air which are covered under the big umprella of the natural and built environment. The present research capacities of ERATOSTHENES are summarized below:

(a) The current state-of-the-art includes characteristic services such as the monitoring and forecast of natural environment (forests drylands, crops) and natural geo-hazards (including desertification, earthquakes, landslides, flooding, fire). The research activities of the ERC focus on crop prediction, soil monitoring, pest control and sustainable land use. Additionally, the monitoring of archaeological and built cultural heritage sites for purposes of their better conservation and valorisation are one of the main activities of the Centre. Systematic services of Land use/land change are of particular importance for urban growth and the built environment (Agapiou et al., 2015; Neocleous et al., 2016). Economic sectors affected by Land Section in Cyprus are hence mainly Agriculture (with focus on Infrastructure and Planning for urban and rural areas) (Papoutsa et al., 2016; Themistocleous et al., 2014a), the built environment (Themistocleous et al., 2012; Themistocleous et al., 2014b) and the efficiency constructions.

(b) The current state-of-the-art focuses on water resources management and agriculture as one of the more important priority sectors for Cyprus, since it has a long history of water challenges, including severe water scarcity problems for centuries. The ERC aims to support public authorities, stakeholders and private interest to retrieve useful information for optimizing water management by using available satellite data. Some of the major research sectors of the Centre, monitoring water quality in dams using satellite remote sensing, with the aim to protect and preserve the quality of available water as well as monitoring coastal areas, and identifying water leakages in urban and rural areas through passive and active remote sensing techniques (Agapiou et al., 2014; 2016). Additional research includes examining drought events due to climate change through earth observation systems as well as Marine Spatial Planning (Hadjimitsis et al., 2015), which focuses on coastal and maritime tourism and the promotion of sea based cargo and passenger transportation are some of the crucial areas included. The Group has a strong research background on monitoring irrigation demand using image-based techniques by integrating remote sensing, UAV and field spectroscopy (Papadavid et al., 2009, 2011).

(c) The current state-of-the-art of the Atmospheric sector of ERC are primarily focused on (1) provision of useful tools and knowledge for the discrimination of manmade from natural sources of pollution, for subtracting the contribution of natural sources before comparing ambient air pollutant concentrations with relevant legally binding limit values (Nisantzi et al., 2014; Nisantzi et al., 2015; Mamouri and Ansmann, 2014), (2) minimization of agricultural losses and efficient planning through better understanding of precipitation and hail initiating processes, since the on-line knowledge of the background aerosol content in terms of freezing nuclei can provide a valuable source of information for future rainfall enhancement and/or hail suppression operations (Mamouri and Ansmann 2015; 2016), and (3) alert mechanisms for high aerosol concentrations (e.g., dust events, volcanic eruptions), for enabling timely information of the public, minimize exposure and reduce hospital admission and other health related costs (health, tourism) (Hadjimitsis et al., 2013a; 2013b; 2013c; Mamouri et al., 2016) and to improve safety in aviation (transport).

(d) The current state-of-the-art of the Cultural Heritage sector of ERC is focused on the integrated use of field spcetrsocopy, UAV, geophysical surveys and earth observation for the detection of archaelogical buried remains, risk assessment using space-based techniques, protection and surveying. This sector is running three funded projects: the Twinning ATHENA project (www.athena2020.eu) and two JPI-CH projects (namely CLIMA: http://www.clima-project.eu and PROTHEGO: http://www.prothego.eu). The “ATHENA” Twinning project aims to establish a Center of Excellence in the field of Remote Sensing for Cultural Heritage in the areas of Archaeology and Cultural Heritage through the development of an enhanced knowledge base and innovative methods (Hadjimitsis et al., 2016). The “ATHENA” project is built around EU policies and international conventions related to Cultural Heritage protection, management and best practice (e.g. Europa Nostra policy documents; COM (2014) 477; UNESCO and EU conventions and multilateral treaties related to the protection of tangible Cultural Heritage).

3. Concluding remarks

The objective of the first phase of the EXCELSIOR project is the development of a detailed and robust Business Plan for upgrading the ERC. Such a Business Plan will target the long term vision to transform ERATOSTHENES itself into an EXcellence Research Centre for Earth SurveiLlance and Space-Based MonItoring Of the EnviRonment by enhancing the scientific and R&I capabilities of the existing center. This enhancement will enable the provision of new, highly innovative products and services to national, regional and international public and private sector, in the Space and Earth Monitoring sectors. The development of the Business Plan is key to ensure the sustainability of the CoE and will also provide the necessary guarantees for its long term self-sustained operations. The Business Plan will establish the foundations for the development of a competitive and high competence profile to expand the Centre's visibility beyond the national level and develop transnational and transregional cooperations aith European, Eastern Mediterranean and Middle East (EMME) and Middle East and North Africa (MENA) countries

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Earth Remote Sensing data for extraction coastal information and bathymetry

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Having updated and precise information about the seabed is crucial for coast development, construction of offshore oil production facilities, seaport operations, ensuring safe functioning of ships at the sea, and conducting scientific research.

Using high-resolution multispectral satellite imagery is a new approach to acquiring information about the seabed terrain. Along with traditional spectral bands, modern remote sensing satellites have extra channels, which are used for atmospheric correction, water quality and vegetation control and many other tasks.

QuickBird and WorldView-2 spectral bands cam be seen in Fig.1

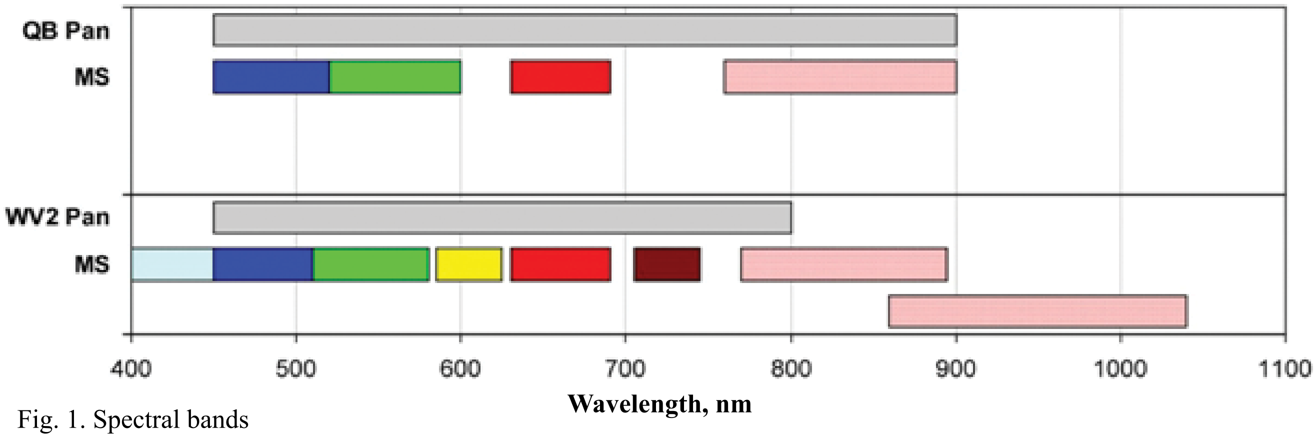

Fig. 1. Spectral bands

The violet or "coastal" band penetrates water better than any other channel does. This band makes taking deep water measurements possible, which cannot be done using traditional spectral bands. At the same time, water quality is very important for the coastal channel that is why using it may sometimes be impossible. When there is much suspended or organic matter in coastal waters we use other bands – yellow and green – which are correlated with the violet channel best of all. Depth measurements can be recalculated into absolute values. For this we need to have information about storm surges and tides at the time of image acquisition.

Using satellite images fully exclude expenses on transportation of equipment and employment of manpower, any damages to equipment when measuring depths in not very deep waters. Also there is no need to get clearances or licenses for taking bathymetric measurements; no visas are required to pass country borders.

Getting bathymetric data from satellite images is much less expensive than measuring the seabed in the traditional way. It takes less time to process satellite images than lidar data, allowing us to get bathymetric measurements worth of 5,000 km2 every month.

PRIME GROUP acquired bathymetric measurements in the part of the Vyborg Bay between the Vyborg Port and Vikhrevoy Island. You can see the area of interest in Figure 2.

Fig 2. Area of interest

WorldView-2 and GeoEye-1 imagery was used to get these measurements. After analyzing the weakening of penetration of light in the water in relation to the water-air level, 50 cm resolution raster images with depth values were acquired. Initially, it was planned to measure water down to 5 meters, but due to high turbidity the maximum measured depth was 2.5 meters. A sample of the resulting data is shown in Fig. 3.

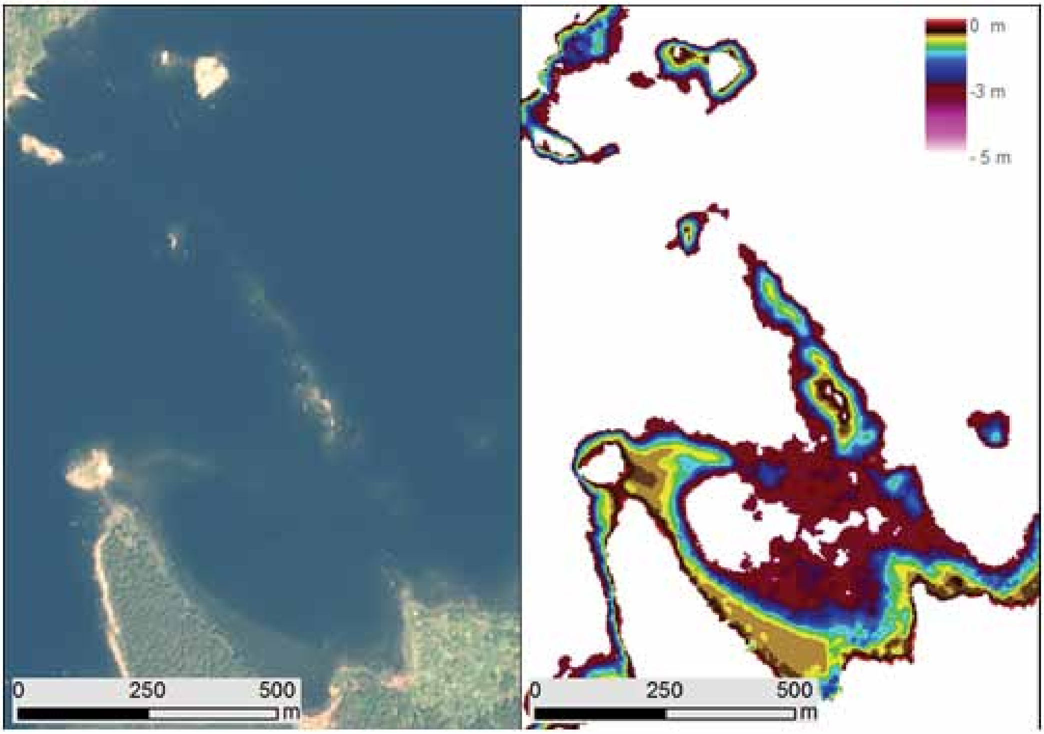

Fig. 3. Satellite and raster depth map

Raster data were interpolated into vector layers – bottom contours with 0.2 meter sections and pinpoint layer showing depth measurements with a 50 cm grid. The resulting data were compared to the measurements taken by a hydrographic vessel in the Vyborg Bay in 2006. Discrepancies were analyzed in those areas where these measurements and satellite derived bathymetric data overlapped. Then, differences between depth measurements derived from satellite images and acquired by depth sounders were defined.

As a result, huge inconsistency was found at depths under 1.8 meters. For depths above 1.8 meters the roof-mean-square-deviation between the actual depth measurements and calculated depth measurements was 42 cm. An overlapping data sample is shown in Fig. 4.

This analysis made it clear that using satellite images it is impossible to measure depths under 2 meters in the Gulf of Finland. It also showed extensive errors in the depth measurements. Final results are much affected by the quality of water, presence of silt on the sea bottom and the level of light on the latitude of the area of interest.

