THE MULTI-APERTURE OPTICAL SYSTEM OF THE PHOTON COUNTING IN THE IMAGE FOR ABERRATIONLESS OBSERVATIONS OF SPACE DEBRIS THROUGH TURBULENT ATMOSPHERE

K. Sviridov, N. Belkin

SE "SPA Astrophysica", "Intellect" Co. Ltd.
Volokolamskoe shosse, 95, 123424, Moscow, Russia
E-mail: skn@intellect.msk.ru

ABSTRACT

For control of space debris of both artificial and natural origin, the passive ground based optical system is proposed. The principles of construction and application strategy of the proposed system are considered.

1. INTRODUCTION

Over the last years, in the connection with a successful space endeavour and its both militarization and pollution, the problem of space control became actual not only from the positions of defence, but also from the ecological point of view for the near-Earth space.

The increasing danger of random impacts of artificial Earth satellites (AES) and piloted spacecraft (PS) with different inactive space objects and their fragments of artificial origin, so-called space "debris", testify to the necessity of studying and solution of the space "debris" problem.

As a whole, the problem of space debris includes:

1) the problem of its control, and
2) the problem of its destroy.

We shall consider here the problem of space debris control. though proposed by us concept of the construction of control system allows to solve also the problem of energy delivery to space for space debris destroy.
The problem of space debris control. as part of the general problem of space control, consists of two problems:

1) The problem of search, detection and measurement of the space fragment trajectories;
2) The problem of obtaining diffraction images and identification of space fragments for their subsequent destroy.

Small dimensions of space fragments ~1cm and large distances to them ~1000 km testify to the possibility of solving the problems shown, mainly, in the optical wavelength range, that provides principally for a high angular resolution of reception and small angular divergence of transmission under application of digital and analogous methods of atmospheric distortions compensation.

Taking into account the specific features of space fragments, as control objects, that is, their great number and randomness of arising, and also their great velocity ~7 km/s and the absence of pointing, that prevent from the application of an active laser illumination, including the illumination with wavefront conjugation, for the solution of the space debris control problem we propose for a ground-based optical system with passive location mode, using, as a source of illumination, the Sun and controlling the space debris at the background of night star sky.

The fact, that the space fragments, contrary to the AES are small-dimension objects of control with angular sizes $\theta_0=10^{-8}$ rad (0.002"), brings to the point, that for their search, detection arid measurement the optical systems are necessary, having such a high penetrating ability and resolution, that will allow to measure coordinates

with the given accuracy and to construct the trajectories of these weak control objects, having an integral brightness to $m_i^* = 17^m$ star magnitude.

Our experience of the development and production of one-aperture systems for space control, testifies to the fact, that the increase of their resolution and penetrating ability in the interests of space debris control is really possible in three directions: firstly, along the way of increasing the size of the telescope input aperture on the basis of aperture synthesis; secondly by rising the sensitivity and reducing the resolution element of the detector on the basis of photon count mode in the image (PCI), and, thirdly, by compensation of atmospheric distortions by a modified method of triple correlations.

Guided by this experience, we propose for a :concept of construction of a ground-based optical system for space debris control, consisting of three sequential and interconnected channels:

- channel of forming on the basis of aperture synthesis array
- channel of detection on the basis of photon count mode in the image
- channel of processing on the basis of parallel architecture of computing hardware organization and program and algorithmic support (PAS) of the digital correlational image processing

Consider briefly the features of the construction and functioning of each above mentioned channels of the proposed system for space debris control.

2. CHANNEL OF FORMING

On the basis of a comparative analysis of existing concepts for the construction of the aperture synthesis optical systems, that is:

- segmented telescope
- multimirror telescope (MMT)
- array of individual telescopes

it was shown, that because of the technological, exploitation and financial problems, today only an array of individual telescopes, with the bases to 550m and more, is able to provide for the required resolution of space debris fragments

As a result of consideration of the theoretical foundation of the aperture synthesis in optics, and research of partially-filled (redundantless and redundant) interferometric systems for image forming, the configuration of the aperture synthesis array was proposed by us for the space debris control, consisting of N-moving telescopes with diameter D_1 obtaining the light radiation from the objects of control in the process of spatially-temporal aperture synthesis, and of a fixed array element, combining the subbeams and electrical signals from moving elements.

Thus, at the stage of search, detection and measurement of coordinates the non-coherent array operation is necessary and enough, with combination of light sub-beams and/or electric signals from its moving elements, and at the stage of control objects recognition by their images with high angular resolution, the coherent array operation is required, in this case, for the control of the far space objects with "low mobility", the coherent combining of light sub-beams from incoherently illuminated object is enough, and for the control of fast moving objects in near space, it is necessary to combine coherently the electric signals from heterodyne detectors. In this case, the configuration of an array is also changed in the process of spatially-temporal aperture synthesis.

