Mono-Photon Technology Based Hyperspectral Systems for Remote Sensing in Russia

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ABSTRACT

Nowadays in the frameworks of the Federal Space Program of Russia three hyperspectral satellite projects are being realized: a) “KVS” hyperspectral instrument designed for “Resurs-O1” spacecraft , b) project developed in the frameworks of the “Volcano” system is a small “Volcan-Limb” satellite having the hyperspectral channel, and the ultraspectral channel for diagnostics of the Earth Limb chemical kinetics, c) small hyperspectral “Volcan-Astrogon” satellite, designed on the “Volcano” space platform base by NIIEM R&D Institute of Istra. This instrument having the spatial resolution up to 3 m with the spectral one of 1-2 nm comes out to be the unique device realized only due to the mono-photon technologies. The last project considered in details.
The aviation prototype of the satellite hyperspectral channel was developed in 1998. The instrument has successfully passed all the test trials at the “Gasprom” trunks for a number of years.
Nowadays is the started joint work on the onboard supercomputer for prospective hyperspectral apparatuses implemented by the united collective of enterprises of the Russian Academy of Sciences and Research Institute for Computer Architecture and Software Technology (GMD FIRST) and DLR (Berlin).

INTRODUCTION

Remote sensing of the Earth with the hyperspectral resolution has a long history in Russia. Yet until recently the given tenor had only been presented exclusively by tracking spectrometers giving no superposition of the Earth and atmospheric spatial signature vs. spectral snapshot in each point of space. It was only the latest achievements in optical electronic photo-receivers and the immense capabilities of the modern computer technology that made it possible to technically bring into reality the mentioned superposition.
Since the middle 80-s works are being done to develop the key elements of the hyperspectral systems [1], including the spectrum splitters based on specialized diffraction grids, acoustic optical tunable canted filters [2], Fabri-Perro adjustable resonators. The USSR optical industry has got mastered the entire list of these elements. M?no-photon technologies for the space-time resolution detection of extremely weak light streams

were worked out on the basis of national technologies in the 90-s [3]. Provided both the complete technological cycle of the spacecraft orbital injection together with sophisticated aviation industry and modern microelectronic base available in the market, it becomes possible to create the whole spectrum of prospective space- and airborne hyperspectral systems based on the national technology [4].
Nowadays in the frameworks of the Federal Space Program of Russia three hyperspectral satellite projects are being realized (hyperspectrometer of «Reagent» R&D Center, Moscow) : “KVS” hyperspectral instrument designed for “Resurs-O1” spacecraft with 20m of the spatial and 1-2 nm of spectral resolution (developed by SKB “Progress” Design Center, Samara), and small hyperspectral “Volcan-Astrogon” satellite weighting about 200 kg., designed on the “Volcano” space platform base by NIIEM R&D Institute of Istra. This instrument having the spatial resolution of 2-3 m with the spectral one of 1-2 nm comes out to be the unique device realized only due to the mono-photon technologies. The third project developed in the frameworks of the “Volcano” system is a small “Volcan-Limb” satellite (weight about 200 kg.) having the hyperspectral channel with rough spatial resolution of 1 km and the spectral one of 1-2 nm, and the ultraspectral channel for diagnostics of the Earth Limb chemical kinetics with the spectral resolution of down to 0.01 nm. The aviation prototype of the satellite hyperspectral channel with the 2 nm spectral resolution was developed in 1998 by joint efforts of «Reagent» R&D Center, Moscow and NIIEM R&D Institute, Istra following an order of “Gasprom” JSC. The instrument has successfully passed all the test trials at the “Gasprom” trunks for a number of years [5].
The global nature of the Earth remote sensing (ERS), technological fulfillment complexity of the hyperspectral projects, and the ERS information globalization make necessary the international cooperation when setting up of these explorations. The first step of such cooperation is the started joint work on the onboard supercomputer for prospective hyperspectral apparatuses implemented by the united collective of enterprises of the Russian Academy of Sciences (RAS) (Keldysh Institute of Applied Mechanics (IAM) of RAS and Institute for Space Research (ISR) of RAS) and Research Institute for Computer Architecture and Software Technology (GMD FIRST) and DLR (Berlin).