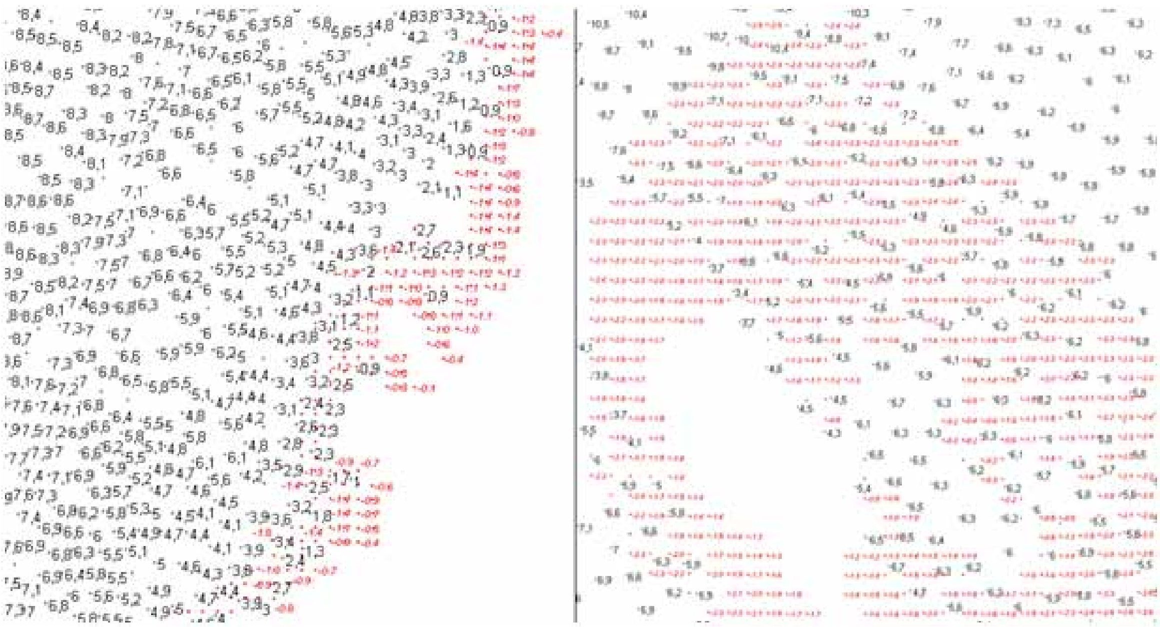

Fig. 4. Depth sounder data and calculated values overlap

It is worthwhile to mention that in good quality water and with enough light we can derive information about the sea bottom using conventional natural color (RGB) images. Our company experts selected and delivered satellite imagery to the Russian Academy of Sciences Egyptian Studies Center for underwater archeological studies.

The Russian Academy of Sciences Egyptian Studies Center was invited by the Supreme Councel of Antiquities of Egypt (SCA) for archeological research in a large area in the sea near Alexandria, extending from the Anfushi cape in the east to the Agami cape in the west. The area of interest is shown in Fig. 5. According to estimates, the sea level near Alexandria has risen by 7 - 8 meters since ancient times. This means that the bigger part of the coast with its precious archeological artifacts was flooded and is 6-8 meters underwater now. Thus, the primary task for The Russian Academy of Sciences Egyptian Studies Center in Alexandria was to study the coastal lines and map out the area of research using various methods of data acquisition.

Without the West Port and fairways, the area of interest covers 30 km2 with depths ranging from 1 meter down to 40 meters. The depths in the area under research do not measure more than 10 meters, which allows using satellite images to get more details about the condition of the sea bottom. The Russian Academy of Sciences Egyptian Studies Center scientists measured depths exceeding 8 meters with a Klein- 3000 side scan sonar.

Fig. 5. Areas of research

PRIME GROUP experts selected very high-resolution images available over the areas of interest. After analyzing historical weather conditions in that area, we chose images for further analysis. Crucial factors included the presence and height of waves, water transparency, flares on wave tops. Finally, a QuickBird image taken on May 13, 2013 was selected. After processing the image it became possible to identify seabed features at depths down to 8 meters. A part of this image is shown in Fig. 6.

The Russian Academy of Sciences Egyptian Studies Center launched a geographic information system, which includes historic maps of the port dating back to the 17th-19th centuries, as well as modern navigation charts and maps created with data from side scan sonars. The analysis of satellite images, historic and modern maps made it possible to map out the location of artifacts on the sea bottom and determine diving sites.

Fig. 6. Image over the area of research

Divers found remnants of ancient port buildings, a large breakwater made of lime blocks, and several shipwreck sites. Research results indicate possible sites of medieval fortresses, which were built on islands – now underwater - adjacent to the port. Due to the marine transgression of about 8 meters in this area, there remains a possibility of finding flooded town blocks, which were a part of ancient and medieval Alexandria.

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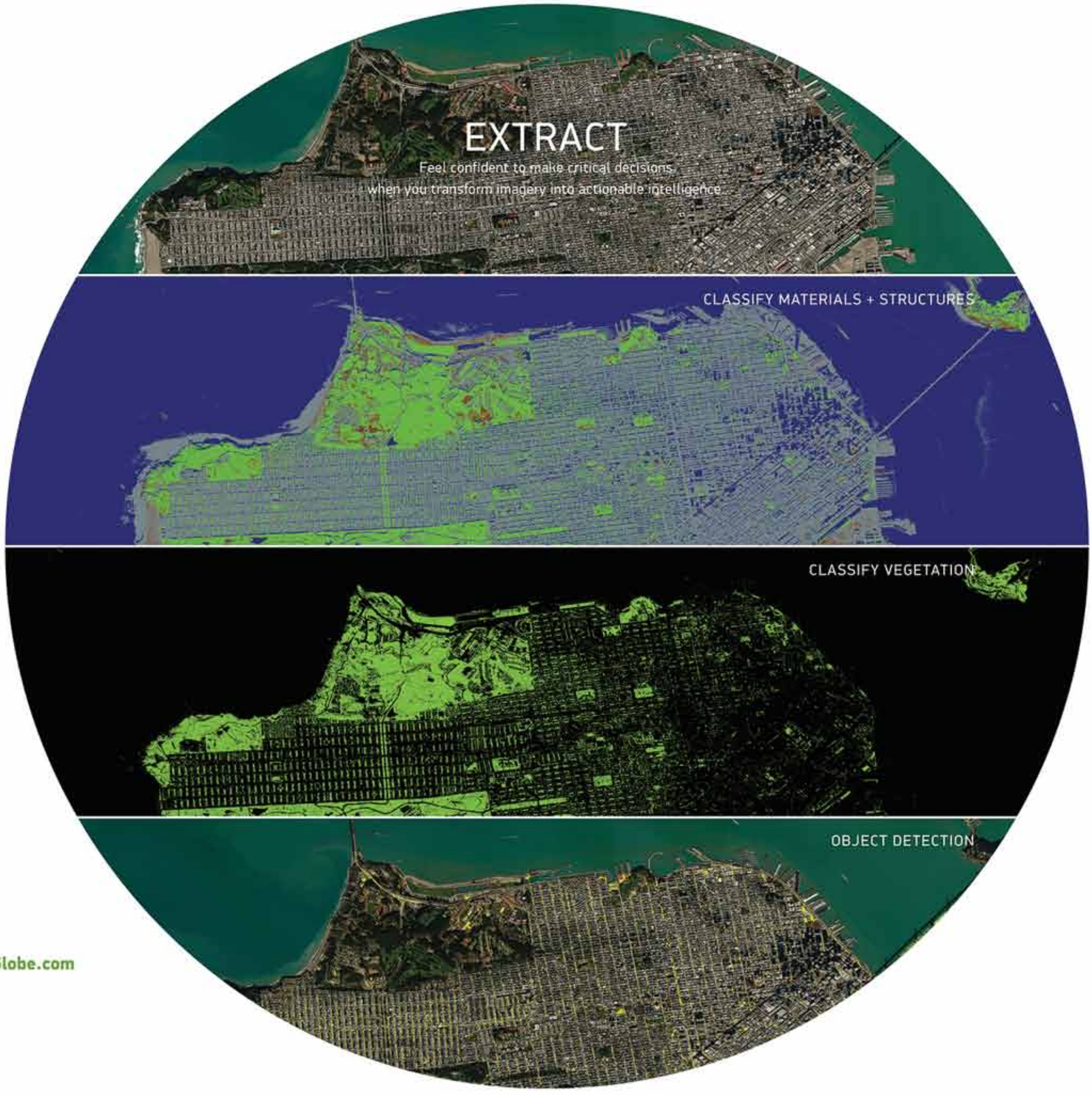

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Resurs-P Earth Remote Sensing constellation

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The Resurs-P constellation was created by the PROGRESS Space-Rocket Centre JSC (RKTs-Progress) on order of the ROSCOSMOS State Corporation under the Federal Space Program based on the existing experience and groundwork in improvement of target characteristics in the following ways: increase in number of narrow spectral bands, provision of hyperspectral, wide-angle, area and stereo imaging, provision of image gridding with an accuracy of no worse than 15m, increase of mission life from 3 up to 5 years.

The Resurs-P constellation is built for highly detailed, wide-angle and hyperspectral detailed optoelectronic Earth observation and meant to provide information for solution of the following tasks:

• Creation and upgrading topographic and other maps;

• Monitoring of emergency regions, areas of natural disasters, accidents anthropogenic disasters, assessment of damages, planning of recovery work;

• Monitoring of farming lands;

• Inventory of natural resources and monitoring of anthropogenic activities to provide rational activity in different branches of the economy;

• Monitoring of conservation areas;

• Search of oil, natural gas, ore and other mineral deposits;

• Monitoring of development of land, obtaining of data to assess land from the point of view of suitability for social and economic activity;

• Environmental monitoring;

• Assessment of ice conditions;

• Environmental assessment.

Obtained information can be also used for development of international cooperation of the Russian Federation in the field of Earth observation and solution of other pressing problems of the Earth remote sensing (ERS).

For the purpose of maximum satisfaction of national economy needs and according to the Federal Space Program, RKTs-Progress built and launched the Resurs-P #1 spacecraft (Fig. 1) on 25th of June, 2013 from the Baikonur cosmodrome. The flight test program was fully implemented in three first months after the launch and the spacecraft was accepted to service as of October 1, 2013 by Poscosmos's Order #192 of October 4, 2013.

Resurs-P #2 was launched (Fig. 2) on December 26, 2014. Upon completion of flight tests it was accepted to service as of June 1, 2015 by Poscosmos's Order #99 of June 1, 2015. Main performance characteristics of Resurs-P #2 are the same as those of Resurs-P #1. For the purpose of extending the capabilities of Resurs-P #1, Resurs-P #2 have the following scientific equipment added on:

- the NUKLON research hardware;

- the onboard radio system of automatic ship identification.

After valid tests, the Resurs-P constellation comprising two spacecraft (#1 and #2) was accepted to service on November 10, 2015.

On March 13, 2016 the Resurs-P Earth remote sensing spacecraft #3 (Fig. 1) was put into orbit. At present the work is underway to commission Resurs-P #3 and to perform flight testing of the three-spacecraft constellation. The Resurs-P spacecraft #3 is already providing consumers with high-quality imagery on requests.

Spacecraft of the Resurs-P family feature qualitatively new capabilities including new target equipment. One of the main principles of forming the appearance of the Resurs-P family was use of technical solutions developed during creation of the Resurs-DK1 spacecraft. The capabilities of the latter were not only preserved but also improved regarding the swath width and panchromatic and spectral resolution. The swath width of highly detailed imaging is 38.6 km, and the coverage is up to 950 km. Besides, the consumer properties, accuracy of image gridding and dynamic behavior of spacecraft were improved too.