So, in the first case, under coherent combining of light sub-beams, the moving telescopes of the array are located along the ellipses of coherence, and in the second case, under coherent combining of electric signals, the moving telescopes of the array are located along the line, perpendicular to the direction of control object movement.

At present, in a number of countries there already exist and are developed actively the arrays of aperture synthesis, consisting of individual telescopes.

3. CHANNEL OF DETECTION

The requirements have been considered to the image detector in aperture synthesis array, and it has been shown, that the necessity to detect interference rings in an image, and, in particular, in every diffraction speckle, make more stringent the requirements both to the value of minimal detector resolution element, and to their number as well. The various ways were proposed for the satisfaction of these requirements on the basis of application of photon count mode in an image.

The estimation was given of the transfer from analogue to photocount mode of detection ($m_{cp}^* = +10^m$) and it was shown, that the mode of photon count in an image (PCI), as a perspective technology of detection, rises the penetrating ability and resolution of the space debris control systems, increases the dynamic range and productivity of the detection process, unifies the algorithms of image processing for active and passive modes of location, and also it provides for the possibility of image processing and identification of control objects in real time.

At present, the mode of photon count is realized in television detectors of a scanned raster in a number of observatories.

4. CHANNEL OF PROCESSING

Under the channel of processing we understand both the computing hardware, and their software as well.

For the array of aperture synthesis, the most logical and perspective is a non-traditional approach to the arrangement of computing hardware, based on the application of numerous (N+l) microprocessors, one-by-one in every moving element of the array, and one, more powerful at the central fixed station. It allows to create an array architecture of computing hardware arrangement, that is equivalent to the architectures of mechanical and optical construction of an array. Such an arrangement of array computing hardware corresponds to above-mentioned modes of array operation for above-mentioned groups of the problems being solved. Thus, the problems of search, detection and tracking, connected with individual array telescopes, in its non-coherent operation, can be solved by local processors, placed at a moving carrier, and the central processor of a fixed array element can solve general problems of array operating in the coherent mode.

As a result of studying of partially-filled (redundant less and redundant) interferometric systems of image forming, there have been proposed and researched the algorithms of image processing in a ground-based array of aperture synthesis. The analysis of the proposed algorithms has shown, that for closing the phase of an object's spatial spectrum between peninsulas along the ellipses of coherence, the optimal method will be the method of triple correlations.

This method is a generalization of the closed phases method for the case of array redundancy both by the dimensions, and by location of its sub-apertures as well.

The iterative algorithms were proposed and studied for expansion of the closed phases equations in a redundantless and redundant arrays of aperture synthesis, The experimental study of perspective technologies for image forming and processing in a ground-based array of aperture synthesis was carried out by the methods of physical and machine modelling. The results of the model experiment confirmed the efficiency of proposed perspective technologies for reaching high angular resolution.

5. CONCLUSION

For the practical realization of the principles and strategies of space debris control by the ground-based array of aperture synthesis, it is necessary to carry out a number of research and development work, connected with the development and creation of:

- new constructional materials and coatings for telescopes and mirrors
- new non-traditional configuration of array telescopes put to the wind
- lightened mirrors with diameter (3–5)m with required profiles and radji of curvature of high precision
- laser interferometers and range finders for high accurate measurements of optical path lengths
- automated systems of monitoring and control by the position of array optical elements, providing for the guidance, phasing and figurization;
- detectors of photon count in the image of parallel action for optical and infrared ranges of wavelength with high sensitivity, great dynamic range, small resolution element and with their large number;
- algorithms and means for image processing in real time.

In conclusion it should be noted, that in case of necessity to increase the accuracy of space debris trajectory measurements, the considered passive optical system can be used as source of pointing for the provision of an active laser illumination, and its elements can serve for the delivery of laser radiation to space. In this case, it is necessary to solve the problem of coherent combining of sub-beams transmitted both from individual telescopes, and from different laser modules as well. In the basis of such researches the principle of coherence can be laid down, and to apply the results of coherent sub-beam combining, obtained in the operation for reception. Guiding by the principle of "mutuality", we can assert, that the attainment of a high angular resolution in the proposed here system for space debris control is the guarantee of attainment of a small angular divergence of the laser radiation, transmitted through it.

6. ACKNOWLEDGEMENTh

This work was supported by the U.S. Dept. of Energy.

7. REFERENCES

[1]. Sviridov K, Belkin N, Bakut P., Sviridova G. "The multiapperture optical system of the photon counting in the image for aberrationless observations of space debris through turbulent atmosphere, Science and Technology Report, SE "SPA Astrophysica", Intellect Co. Ltd., 1995.