Some Issues of Creation of Wide-Field Telescopes for Monitoring Satellites and Space Debris in High Earth Orbits

I. Tarasenko(1), V. Terebizh(1), S. Markelov(2)

(1) Open Joint Stock Company “Research-and-Production Corporation “Precision Systems and Instruments”, (OJC «RPC «PSI»), Moscow, Russia
(2) SAO RAS, Karachai-Cirkasia, Nizhnij Arkhyz, Russia

Maui, Hawaii, April 2010
Contents

1. Introduction
2. Substantiation of required telescope characteristics
3. A design of the wide-angle telescope for detecting space objects in GEO and HEO
4. Brief information on the photo detector
5. Concluding remarks
Introduction

The basic requirements laid to the space survey electro-optical detection systems:

• as great as possible informative (productivity)

\[ E = A \Omega = (\pi w D/2)^2, \]  

where:

\( A = \pi D^2/4 \) is effective aperture area of telescope;
\( \Omega = \pi w^2 \) is area of solid angle, covered FoV of telescope;
\( w \) is an angular radius of FoV;
\( D \) is a diameter of the telescope objective entrance pupil.
Introduction

- high optical power

\[ M \approx \mu/2 + 2.5 \log (D/\beta B) + 1.25 \log (n_{0\lambda} \cdot T \cdot \Delta \lambda \cdot \tau \cdot q), \]

where:

\( \mu \) is sky background brightness in magnitudes from one arc second squared;

\( D \) is a diameter of the telescope objective input pupil in cm;

\( \beta \) is an angular diameter of the visible image of a star in arc seconds;

\( B \) is received value of the intelligent signal to noise ratio;

\( n_{0\lambda} \) is light stream density from a star having zero magnitude;

\( T \) is signal accumulation time in seconds;

\( \Delta \lambda \) is width of spectral band in Å;

\( \tau \) is atmosphere and optics transparency factor;

\( q \) is photo detector quantum output (events/photon).
«M» or «2w». What is the preference?

- Productivity increasing: $E \uparrow \rightarrow D \uparrow + 2w \uparrow$
- Sensibility increasing $M \uparrow \rightarrow D \uparrow$
- $M \uparrow + 2w \uparrow = ???$ (critical production features → available routine practice)
- $D = 75 \text{ cm, } M = 18^m-19^m (25-30 \text{ cm}), \ 2w \approx 7^\circ \rightarrow \text{survey rate } \approx 4000-5000 \text{ sq. deg/hour. (survey of GEO zone 4-5 times per night)}$
- $D = 2-3 \text{ m, } M = 19^m.5-21^m.0 (5-20 \text{ cm}), \ 2w \approx 1-2^\circ \rightarrow \text{survey of local zones near the active spacecrafts}$
Substantiation of required telescope characteristics

Observation conditions:

- the region of visible band spectrum $\Delta \lambda = 3\cdot10^3 \text{ Å}$;
- the sky background brightness $\mu \approx 21^m - 22^m/\text{ang.s}^2$;
- the angular diameter of a star image $\beta \approx 2'' - 3''$;
- the resulting transparency coefficient $\tau \approx 0.3$.

Photo detector characteristics:

- quantum output $q \approx 0.8 - 0.9$ events/photon;
- the pixel size is $13.5 \times 13.5 \text{ μm}$;

System characteristics to be achieved:

- signal to noise ratio $B \approx 5...7$;
- $M \approx 18^m - 19^m$ the acquisition interval $T \approx 1 - 5$ s;
- the angular diameter of FoV $2w \approx 7^\circ$. 
Substantiation of required telescope characteristics

The preliminary estimates for the diameter of entrance pupil (D) and for the effective focal length (F_{mm}) of a telescope are following:

\[
D \approx 60\div80 \text{ cm}
\]
\[
F_{mm} \approx 206 \cdot p_{\text{mcm}} / p'' \approx 1390 \text{ mm on the assumption of:}
\]

\[
p'' \approx 2'' \text{ expected atmospheric quality of images;}
\]
\[
p_{\text{mcm}} = 13,5 \times 13,5 \mu\text{m linear dimension of pixel.}
\]
A design of the wide-angle telescope for detecting space objects in GEO and HEO

The optical scheme

1+2 – Input lens compensator;

2 – Lens and counter-reflector;

3 – Principal mirror;

4 – Output compensator;

5 – Focal plane.

8th US/Russian Space Surveillance Workshop
## Basic telescope characteristics

<table>
<thead>
<tr>
<th>A characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrance pupil diameter</td>
<td>750.0 mm</td>
</tr>
<tr>
<td>Equivalent focal distance</td>
<td>1380.5 mm</td>
</tr>
<tr>
<td>Lens aperture</td>
<td>1:1.84</td>
</tr>
<tr>
<td>FoV angular/linear diameter</td>
<td>$7^\circ.0/169.1$ mm</td>
</tr>
<tr>
<td>Length of the rear segment</td>
<td>100 mm</td>
</tr>
<tr>
<td>Optical surfaces type</td>
<td>All spheres</td>
</tr>
<tr>
<td>RMS image diameter of a point light source in integral light over the whole FoV</td>
<td>$10.5 – 15.6 \mu$m, $1^\prime.6 – 2^\prime.3$</td>
</tr>
<tr>
<td>$D_{80}$, diameter of a circle containing 80% of the image energy for a point source in integral light over the whole FoV</td>
<td>$16.0 – 23.3 \mu$m, $2^\prime.4 – 3^\prime.5$</td>
</tr>
</tbody>
</table>
The rated quality of image

Point diagrams along the FoV in integral light.
The rated quality of image

Energy concentration in polychromatic image of the point light source (fraction of enclosed energy in the circle depending on its radius). The diffraction limit is given in black.
Construction of the telescope

- Mouthpiece
- Principal mirror
- Input lens
- Lens and counter-reflector
- Compensator
Photo detector

8 x CCD 42-90 (E2V Technologies);
Total format $8192 \times 9216$ pixels;
The pixel size being $13.5\,\mu m \times 13.5 \,\mu m$;
Total size of the light sensing $125 \, mm \times 113 \, mm$;
The detector quantum output in visible band of wavelength is 0.89-0.92.
Concluding remarks

The main features of the presented telescope:

- offset of the image of Kassegren type;
- increase of distance between the input corrector lenses (which helps suppressing the image coma);
- two-lens output corrector;
- optical elements have the simple surface form;
- the lenses be made from simple and reliable sorts of glass.