Fig. 1. General View of Resurs-P #1 and #3

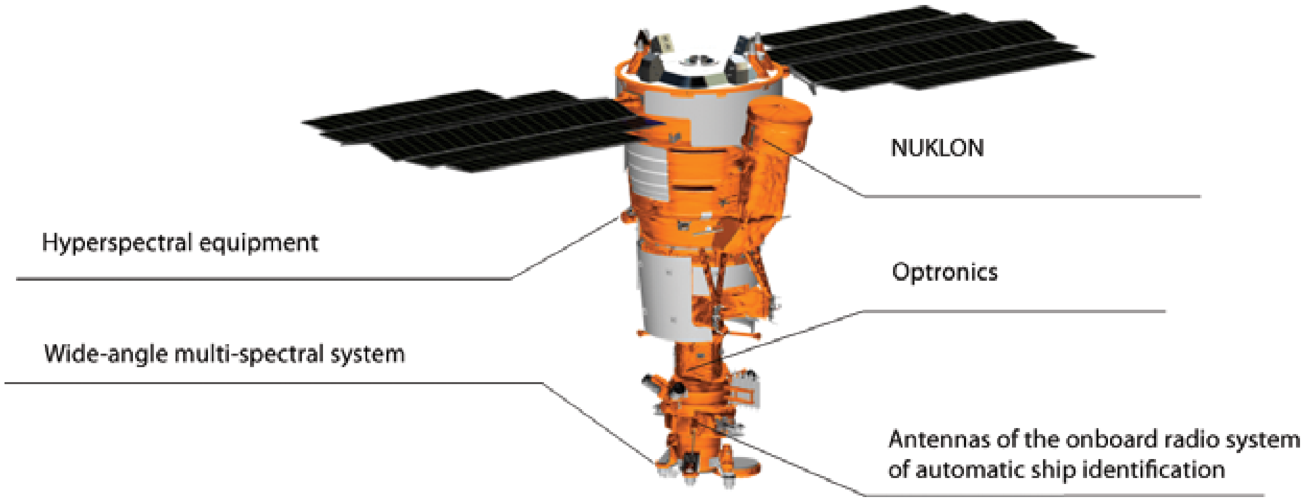

Fig. 2. General View of Resurs-P #2

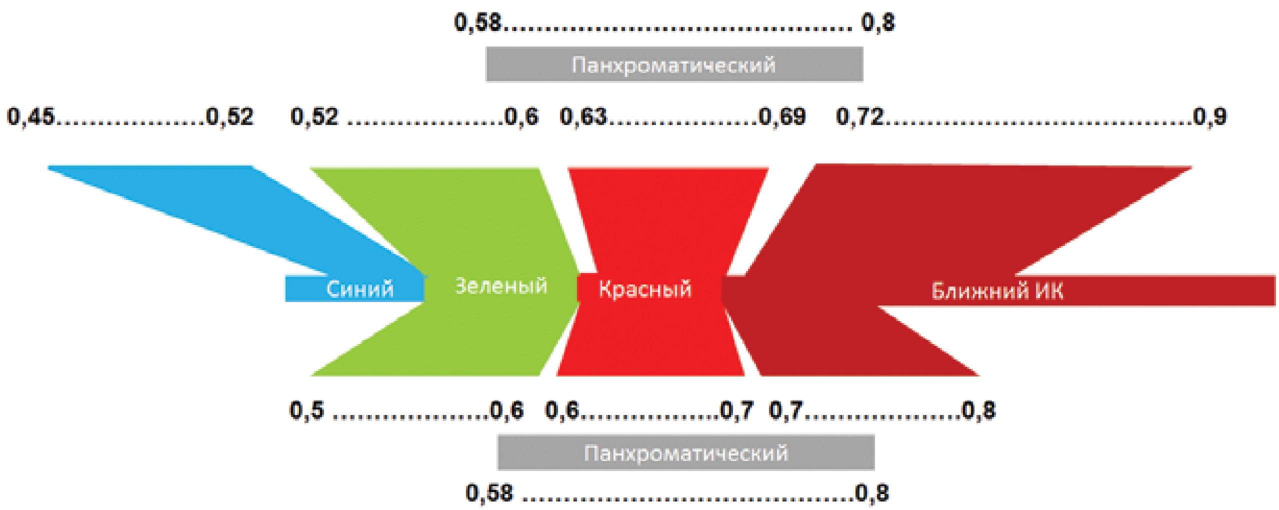

Fig. 3. Comparison of spectral ranges of Resurs-P and Resurs-DK1

Created within the framework of spacecraft constellation development, Resurs-P #1, #2, and #3 are unique for their class since, as opposed to single-purpose satellites designed to solve one task, Resurs-Ps are multi-purpose spacecraft, which is achieved due to several types of imaging equipment installed on them.

Resurs-Ps have the Geoton-L1 optronics that allow obtaining highly detailed imagery with panchromatic resolution of no worse than 1 m and resolution of no worse than 3-4 m in narrow spectral bands. The target equipment of the Resurs-P family's spacecraft also comprises a hyperspectral imaging equipment (GSA), developed by PAO Krasnogorsky Zavod im. Zvereva plant, and a wide-angle multi-spectral system (KShMSA), developed by RKTs-Progress's branch NPP OPTEKS.

GSA's swath is 30 km, the number of spectral bands is 130, resolution is about 30 m. KShMSA allows wide-angle observation with 12-m resolution across a swath of no less than 100 km and with 60-m resolution across a swath of no less than 450 km.

Processed highly detailed Earth image data obtained by the Resurs-P constellation are widely used for solving different Earth observation tasks in the interests of different customers.

Resurs-Ps' image data have shown they are in considerable demand for fire fighting and flood monitoring in the territory of Russia and particularly in Siberia and the Far East. Emergency regions are monitored both by KShMSA and Geoton-L1 daily. Imagery obtained by the Resurs-P constellation also has shown its great demand in the international arena.

Yielding to no foreign analogues in respect of their consumer properties, the space-based imagery features a price, which is attractive for nongovernmental consumers, and profitable conditions of commercial delivery.

The pictures below show example image data obtained by spacecraft of the Resurs-P family.

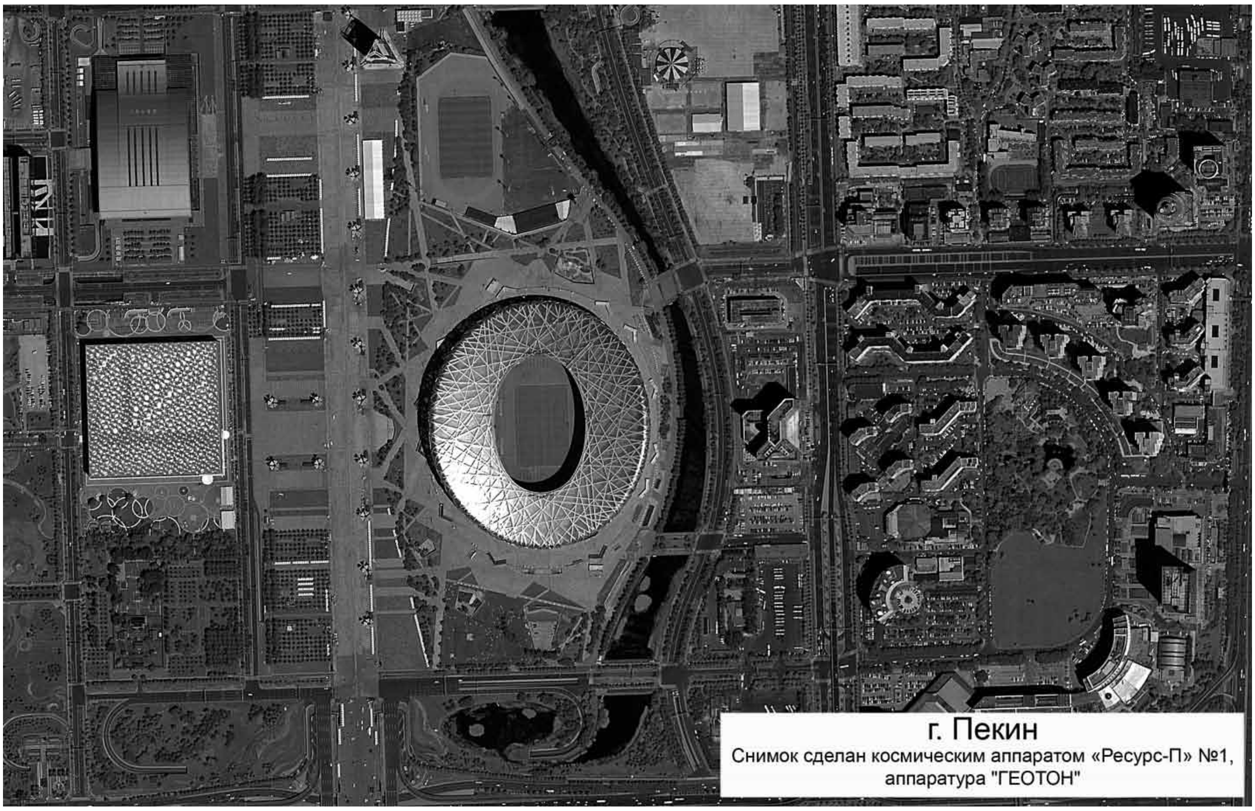

Fig. 4. Image taken by the Geoton-L1 optronics of Resurs-P #1

Fig. 5. Image taken by the ShMSA-VR wide-angle multi-spectral high-resolution equipment of Resurs-P #2

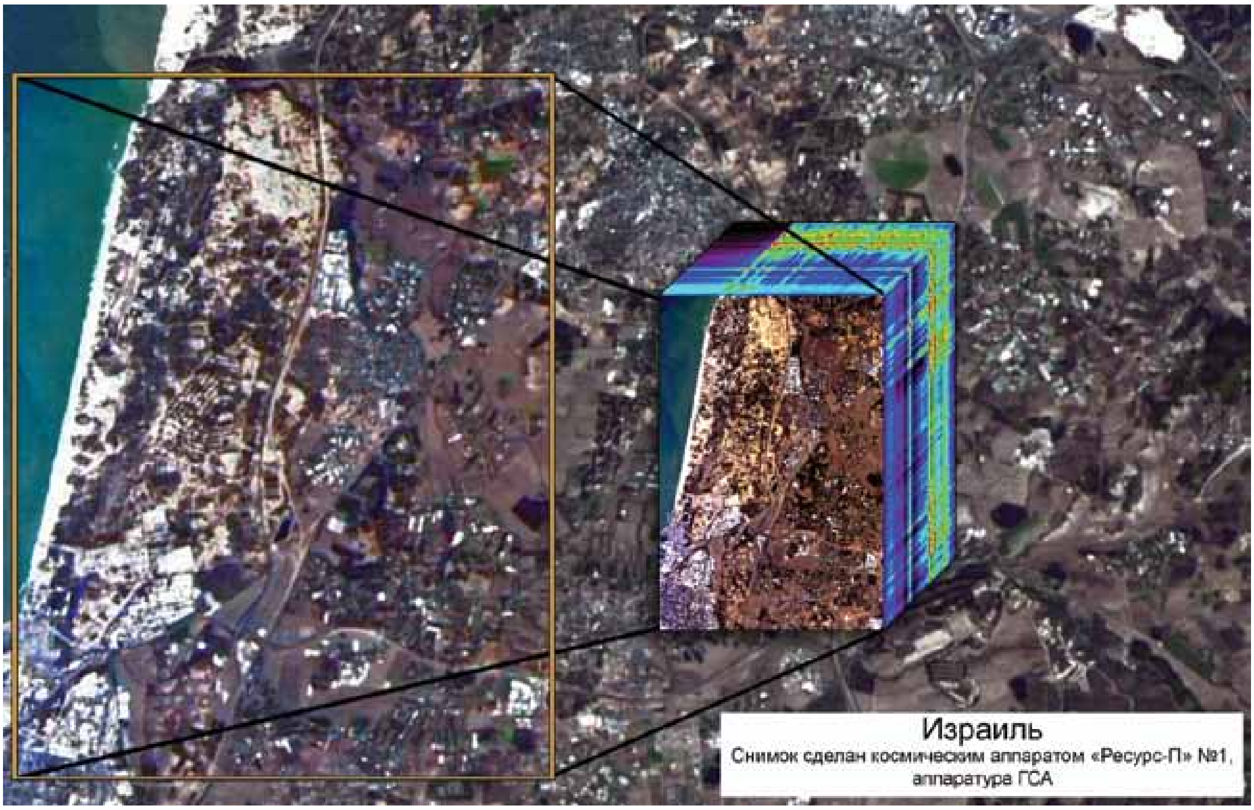

Fig. 6. Image taken by the hyperspectral equipment of Resurs-P # 1

Fig. 7. Image taken by the Geoton-L1 optronics of Resurs-P #3

Not yielding to foreign satellites in the respect of performance or target data properties, spacecraft of the Resurs-P family take their place in the world's cluster of Earth observation satellites. The Resurs-P efficiency in solving of a wide range of social and economic tasks is provided by its capacity to comprehensively observe the Earth surface.

Table 1 summurizes technical characteristics of the Resurs-P spacecraft and foreign analogues.

Table 1. Comparison of Resurs-P to foreign satellites.

Parameter	**Ресурс-П (Russia)**	**Ikonos-2 (USA)**	**GeoEye-1 (USA)**	**Pleiades-1A,1B (France)**	**Kompsat-3 (Korea)**	**World-View-3 (USA)**
Launch year	#1 – 2013 #2 – 2014 #3 - 2016	1999	2008	1A – 2011 1B – 2012	2012	2014
Resolution, m - PC-channel - MS-channel	 0.7* 2.1*	 0.8* 3.2*				
Swath - km - pixel	 38.6 ~54,300	 11 -				
Number of spectral channels (MS-channel)	7	4	4	4	4	16
Hyperspectral equipment	Yes	No	No	No	No	No
Wide-angle equipment	Yes	No	No	No	No	No
Geolocational accuracy (without reference points), RMS error	<15	10	2-6	<10	-	4

Comparative analysis of characteristics given in Table 1 reveals that the satellites – though being products from different periods of space engineering – are of the same class of Earth observation systems by their all characteristics, which determine consumer properties of image data obtained by them. The Geoton-L1 highly detailed imaging equipment installed on Resurs-P provides observation data with linear resolution on a level with the best foreign systems, insignificantly yielding to American observation systems only, and outperforms most foreign analogues in swath and number of spectral bands by 1.5-2.