BASIC TECHNIQUES

The reaching for a spectral resolution of $\Delta\lambda$~1nm gives a steep surge to the equipment sensitivity requirements or the equivalent expanding of the optical systems aperture.
Whereas construction of the large aperture optical instruments with complex systems of image stabilization at the photo-receiver’s focal plane highly boosts the cost of such systems, increases the development and start times. Therefore, the major trend in the Earth monitoring equipment designing in terms of commercial use is finding the way to reduce the size, mass and power consumption parameters as well as to considerably lessen the requirements for the SC platform stabilization. The on-line flexibility and globalness of the observations are not the obligatory factors in the commercial use. This allows us to operate the optical electronic system according to the user request (e.g. via Internet) pointing out the local observation area and the specific spectral lines (or their suspension) at which the observation should be made. Therewith one may evade the high redundancy degree of the conventional observations.

The practical realization of this ideology can be based on the two technological achievements. They are programmable acousto-optical filter and separate photons counting device with the high space-time resolution.

Acousto-Optical Tunable Filters

Acousto-optical tunable filters (AOTF) with optical size of approximately 8-10 mm for visible and ultraviolet spectrum on the base of TeO_2 and KH_2PO_4 (denoted by KDP) crystals are developed and manufactured by “Reagent”. R&DC These devices have the highest space/frequency and time simultaneous resolutions. The spectral resolution is better than one nm [2].

The Micro-Channel Plate Photon Detectors (MCP)

The most sensitive detectors known at the moment are those based on the MCP technology which provide (unlike the CCD-storing systems) detection of the photon beam in the single photon sequential analysis mode determining the coordinates at the 2D focal plane with high spatial resolution along with a high time resolution. The technology of these detectors is based on the principle of conversion of a weak photon beam into the photo-electron current from the photo-cathode surface and its subsequent amplification by $\sim 10^6$ factor with the MCP while preserving the spatial-time resolution (with the accuracy of ~20 μm in space and 10^{-9} s in time). Further on one of the multi anode collector system read-out options of the remitted electron flow yields the X, Y, t coordinates by the computation unit. The best specimen of such systems reaches the 1000 x 1000 pixel of spatial resolution and the photo-electron counting rate of 10^6 s^{-1} under the photo-cathode quantum output of ~10-20%.
One of this detector version with counting up to 10^8 photon per second was supported by “Reagent” R&D C in the framework of the «Volcan-Astrogon» project.

Star-Tracker

The MCP detector is a proper star-tracker due to high sensitivity and high space-time resolution. Essential factor is that mathematical conversion of the MCP-detector data may compensate the star-tracker’s angular motion with sufficient high rate by transferring to the proper reference system. Highly accurate definition of angular motion of the optical axis is the result of this procedure. The high sensitivity of the MCP-detectors allows us to construct a narrow-angle star-tracker which recognizes the starry sky image and does not require the basis-system of bright stars.

General Concept of Scientific Instruments project «Astrogon-Vulcan»

Cutting down the scope angle θ_0 to 10^{-3} rad under the extended effective aperture diameter of the input lens eyes up to 20 cm makes it possible to sharpen the angular resolution to $\Delta\theta \sim 0.5*10^{-5}$ rad that corresponds at H~500 km to 3 m of the spatial resolution, sufficient to solve the ecological and urban infrastructure monitoring tasks in terms of the local Earth parts.

A detector combined with the star-tracker provides photon coordinates fixing an accuracy of 3 m with respect to the ground based reference coordinate. Whereas the detector plane image hold system can be a rough mechanical circuit with an accuracy of $\sim 10^{-3}$ rad that implies no problem. While the given local plot can be traced by the SC during ~100 s of flight. This time allows us to gain the hyperspectral (due to synthesizing of the base during the flight) image.

REFERENCES

1. I.Rodionov,A.Ponomarev at al, *Active Optical Ecological Monitoring*, SPIE Vol. 2107, 476-494 (1993)

2. I.Rodionov,A.Ponomarev at al, Wide aperture acousto-optic turnable filters for visible and UV lights, SPIE Vol. 2449, .200-207 (1996)

3. I. Rodionov, I.P.Rodionova, M.Ovchinnikov, Approaches to develop the earth observing systems based on the turnable acousto-optic filter and separate photons counter with MCP, SPIE, Vol.3117, ? 3117-10 (1997)

4. I. Rodionov, I.P.Rodionova, M.Ovchinnikov , *The microsatellite for remote exploration of environment*, SPIE,Vol.3119, ? 3119-11,(1997)

5.Dedikov E., Khrenov N., Lukyaschenko V., Salikhov R., Ponomarev A., Ovchinnikov M., Rodionov I., *The Russian Small Satellite for Hyperspectral Monitoring of Gas Pipelines*. Digest of the 3rd International Symposium of the International Academy of Astronautics, Berlin, p.235-239,(2001)