The Resurs-P constellation, as opposed to foreign analogues, has hyperspectral observation equipment that provides imaging of the earth surface in over 100 separate spectral channels. The said equipment allows brand new observation data suitable for solving new ERS tasks. To sum it up we can say that high degree of image detailing, wide imaging swath, gridding accuracy and availability of hyperspectral equipment, put the Resurs-P ERS constellation on the same level with cutting-edge space-based observation systems. At present, commercial satellite constellations with similar resolution and performance are owned by the USA (GeoEye, WorldView), and France (Pleiades). Other countries own single satellites of highly detailed observation.

Beside three spacecraft, the key elements of the Resurs-P system are a ground control complex and ground complex of ERS data planning, receiving, processing and distribution.

Taking advantage of the high degree of Resurs-Ps' operational autonomy, the ground control complex allows simultaneous control of the three spacecraft with the help of minimum operators, automates all tasks to control the flight of the spacecraft simultaneously operating in orbits through their entire mission life including cases of possible emergencies in any of.

The ground complex of Resurs-Ps' ERS data planning, receiving, processing and distribution provides prompt acquisition of imagery up to real time, generation of geo information products.

The spacecraft of the Resurs-P family have been successfully operating for several years providing ERS data of high quality to both Russian and foreign consumers, which are tens of federal and regional executive bodies representing different branches of the economy (agriculture, forestry, water industry, power industry, cartography and so on). At the middle of 2016 Resurs-P's Geoton-L1 highly detailed equipment imaged over 150 mln. km2. It should be noted that domestic government consumers are provided with Resurs-P's Earth remote sensing data free of charge.

At present under the 2016-2025 Federal Space Program, the work is underway to build Resurs-P #4 and #5, which are planned for launch within the next 2-3 years.

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Super Voxel based Multi Object Segmentation from Point Clouds

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Abstract

The segmentation of point clouds is a critical step for many remote sensing tasks, such as object recognition and scene reconstruction. In order to segment multi objects, we propose a super voxel based algorithm to describe the local characteristics of the point data. First, we define the topological relation and distance metric of points in the framework of Riemannian geometry, and using K-means method generates over-segmentation results, e.g. super voxels. Then these voxels are formulated as nodes which consist a minimal spanning tree. High level features are extracted from voxel structures, and a graph based optimization method is designed to yield the final adaptive segmentation results. The implementation experiments on real data demonstrate that our method is efficient and superior to state-of-the-art methods.

Key words: Point clouds segmentation, Riemannian geometry, super voxel, minimal spanning tree, feature extraction

1. INTRODUCTION

In the last decade, the development of various data acquisition technologies, such as Light Detection and Ranging (LiDAR), RGB-D cameras, Structure from Motion (SfM), and Multi-view Stereo (MVS), enables users to effectively obtain 3D sampling of urban scenes, i.e., 3D point clouds. These point clouds of urban scenes have significant values for various applications, such as urban planning, vehicle navigation, environmental assessment (Musialski et al., 2012; Rottensteiner et al., 2014).

Typically the raw points from images or other sources often exhibit unorganized structures. This problem causes the point clouds to be difficult in extracting accurate feature information. Besides, any uneven densities of the point clouds will seriously hinder local feature extraction. That is because most feature extraction algorithms depend on the statistical properties of points in a local region, while uneven densities make it difficult to define suitable neighboring radius parameters over all scenes (Alexa et al., 2003; Hoppe et al., 1992). Since the initial point clouds are unstructured and often massive, seeking a transitional way to process point cloud is becoming urgent.

In the field of point cloud processing, semantic segmentation have been extensively researched (Vosselman et al., 2017). Region growing based methods are widely use to segment point clouds because they are easy to implement (Vo et al., 2015). Model-fitting based methods could extract specific geometry structures from the sampling, such as detecting plane or circle hypothesis by using a random sample consensus (RANSAC) method (Schnabel et al., 2007) or Hough transformation (Vosselman et al., 2004). In another aspect, grid based methods are also used to compensate the defect of initial points. Morales et al. (2010) present a semi-rigid grid decimation method on point clouds, which achieves a superior time performance compared with many surface denoising methods. Benhabiles et al. (2013) attempt to simplify the entire input dataset while preserving sharp edges based on dividing the data into a 3D grid of clusters, approximating the local shape of objects in each cluster and removing points located far from those shapes. Besides, many urban modeling methods some predefined patterns such as Manhattan assumption [Li et al., 2016] and pattern symmetry and repetition [Nan et al., 2015] to represent specific artificial structures in the scene. Aforementioned methods require that the data satisfy certain preconditions, and this hinders their capabilities on general scenes.

In this work, we address the problem of automatic segmentation of point cloud into multi objects using a super voxel based approach. The algorithm consists of two main phases: extracting a set of super voxels to represent the whole scene with less data; segmenting the point cloud using a graph model built based on the super voxels.

2. PROPOSED METHOD

2.1. The extraction of super voxels

The first phase of our approach is to extract initial cluster centers using an adaptive octree algorithm, so that region growing based over segmentation is implemented to generate super voxels. The selection of seeds and the criteria for growing are critical in these processes. In order to obtain consistent segments, Vieira and Shimada [2005] and Nurunnabi et al. [2012] removed points along sharp edges using a curvature threshold and the remaining points were considered as seed points. However, this strategy will lose the applicability for some protruding structures. To overcome this limitation, we use an adaptive octree to extract seed points.

Given a point cloud P={p_1,p_2,…,p_n}, an adaptive octree aims to efficiently extract a set of leave nodes N={n_1,n_2,…,n_m} as initial center points. In practice, at the beginning the minimum cubic bounding box enclosing P is used as the root node. Then the root node is recursively subdivided into eight child cubes with the same size until reaching a termination criterion. Based on the work in [Kazhdan et al., 2006; Vo et al., 2015], we choose the residual threshold R_{th} and the minimum threshold on voxel size d_{min} as the stopping conditions. Besides, a minimal depth is mandatory to subdivide the space to a certain level as the initial partition. Space decomposition is performed recursively to divide the non-empty cubes until either the residual error or the minimum voxel size criterion is satisfied.

Our super voxel segmentation is an adaptation of the K-means method combined with a region growing method. Initial cluster centers are computed by node localizations of octree at a fixed depth.

Next, a merging step is conducted by incrementally grouping adjacent points that have similar characteristics to the nearest cluster centers. Since the number of octree nodes was determined in the previous step, only the merging criteria needs to be considered.

The problem corresponds to classification in a matric space where one needs to define a distance measure D. Hence, a weighted distance measure is designed to combine the normal vector and its spatial proximity while simultaneously providing control over the size and compactness of the super voxels.

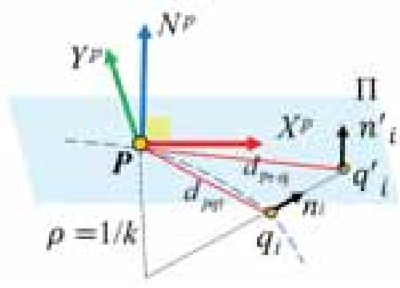

Fig.1 New distance metric considering local curvature

Since distance matric in Euler space lack the ability to describe local traits of the scene, we design a new distance matric d_{Proj} that combines local curve feature of the data in Riemannian geometry. As shown in Fig.1, from point p to its neighbor q_i the distance is calculated by the projected point q_i of q_i on the tangent plane over point p, and ρ here is the radius of the curvature. If the tangent plane fits well all local points, $\rho \to \infty$ and q_i is close to q_i; on the other hand, if the value of curve is big, the value of d_{Proj} is greater than Euler distance. During computing the curve value, a principal component analysis (PCA) method is employed to estimate the normal of each point assuming that the local surface is planar (Hoppe et al., 1992). Thus, using our novel distance matric measure, it is able to calculate all points' feature distances to their candidate cluster centers.

Since the expected spatial extent of a super voxel is a surface region with an approximate size w×w, $w = W/2^{Depth}$, we set the search for similar points in a 3D space of 2w×2w×2w around the super voxel center. Once each point has been associated with one nearest node, an iterative step updates the cluster centers to be the mean vector $[x,y,z,nx,ny,nz]^T$ of all the points belonging to the cluster. The spatial distance between the new cluster center and previous cluster center is the residual error.

In our case, the seeds are octree nodes, which are used to produce regularly shaped voxels. The super voxels are computed over a spatial octree with resolution Depth, corresponding to an effective voxel volume resolution of $2^{-3 \times D}$. Hence, the point sampling density can be approximated during octree construction.

2.2 Super voxel based segmentation

In the second phase, super voxels are formulated as nodes which consist a minimal spanning tree (MST) graph. High level features are extracted from voxel structures, and a graph based optimization method is designed to yield the final adaptive segmentation results. Graph based methods have been used in point cloud segmentation (Rusu et al., 2009; Ural et al., 2012). However, previous methods build graph based on points, which lack reliable features and efficiency. In our graph model, each voxel is regarded as a compact surface patch and a voxel denotes a node in the model.

After over segmentation, point set belonging to a voxel is regarded as whole, and they are used to fit a local plane patch. When building the MST, the feature distance D_feature is defined based on the criterion of normal proximity and spatial distance. The distance between a voxel and its neighbors is calculated in a feature space combining $[x,y,z]^T$ and normal $[nx,ny,nz]^T$, which are the value of fitted plane based on all points belonging to the voxel.

In this paper, we use Kruskal coordinate (Robles-Kellya and Hancock, 2007) to build MST to realize the topological indexing. Setting a voxel node as v, we sort all of its neighbor nodes $\{v_{neighbor}\}$ depending the distance value $D_{feature}$ from small to large. Then, loop from the edge with the minimum distance to the next edge until all edges are connected to an unicom component. Starting from the original node of the MST, a region growing method clusters similar node as a group depending on the weight of neighbor edges until reaching the terminal threshold. Then a new growing step is conducted and finally all nodes are classified into different groups, which are the segment results.

In summary, using the super voxels as a transitional atoms to process point clouds could reduce the redundancy of points and to better describe local distributions. And the MST graph greatly improve the efficiency of the region growing algorithm used in the final classification.

3. EXPERIMENTAL RESULTS

We test our method with a point cloud of indoor artificial scene. Experiment demonstrated the advantages of the proposed method based on the super voxels. The point data is obtained by a Leica C10 laser scanner from the range around 3 meter.

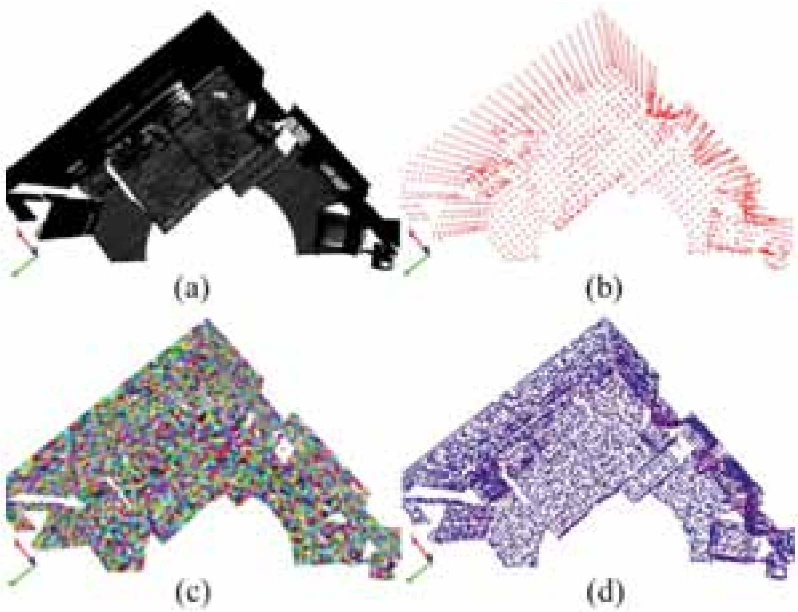

Fig.2 (a) Original point cloud; (b) adaptive distribution of cluster center; (c) super voxels; (d) MST of voxels.

As shown in Fig. 2(a), the input point cloud is consisted of mass points with a density about 9000 points/m^2. The local region growing method combining with an adaptive octree significantly reduces the workload and produces reliable super voxels as shown in Fig. 2(c). During the segmentation phase, MST graph connects all voxels in a unicom component, as shown in Fig. 2(d). Based on the high level extracted from each voxel and the MST graph, the growing algorithm makes similar voxels merge into clusters.

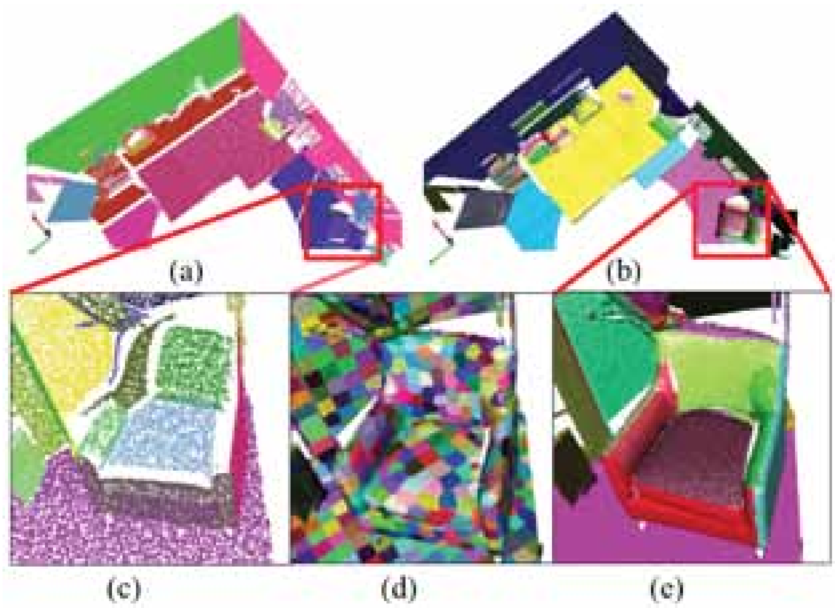

Fig.3 A comparison between the results of RANSAC based method and our results. (a) is the RANSAC based partition result; (b) is our segmentation result; (c), (d), and (e) are the enlarged sofa illustrations from the RANSAC based method, super voxels and our final result.

Tab.1 Statistics of two different algorithms.

Approach	Timing (ms)	Segment numbers	Residuals (m)
RANSAC partition	6019	49	0.02
Our method	5652	98	0.02

A comparison experiment is conducted between our method and RANSAC based partition method. As shown in Fig. 3, RANSAC based method could extract many major planes that reflect the distribution of the whole scene, but the many detail informs will not be detected since they do not match specific geometry criterias. On the contrary, our method could fit the local geometry well based on many super voxels, hence achieve a better segmentation performance.

Table 1 shows the algorithm performances for the experiment. All examples were run on an Intel(R) Core(TM) i7-6500U at 2.50 GHz with 8 GB RAM. Our algorithm has a comparable accuracy with the RASAC partition method. However, our algorithm win in the processing time and segmentation numbers because of the using of super voxels that significantly simplify the process items and better describe local characteristics of the scene.

4. CONCLUSION

The proposed segmentation algorithm is a novel tool to extract partition relationship in a mass point cloud. The approach employs an adaptive octree and super voxel based MST graph to achieve both better convergence and a more convincing point segmentation. Experiments demonstrate that the method can be successfully applied to the artificial point cloud in challenging situations. In the future work, we will extend our high level feature extraction method to resolve many semantic interpretation problems.

ACKNOWLEDGMENTS

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Mapping of natural reserve fund from space images

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Picture of Earth from space, provide tremendous opportunities for the study of the processes occurring in the World, to address complex research, development and management of natural resources. Space photos are best available source of information for global projects studying the Earth, they can solve problems much faster and more economical compared with aviation and ground systems. Therefore, the section presents you the basic directions of use of pictures of the Earth from space, space systems obtained by remote sensing. Topographic maps give us an idea about the world and can navigate it, showing all the visible elements of the terrain with the same detail. They appear, topography, hydrography, vegetation, soil, human settlements, road network, socio-economic and other facilities that allow to evaluate the area. Topographic assumed several maps of scale 1:10 000-1: 100 000.

Currently on a World Map virtually no blind spots - topographic maps covering almost the entire land surface of the planet, although they are not all equally detailed. Almost all the territory of today are covered with maps in scale 1:25 000, and near-thirds of the World - the scale of 1:10 000. However, most of these maps are not updated regularly. But the modern World is very variable, changing city, new settlements, built roads, communication networks, engineering structures, and new areas of mining, deforestation, land use structure changes. Therefore, there is always the task of updating topographic maps.

As the primary material for topographic maps have traditionally been used aerial photographs. Space digital photos reveal new opportunities, reduce the cost of repeated surveys, increasing the area of coverage areas and reduce distortions related to topography. In addition, the simplified generalization images on small-scale maps, instead of laborious simplify large-scale maps can immediately use satellite imagery differentiation medium. Because shooting space used increasingly, and in the future may become the main method of updating topographic maps. When choosing images for mapping consider certain scale precision drawing and graphics cards print (0.1 mm). For example, the pictures must have spatial resolution of at least 100 meters for maps of scale 1: 1 million and at least 10 meters for maps of scale 1: 100 000. According to the pictures BUT IRS-1C/D PAN resolution of 5.8 m can be many elements make content maps of scale 1:50 000 (topographic maps of some elements, such as trees, detached, width and other rivers. to scale maps require more detailed pictures). For example, satelite images Landsat 7 ETM + and Terra ASTER with a resolution of 15 m allow making many items of content maps of scale 1: 200 000 and larger scale. However, some settings, such as such as length, width and material bridges depicted on maps of 1: 200 000, can not get the images, so you need to attract additional sources of data.

When applied map update only changes the contours of the elements, while mapping necessary to determine the exact position of these elements. Therefore, drafting topographic maps satellite images required higher division than update them. And keep in mind that when drawing up and updating topographic maps certain scale one and the same types of satellite images may be suitable or unsuitable content for different elements of topographical maps.Satellite images allowed not only to speed up the drafting and updating thematic maps, but also open a new phenomenon, and create new types of maps. For example, only on the visible satellite images of cloud systems, operational survey which allows meteorologists to refine forecasts and monitor dangerous natural phenomena, such as hurricanes. Geologists make up for the small-scale satellite images map lineaments and circular structures required for mineral exploration. In the large-scale aerial photographs of structures not visible. Photos commonly used to update the geological, geomorphological, hydrological, oceanographic, meteorological, geo-botanical, soil, landscape maps. For each type of thematic maps have their own methods of their preparation and update of satellite images using a particular combination of photography and image brightness at each point of it (corresponding spectral reflectivity surface, its temperature or other characteristics, depending on the type of image). The use of satellite images in the preparation of thematic maps of detail increases cards and drawing contours are more relevant to the natural figure.

Table 1. The scale recommended for compilation and updating of topographical, survey and topographical survey maps and satellite images

Type of equipment resolution	Scale													
	10000-25000		25000-50000		50000-100000		100000-200000		200000-500000		500000-1000000		More 1000000	
Terra/Aqua MODIS 250-1000 m.														
Resurs MSU-SK 140 m														
Resurs/Meteor MSU-E, 35-45 m.														
Landsat TM 30 m														
Landsat ETM +, 15-30 m.														
Terra ASTER 15 m.														
IRS LISS 23 m.														
RADARSAT SAR 8 m., 25-30 m.														
IRS PAN 5,8 m.														

	make mapping
	map update
	base scale of map of Natural Reserve Fund

In thematic mapping requirements for precision application object position generally somewhat lower than for topographic maps. Therefore, the same images can be added thematic maps scale retail and restaurant. For example, images obtained from satellites IRS PAN Spectroradiometer division 5.8 meters, suitable for creating content of some elements of topographic maps of scale 1:50 000, and for the purposes of thematic mapping - up to the scale of 1:10 000 (depending on the subjects maps). Importantly, the use of satellite images, combined with field research, allows you to quickly update the different series of public maps including forest inventory maps, maps of soil, geobotanical maps.

Traditionally assembly of small-scale vegetation maps the method keys. For typical areas expeditions gathered detailed geobotanical data. Then spread the information received on the site, similar to the key, and so filled the whole area of the map. Similar areas (of the same type by moisture, exposure, altitude, predominant species of plants) are allocated based on the analysis of topographic maps, forest inventory maps previously drawn maps of vegetation in some areas. This vegetation maps for the same area can vary significantly due to different approaches to their preparation, various purpose cards, quality and completeness of the initial material.

As to date, virtually the entire territory covered by modern digital world multizonality spacecraft remote sensing imagery, new opportunities for mapping vegetation. Automated fragment decryption of satellite images in different areas can significantly refine contours of different natural objects and to introduce additional types of objects for recognition. Photos of this detail suitable for retail and restaurant mapping scale (1:100 000 to 1: 1,000,000).

Phase One iXU-RS1000 Accuracy Assessment Report

Yu. Raizman, PhaseOne.Industrial, Israel

1. Introduction

The Phase One medium format cameras of the series iXU-RS1000 are well known worldwide and very popular for small and medium size area mapping projects, corridor mapping, LiDAR mapping, urban mapping, 3D City modeling and oblique imagery capturing, constructions and infrastructure monitoring and inspection.

The 100MP cameras with pixel size of 4.6 μ, very high image capture rate -1 frame every 0.6 seconds and exposure time of up to 1/2500, a set of metric lenses with different focal lengths (50, 70, 90, 110, 150 mm), provide a very effective solution in many areas of aerial mapping, monitoring and object inspection.

A very small form size (10x10x20cm including lenses) and a very light weight (less than 2 kg) are also significant advantages of the camera – it may be installed easily in every small and light aircrafts, gyrocopters, medium size drones or UAVs that essentially increase a range of airborne vehicles utilized for mapping and significantly reduces operational costs of mapping projects.

The main goal of the report is photogrammetric accuracy analysis and assessment of IXU-RS1000 camera.

2. Testing procedure

The photogrammetric accuracy assessment was done according to widely accepted aerial survey camera testing procedure, including the following steps:

• Test field establishment

• Flight planning and flight execution

• Automatic image matching and aerial triangulation (AT)

• Flight camera calibration based on AT

• AT accuracy analysis with different GCP & ChP configuration

• Stereoscopic measurements of GCP & ChP

• Final conclusions

The main steps of the project were executed by several geospatial, geodetic and photogrammetric companies, which are most experienced in the relevant fields:

1. Test field preparation

a. Planning – Dr. Yuri Raizman, PhaseOne. Industrial (http://industrial.phaseone.com/)

b. Geodetic measurements – ARMIG Geodetic Engineering Ltd. (www.armig.co.il/english)

2. Test flight planning, flight execution and image preparation– Oodi Menaker, PhaseOne. Industrial

3. Image matching (automatic tie points measurements), bundle block adjustment, GCP & ChP measurements – Dr. Ziv Shragai from Simplex Mapping Solutions Ltd. (www.simplex-mapping.com) and Dr. Erwin Kruck from GIP, Dr. Kruck & Co. GbR (http://bingo-atm.de/)

4. Stereoscopic GCP&ChP measurements – Mapping Technology Ltd.

5. Accuracy analysis and report preparation – Dr. Yuri Raizman, PhaseOne.Industrial

The following software was used for the project:

• iX Capture – original image processing and export to TIFF format

• Agisoft Photoscan Pro – automatic image matching and GCP & ChP measurements

• Bingo – aerial triangulation, bundle block adjustment, camera calibration, and accuracy assessment

• AtlasKLT – stereoscopic measurements of GCP & ChP

3. Test Field

3.1. Area

The test field is situated in the area of a village Kfar-Vitkin, Israel. It extends on 2.0 km in the West-East direction and 1.2 km in the South-North direction. It is mostly an urban area with low height one-two-story buildings.

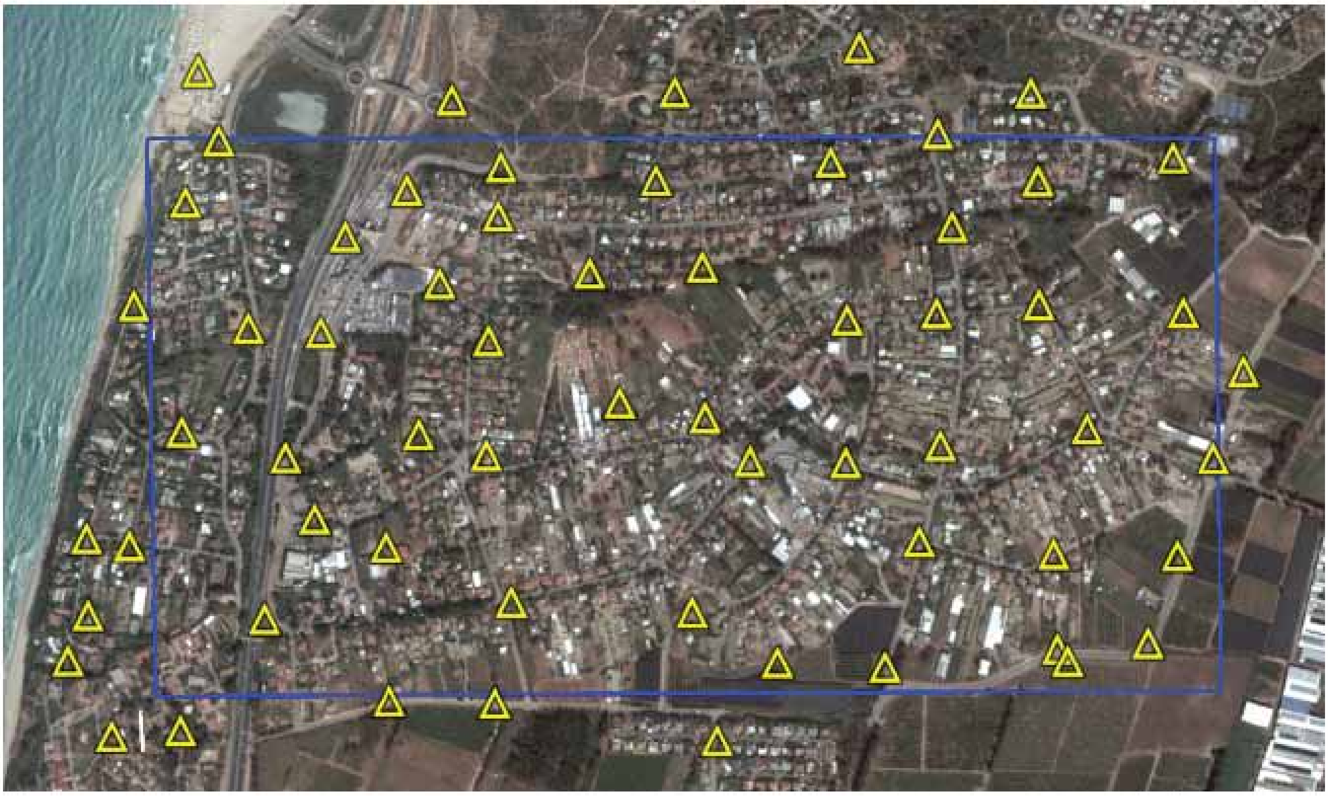


Figure 1: Test field

The area characterized by existence of many permanent, visible from all sides and well-defined manmade features, which were chosen to serve as signalized GCPs. All GCPs are located on the ground. The following manmade features were mainly used as GCPs:

There are 53 GCPs in the test field.

3.2. Geodetic measurements

Before making the field measurements, all GCPs were identified and marked on the Phase One images of the area. The geodetic observations were made according to static GPS survey procedure with one reference station 903AGR. The reference station was established at the high and open area in the north part of the test field. The reference station was measured against CSAR permanent GPS station by two independent 1-hour long observation sessions. Every GCP was measured by two independent half-hour long observation sessions.

The following accuracies of the GCPs were received after processing all the observations:

	RMSxy (cm)	RMSz (cm)
CSAR	± 0.3	± 0.5
903AGR vs CSAR	± 0.1	± 0.1
GCPs internal between observations	± 0.7	± 1.2
GCPs absolute	± 0.8	± 1.3

4. Flight Planning

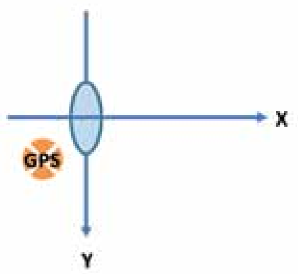
4.1. Aerial camera

The aerial camera iXU-RS1000 with focal length of 90 mm was used for the test. The main parameters of the camera are as following:

Camera Specifications	
Lens type	Rodenstock
Focal length (mm)	90
FOV (across flight, deg)	33.0
FOV (along flight, deg)	25.1
Aperture	f/5.6
Exposure principle 1	Leaf shutter
Exposure (sec)	1/2500 to 1/125
Image capture rate (sec)	0.6
Light Sensitivity (ISO)	50-6400
Dynamic Range (db)	>84
Sensor Specifications	
Sensor type	CMOS
Pixel size (μm)	4.6
Array (pix)	11,608 x 8,708
Array volume (MP)	100
Analog-to-digital-conversion (bit)	14
Frame / Image Specifications	
Frame geometry	Central projection
Typical image size (MB) for TIFF	300
Image format	PhaseOne RAW, Undistorted TIFF, JPEG
Frame Coverage	
Frame width for 10 cm GSD (m)	1,161
Frame height for 10 cm GSD (m)	871
Frame area for 10 cm GSD (sq.km)	1.01

4.2. Aircraft installation

Aircraft Cessna 172 was used for the flight. The camera was installed in the rear part of the plane with the following parameters of lever arm (distance between GPS antenna and the exit pupil of the camera):



dX (cm)	-15.4
dY (cm)	10.1
dZ (cm)	0.99

4.3. Aerial survey parameters

The flight was planned and executed with the following aerial survey parameters:

- Flight altitude (above ground) - 2,500 feet
- GSD – 4 cm
- Distance between flight lines – 230 m
- Side overlap – 49%
- Forward overlap – 80%
- Frame size – 450m x 340m
- Orthophoto angle - 17°
- Building lean – 15%
- Ground speed – 100 knot
- Strips: SN – 9; WE – 2;

Figure 2: Test field with flight lines

5. Image matching and aerial triangulation

The image matching was performed with Agisoft Photoscan Pro software. There were 202 images in the matching and 6,434 tie points (39,335 x,y image measurements) were identified during the matching. The image coordinates of all GCPs were manually measured in Photoscan Pro.

After the matching, all tie points and GCPs image coordinates were provided to Bingo software for further processing.

The Bingo software was used for bundle-block adjustment with additional parameters for self-calibration and exterior orientation of the block with different number and configuration of used GCPs. Photogrammetric accuracy of the block is estimated by residuals on tie points or by sigma 0. Geodetic accuracy of the block is estimated by residuals on GCPs, which are not participated in the adjustment – Check Points (ChP).

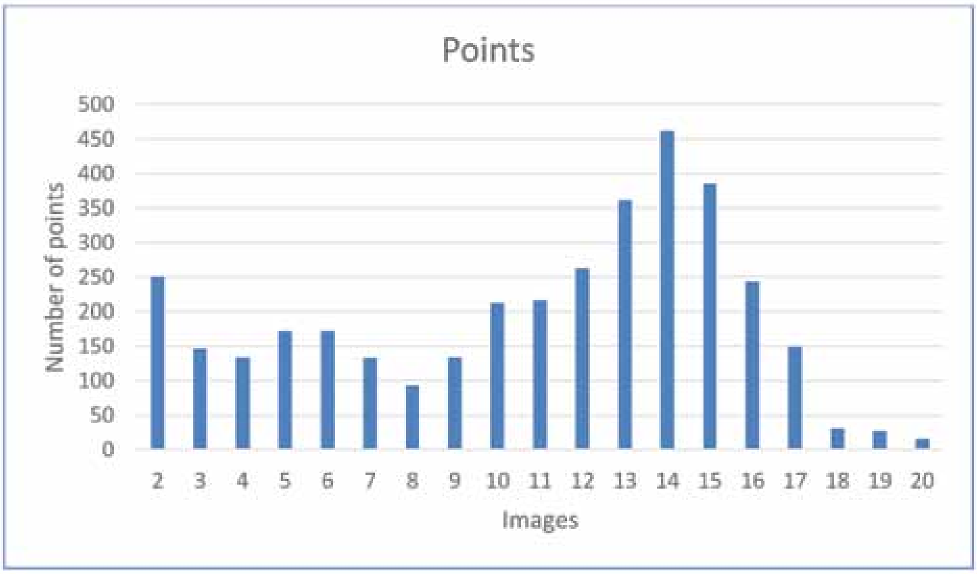
There were five runs of Bingo for different purposes:

1. Tie point and all 53 GCP adjustment with additional parameters 61, 62 for camera calibration
2. Tie point and all 53 GCP adjustment with additional parameters 17,18,19,39,61,62 and 65 for camera calibration
3. Tie points, 5 GCP and 48 ChP for the block geodetic accuracy estimation
4. Tie points, 9 GCP and 44 ChP for the block geodetic accuracy estimation
5. Tie points, 15 GCP and 38 ChP for the block geodetic accuracy estimation

Common parameters of the block for the above Bingo runs are as following:

- Number of images – 202
- Number of used tie points – 3600
- Number of skipped tie points - 2835
- Mean number of points per image – 222
- Number of measured GCPs - 53

The following graph presents a tie points distribution per images:



Images in the middle of the block with multiple overlaps have more identified tie points than images along the perimeter of the block with only a few overlapping images.

6. Camera self-calibration analysis

The self-calibration procedure is a simultaneous bundle adjustment of all images of the block with many tie points and many GCPs participating in the adjustment. During the self-calibration, the camera interior orientation parameters (camera model), F, xo, yo, k1, k2, p1, p2, p3 are calculated. The accuracy of these parameters depends on many factors – number and size of image overlaps, number and accuracy of identified tie points, number and accuracy of GCPs, existence and accuracy of GPS during the flight and some more.

As mentioned above, 202 images with an average 202 tie points per image and 53 GCPs participated in the adjustment. Only approximate GPS data was used for the adjustment.

The camera self-calibration procedure was processed twice with different sets of additional parameters. The first set included additional parameters 61 and 62, which correspond to K1 and K2 radial distortion coefficients in standard Brown-Conrady distortion model.

The second set included additional parameters 17, 18, 19, 39, 61, 62 and 65 and was provided and tested by Dr. Erwin Kruck, the developer of Bingo software.

After the adjustment of all images, the following results obtained:

Tie points residuals						57 GCP		
	Image		Ground			Ground		
	dx (µm)	dy (µm)	dX (cm)	dY (cm)	dZ (cm)	dX (cm)	dY (cm)	dZ (cm)
MIN	-7.1	-8.1	0.3	0.3	0.5	-3.0	-3.1	-0.3
MAX	7.2	9.3	5.7	3.5	16.6	1.2	1.7	0.3
Mean	0.0	0.0	0.7	0.6	3.2	0.0	0.0	0.0
STDEV	1.7	1.6	0.4	0.3	2.1	0.6	0.7	0.1
RMS	1.7	1.6	0.8	0.7	3.8	0.6	0.7	0.1
Sigma 0	1.79 / 1.83 µm (depending on a number of additional parameters) 0.4 of pixel size							

The results clearly present a very high photogrammetric accuracy of the block. The RMS of tie point s is just 1.7 µm in the image plane (0.3 of pixel). The RMS of tie points on the ground is 0.8 cm in position (0.2 of pixel size on the ground) and 3.8 cm in height that is 0.8 of pixel size on the ground.

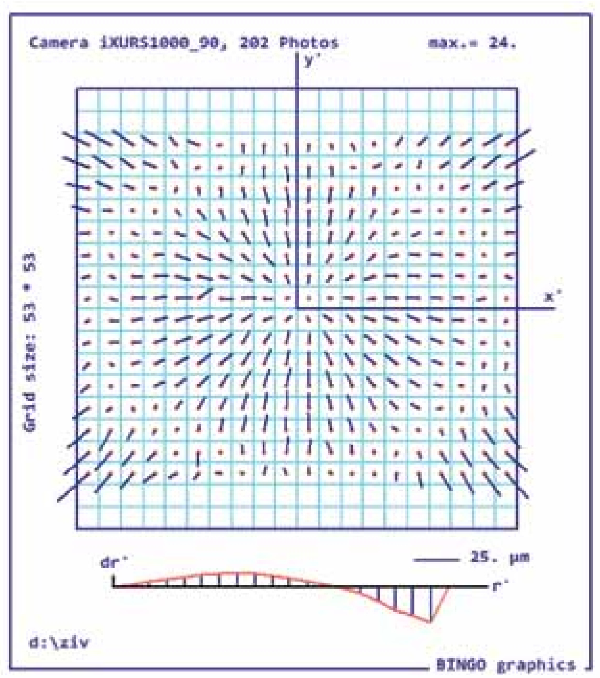
The relatively large difference in position and height accuracy may be explained by two factors: low accuracy of GPS during the flight and long focal length (90 mm) of the camera that influence the height accuracy.

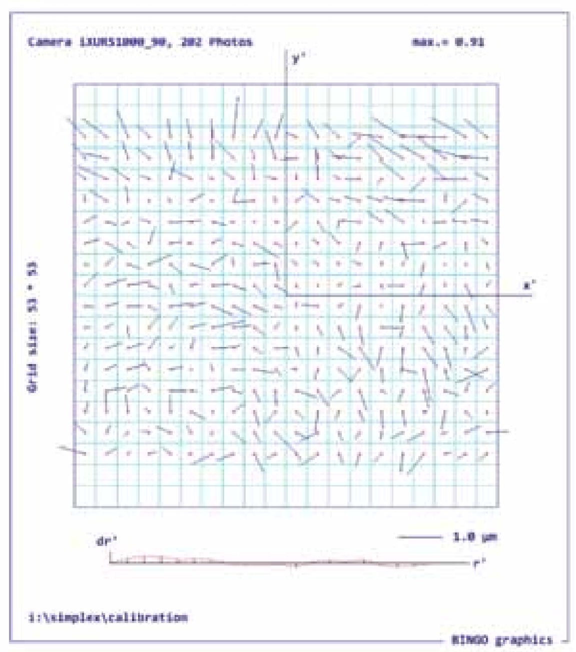
After the adjustment, the following main camera parameters were calculated:

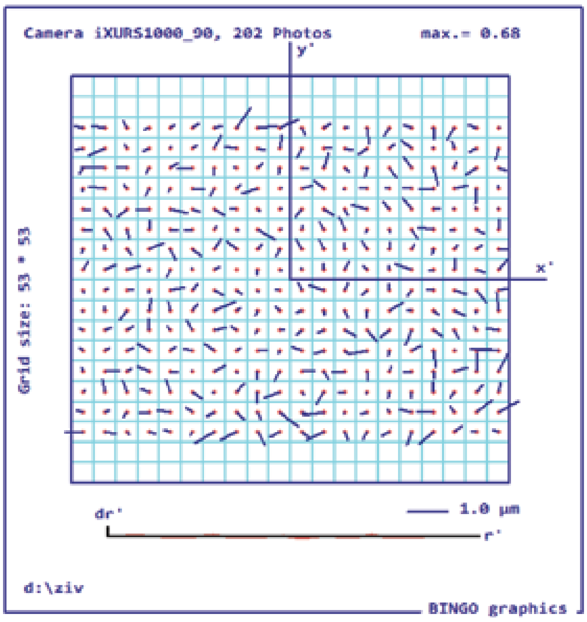
	F (mm)	Xp (mm)	Yp (mm)
	89.5447	0.0244	0.0149
RMS (µm)	10.1	1.5	1.5
RMS (pix)	2.20	0.33	0.33

The low accuracy of the focal length calculation (10.1 µm) may be explained by the low accuracy of GPS data already mentioned above.

During the self-calibration the camera model distortion was also calculated. The left picture below presents a clearly visible symmetrical radial distortion model of the camera with a maximal distortion of 24 µm before fixing the image.







The right image presents the same image after its fixing with 61, 62 additional parameters describing a simple symmetrical radial distortion model (corresponds to K1 and K2 coefficients). Maximal residual here is 0.91 µm, which is just 0.2 of pixel (4.6 µm).

The third picture from the left presents the same camera after implementing the following additional parameters 17,18,19,39,61,62,65, describing more complicated distortion model. In this case, the maximal residual equals to 0.86 µm.

As a conclusion, should be explicitly stated that the distortion model of the camera iXU-RS1000 with 90 mm focal length fully corresponds to a standard Brown-Conrady distortion model and images captured with the camera may be easily transformed to undistorted model with a maximal residual less than 1 µm.

7. Accuracy analysis for different GCP & ChP configuration

Several different GCP and ChP configuration were chosen for testing geodetic accuracy of the block.

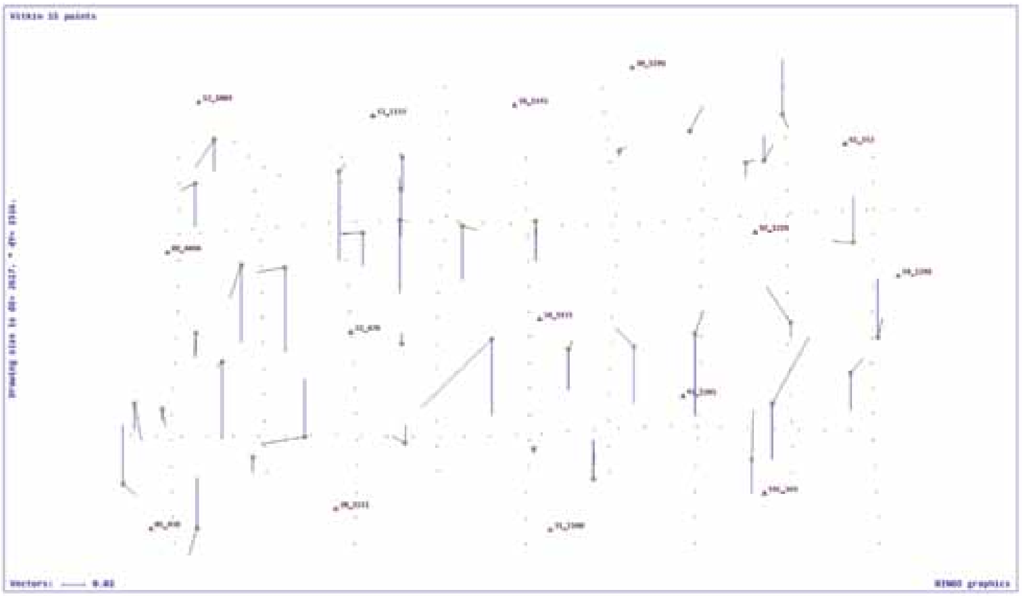
One of them is based on 15 GCP and 38 ChP:

The following results were obtained for this configuration:

	15GCP			38 Check Points			
	dX (cm)	**dY (cm)**	**dZ (cm)**	**dX (cm)**	**dY (cm)**	**dXY (cm)**	**dZ (cm)**
MIN	-0.8	-1.2	-0.2	-6.3	-6.2	8.8	-8.1
MAX	0.6	1.8	0.2	3.3	5.9	6.8	5.3
Mean	0.0	0.0	0.0	-0.3	0.1	0.3	-1.8
STDEV	0.4	0.6	0.1	1.6	2.1	2.7	4.0
RMS	0.4	0.6	0.1	1.7	2.1	2.7	4.4

With 15 GCP and for 38 Check Points the RMSxy = ± 2.7 cm (0.7 pix) and RMSz = ± 4.4 cm (1.1 pix) were obtained.

The following chart is a graphical representation of the residuals on Check Points:



The red vectors represent XY residuals and the blue one – Z residuals. There is no visible systematic errors in the block.

The planimetric accuracy of the block on Check Points is always at the level of 0.7 pixel independently on the number and configuration of GCPs used for adjustment and exterior orientation of the block.

The altimetric accuracy of the block on Check Points varies from 1.0 to 1.5 pix depending on the number of GCPs. This altimetric accuracy is considered as high accuracy and even may be improved by use of high accuracy GPS data.

8. Accuracy analysis from stereoscopic measurements

The aim of the stereoscopic test is to check a potential accuracy of stereoscopic measurements on images captured by iXU-RS1000 camera with focal length of 90 mm and to test a possible existence of the vertical parallax residuals after relative orientation .

The theoretical accuracy of stereoscopic measurements may be calculated as flowing:

*Mxy= H/F*mxy ; Mz=H/b*mp*

Where:

Mxy – theoretical planimetric accuracy of stereoscopic measurement on the ground,

Mz – theoretical altimetric accuracy of

stereoscopic measurement on the ground,

mxy – accuracy of x,y measurement on the image plane,

mp – accuracy of parallax measurement on the image plane.

With the assumption, that mxy=mp=0.3 pix, for camera with F=90 mm and forward overlap of 60% the theoretical planimetric accuracy will be 0.3 pix and the altimetric – 1.7 pix.

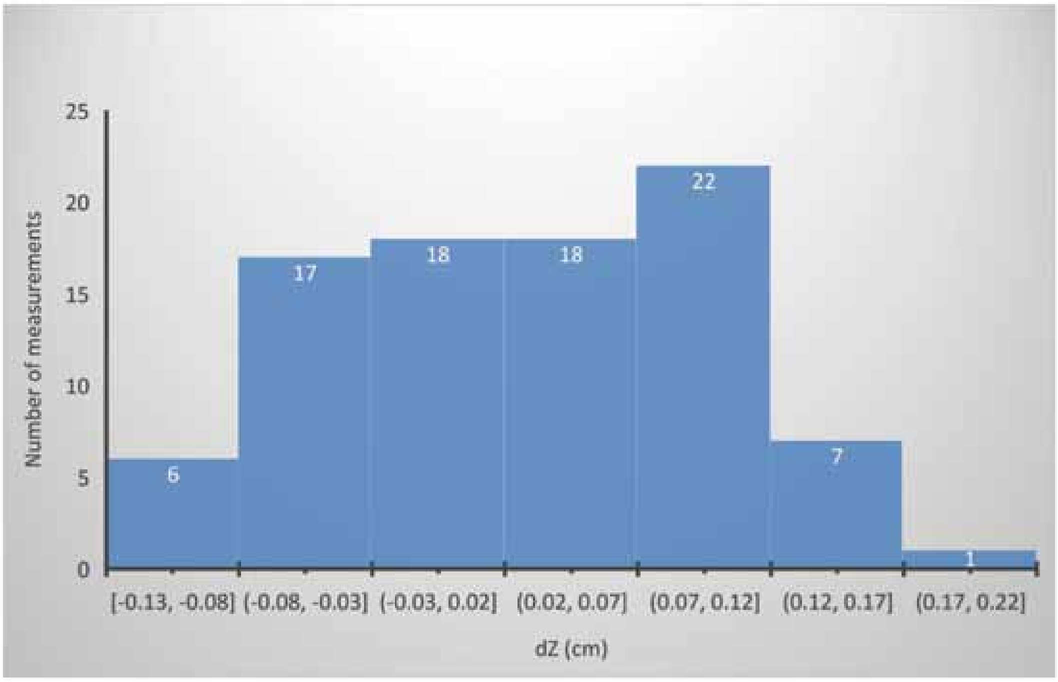
Mapping Technology Ltd. executed stereoscopic measurements. For the analysis, 56 GCPs on 91 stereopairs were measured. Stereopairs with 60% forward overlap were mainly selected. Several measurements were done with stereopairs formed with images from adjacent strips with using side overlap for stereoscopy. Every point was measured twice on the same stereopair. The Atlas KLT software was used for the stereoscopic measurements.

Exterior orientation parameters were calculated from bundle block adjustment with self-calibration and with use of all 56 GCPs for the block orientation. It was done to eliminate an impact of possible block deformations on stereoscopic measurements.

The results of the test are as following:

	Xg-Xp (cm)	Yg-Yp (cm)	Zg-Zp (cm)	Xg-Xp (pix)	Yg-Yp (pix)	Zg-Zp (pix)
MIN	-5.10	-6.40	-13.20	-1.27	-1.60	-3.30
MAX	5.90	6.30	18.20	1.48	1.58	4.55
Mean	-0.16	-0.18	2.94	-0.04	-0.04	0.73
STDEV	2.03	2.40	6.87	0.51	0.60	1.72
RMSE	2.04	2.41	7.47	0.51	0.60	1.87

The distribution of dZ residuals may be presented as following:



9. Conclusions

This Phase One iXU-RS1000 Accuracy Assessment Report was dedicated to check the camera's capabilities to be used in high accuracy mapping projects. Only the camera with focal length of 90 mm was tested.

The test preparation included:

1. Test field development with precisely defined and measured GCPs,
2. Tie points automatic measurements (image matching) and GCP measurements with Agisoft Photoscan Pro software,
3. Bundle block adjustment with Bingo software.
4. Stereoscopic measurements with Atlas KLT digital photogrammetric workstation.

The results obtained during the data analysis clearly evidence that:

1. Phase One iXU-RS1000 is a metric camera with stable and clearly definable interior orientation parameters,
2. The images captured by the camera are of high geometric and radiometric quality ensuring the use of the camera in high accuracy mapping projects, including sterecompilation.
3. The final photogrammetric accuracy without use of GNSS data reached 0.5 pixel in position and 1.0 pixel in altitude.
4. The right use and high quality of GNSS data will even improve the results.

190MP Aerial Solutions

Phase One Industrial designed a powerful and fully integrated 190MP aerial system that offers a high-resolution 190 MP large frame, and enables customers to execute mapping projects faster in a more efficient manner providing higher photogrammetric accuracy.

The system integrates state-of-the-art hardware and software components, including:

- iXU-RS1900 dual 90 mm lens aerial camera - the latest Phase One innovation to offer large format metric camera functionality
- IX Controller MKIII – a rugged, fanless PC that acts as a central hub of the Phase One 190MP Aerial System
- iX Capture - an aerial capture, control and image processing software
- Gyro Stabilized Mount - SOMAG DSM400 - was specifically designed for the Phase One 190MP Aerial System
- GNSS/IMU system - Applanix' POS AV system that enables direct georeferencing of aerial images
- Flight Management System by TopoFlight - enables the planning and navigation of the aerial survey mission
- 4-Band Configuration - additional configuration for simultaneous capturing RGB and NIR images, comprises dual 90 mm lenses for capturing RGB information, and a 50 mm lens for capturing NIR information and thus providing 4-Band (R,G,B,NIR) or CIR imagery.

Monitoring of petroleum pipelines using aerial laser scanning and digital aerial photography

A. Voitenko, Kadastrsyomka, Irkutsk, Russia

Monitoring of petroleum pipelines is one of the important tasks affecting operational safety of trunk oil and gas pipelines.

For these purposes, JSC "Kadastrsyomka" has developed a monitoring technology based on aerial laser scanning and digital aerial photography technology, which has been tested at a pilot section of a trunk oil pipeline.

This development pursued the following goals:

1. to determine the tolerance of object points coordinates and error in measurement of geometric parameters of structural elements based on aerial laser scanning
2. to identify the capability of detecting terrain forms caused by exogenic processes. To set the minimum dimensions of laser reflection forms reliably identifiable with all points at preset scanning altitude;
3. to identify the capability to trace changes in terrain shape based on prior monitoring observations;
4. to determine the capability of controlling elevation position of the subsurface part of pipeline by measuring the height of elevation markers of underground oil pipelines and surveying the surface portion of protective berm.
5. to determine whether it is possible to detect vertical deviation of power transmission line posts and communication masts.

Requirements to accuracy of coordinates measurement and terrain form dimensions measurement were set prior to the start of pilot work.

1. Maximum elevation discrepancy – not more than 0.05 m;
2. Error in detection of mutual position – not more than 0.05 m;
3. Average point density - 16 points/m^2;

At the first stage, we performed geodetic survey of the surface to establish and set equal level of the two base stations distanced at 30 km. Then we marked a rectangular site composed of 25 points with spacing of 1 m from each other and conducted measurement of vertical deviation angles of power transmission line towers and communication masts in two mutually perpendicular planes. Using the method of ground geodetic survey, we determined the areas with terrain microforms, oil pipeline elements (inspection hole covers) and elevation detection devices. The works were performed by specialists of the pipeline operator organization (Fig. 1).

Fig. 1.

At the second stage, we performed aerial laser scanning and digital aerial photography using special equipment by Swiss manufacturer Leica, which undergoes annual calibration. Aerial laser scanning and digital aerial photography parameters were chosen so as to match particular requirements (Appendix 1). Survey was performed from a MI-8 helicopter, following pre-calibration of equipment.

Appendix 1

Laser survey parameters

Flight speed	120 km/h
Flight height	250 m
Scanning angle, scanning rate	56°, 190000 Hz
Average point density per 1 sq.m. of surface	22 points
Accuracy of plan point position	0.03 cm
Elevation scanning accuracy	0.04 cm

Key technical parameters of aerial photo camera and survey mode:

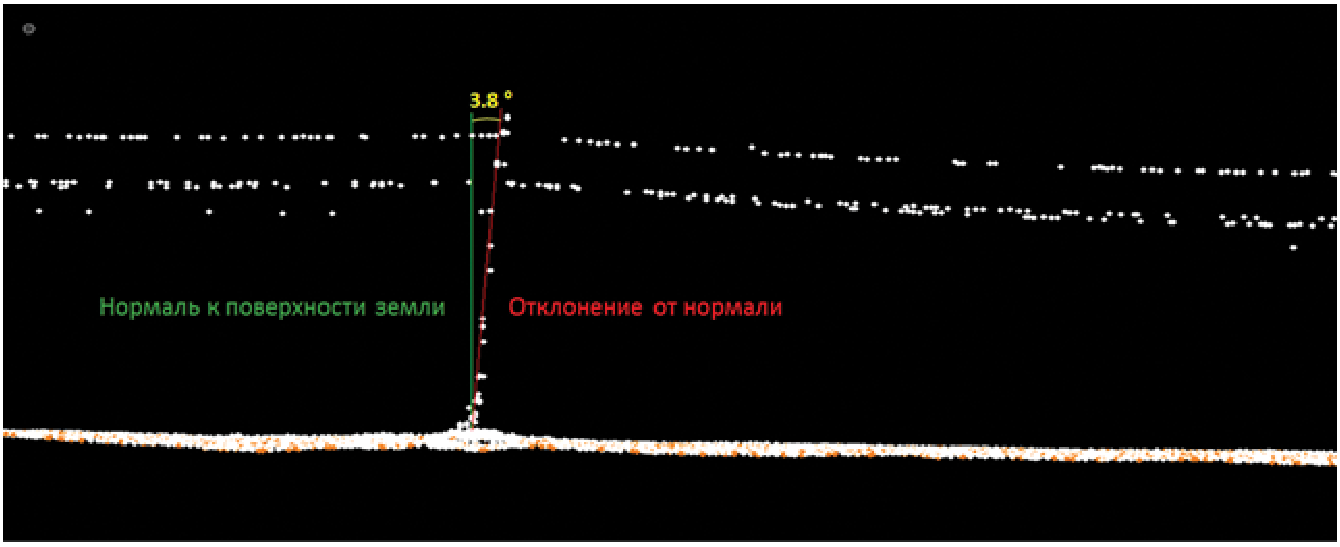
Flight height	250 m
Image size	8956px*6708px
Lens focal distance	52 mm
Camera pixel size	6 µm
Acquisition interval	2.32 sec
Calibration	RCD30 incorporates photogrammetric calibration data
Average pixel size on terrain (GSD)	0.03 m

At the third stage, we adjusted the level of flight trajectory from two base stations, downloaded laser reflection points, performed image decoding and calibration of recorded laser reflection points, verified digital camera parameters, classification of laser reflection points, plotted digital orthophotomaps and digital terrain models (Fig. 2).

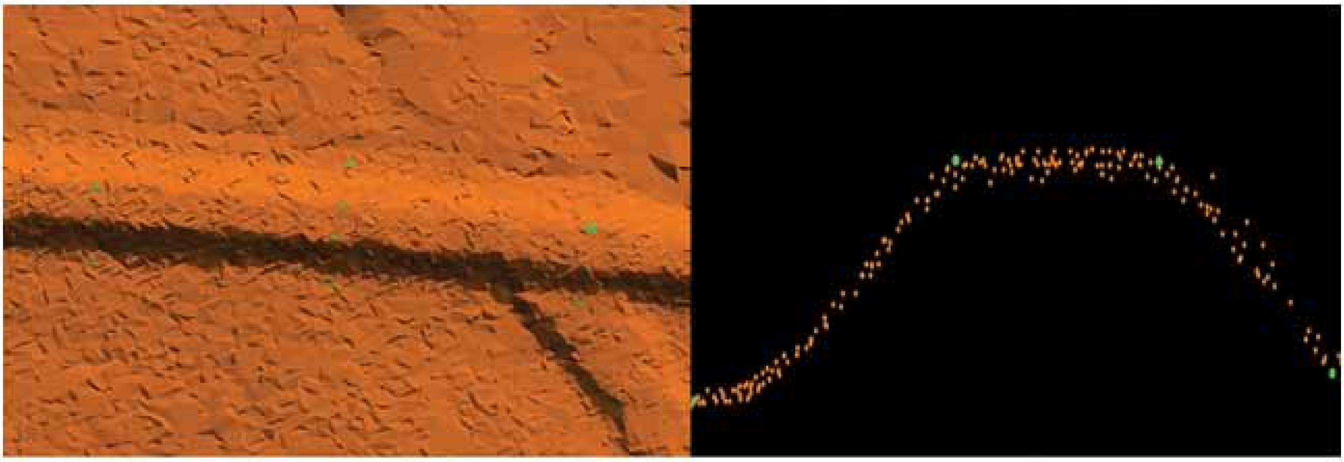
At the fourth stage, together with representatives of the pipeline operator organization, we performed joint evaluation of the collected data represented in Appendix 2.

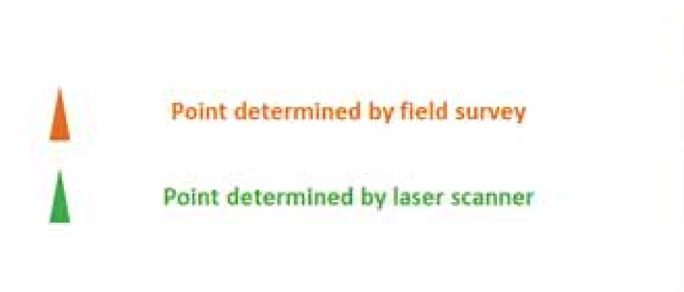
Fig. 2.

Item No	Form	Dimensions according to ground measurements (L x W x D), m	Dimensions according to ALS (L x W x D), m	Difference, m
1	2	3	4	5
1	Shape 13	0.25 x 0.50 x 0.10	0.25 x 0.50 x 0.13	0.0 x 0.0 x 0.03
2	Shape 11	0.50 x 0.75 x 0.20	0.45 x 0.70 x 0.22	0.05 x 0.05 x 0.02
3	Shape 12	0.75 x 1.00 x 0.30	0.70 x 1.00 x 0.27	0.05 x 0.0 x 0.03
4	Shape 15	0.50 x 0.10	0.50 x 0.21	0.0 x 0.11
5	Shape 10	0.75 x 0.15	0.80 x 0.20	0.05 x 0.05
6	Shape 14	1.00 x 0.30	1.00 x 0.34	0.0 x 0.04
7	Shape 4	0.25 x 0.50 x 0.10	0.25 x 0.50 x 0.08	0.0 x 0.0 x 0.02
8	Shape 1	0.50 x 0.75 x 0.20	0.50 x 0.65 x 0.17	0.0 x 0.10 x 0.03
9	Shape 3	0.75 x 1.00 x 0.30	0.80 x 1.00 x 0.37	0.05 x 0.0 x 0.07
10	Shape 2	0.50 x 0.10	0.50 x 0.11	0.0 x 0.01
11	Shape 5	0.75 x 0.15	0.70 x 0.18	0.05 x 0.03
12	Shape 7	1.00 x 0.30	1.00 x 0.33	0.0 x 0.03
13	Additional shapes			
14	Shape 6	0.70	0.68	0.02
15	Shape 8	1.90 x 0.50 x 0.40	2.00 x 0.50 x 0.42	0.10 x 0.0 x 0.02
16	Shape 9	2.10 x 0.60 x 0.40	2.00 x 0.60 x 0.40	0.10 x 0.0 x 0.0
17	Wood log	2.40 x 0.13	2.40 x 0.10	0.0 x 0.03
18	Employee1	+	+	–
19	Employee2	+	+	–
20	Employee3	+	+	–
21	Shape	4.85 x 0.92	4.95 x 0.95	0.10 x 0.03
22	elevation markers	0.5x0.5	0.5x0.5	0.0x0.0



Tower No.	Vertical deviation angle based on tacheometrical survey, degrees	ALS-based tower deviation angle, degrees	Difference, degrees
1223	4.2 (направление крена – 324)	3.8	0.4





Mean height, m	0,000
Minimum height, m	-0,010
Maximum height, m	0,070
Standard deviation, m	0,048

Resulting from the study, we have come to conclusion that minimum dimensions of reliably identifiable terrain forms must be at least 28 x 40 cm for aerial survey height of 250 m. In this case, accuracy of pipeline elements geometry measurements remained under 3 cm. Elevation dimensions (depth, height) were detected with mean error of under 4 cm.

The following results were obtained for dimension measurement of modified elevation markers and surface of protective berm:

Maximum measurement error for elevation markers amounted to 6 cm, RMS error – 1 cm;

For surface of protective berm, the maximum error was 8 cm, RMS error – 6 cm;

For surface of water drainage berm, the maximum error was 7 cm, RMS error – 5 cm;

Inferences:

Aerial laser scanning and digital aerial photography technology enables identification of terrain forms, which are created by exogenic processes, along the oil pipeline route and beyond, including those covered by vegetation.

Aerial laser scanning and digital aerial photography technology allows controlling the elevation of the subsurface portion of an oil pipeline using measurement of elevations of modified elevation markers and surface of protective berm, with the accuracy specified in the program of not more than 4 cm.

Aerial laser scanning and digital aerial photography technology allows monitoring of vertical deviation of power transmission line towers and communication masts;

It also enables to measure geometric parameters of pipeline elements with error under 3 cm.

The company is prepared to use the experience gained in this project for monitoring of other trunk oil and gas pipelines in operation.


Resurs-P
High resolution optical-electronic sensor
Panchromatic mode / Multispectral mode (1 / 3.4 m)
High resolution sensor (SHMSA-VR)
Panchromatic mode / Multispectral mode (12 / 23.8 m)
Medium resolution sensor (SHMSA-SR)
Panchromatic mode / Multispectral mode (60 / 120 m)
Hyperspectral sensor (GSA)
96 spectral bands (30 m)
Brussels Airport, Belgium, Resurs-P satellite image
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