CONSTRUCTION OF TELESCOPE INACCURACY MODEL ACCORDING TO DATA OF SATELLITES LASER RANGING

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ABSTRACT. The method of constructing error model of pointing the telescope to the target is present in the article. It bases on using the angular encoders data (azimuth and elevation). This angles are fixed in time in the satellite laser ranging. The data is presented in the codes of angles (in inside frame) and the moments of time, in which they are fixed. The consistence of procedures and result of received model are presented in article. Also advantages and disadvantages of the new model are considered in comparison with the method of stars observers. The method tested on the 40 passes of the satellites. The model constructing in station “Kyiv-Golosiiv” in 2003 year is used for the comparison.[1]. The accuracy of this model is on the level 15 arcsec.

TARGET SETTING

For successful observation of any object it is necessary to point at it instrument, with a help of which we will do observation and track it with necessary accuracy during all necessary time. Accuracy of pointing and tracking depends on type of observations and can be changed from dozens of angular minutes to fractions of angular seconds. So, the higher accuracy of pointing and tracking we need the more careful we will study and take into account reasons, which lead to inaccuracy.

It was always paid much attention to the questions of construction of telescope inaccuracy model. It is necessary to pay attention to some of the following works [1]-[4]. For example, for radio-telescopes which function in VLBI network, created standard complex of software for observation of radio sources with aim of defining more precisely of telescope model parameters, because these radio-telescopes function under total control of computer, that is in automatic regime.

Tendency of development of SLR technique directed to creation of automatized systems that can do observation of satellites in semiautomatic and automatic regimes. For this purpose it is necessary to provide accuracy of pointing by laser beam at observed object and make it's tracking with accuracy that does not exceed a half of beam width. Reasons of not accurate laser beam pointing at satellite can be inaccuracy in telescope assembling and searching ephemeris.

Inaccuracy in searching ephemeris can be compensated by moving calculated position of satellite along orbit. This correction can be done automatically during observation session changing “ephemeris” time of observations since we get reflected from satellite signals. More than that, at regular observations we can determine corrections to searching ephemeris

according to data of previous observation sessions of given satellite. Because we consider this reason of inexact laser beam pointing not actual.

The more complicated is a question of considering of instrumental inaccuracy of telescope. These inaccuracies always have their particularity, that is specified by the type of telescope, quality of adjustment of the whole optical system, quality of operation of telescope mechanical units etc. Therefore only creating high accuracy model of telescope inaccuracy and having possibility of operative control and defining more precisely of this model we can satisfy demands of automatic observation. Besides this, using of system with precise object pointing and tracking increases significantly laser station work effectiveness, even when it works with active interference of observer. More important this question is during caring out of day-time observations, when most of satellites are not seen by observer.

If system includes absolute angle sensors, for example inductosin type, then case inaccuracies' model is easy to bind with "zero point" of sensors, because it is not changed with time. On the laser station "Kyiv-Golosiyv" works on creation of telescope inaccuracy model were already started in the middle of the nineties of the last century. At beginning of this work we investigated separately inaccuracies in producing of azimuth platform and inaccuracy in system of angle's sensors by laboratory methods. Analysis of getting data showed very difficult type of inaccuracies of system [1] components. During model making were identified parameters which had physical reason: inclination of vertical axle, inaccuracy of sensors, not perpendicularity of axles, etc., therefore in such case we can foreseen action of one or other model parameter and also determine not stable system units aiming to increase their parameters or change to the new one. Taking into account complicity of inaccuracies in mechanical units, inaccuracies were factorized into Furie harmonic row. Amplitude of harmonic components of Furie row and other parameters were determined according to star observation data.

The system of automatic stars observation, that were developed in MAO of NAS of Ukraine, could be done only with photoreceiver of PMT type. Similar system practically can not be implemented with semi-conducting avalanche receiver (APD, SPAD), because we need to check value of light flux that goes on photoreceiver from the star. PMT that works in regime of photons counting don't have "dead time". So that it can correctly measure light flux from the star. Avalanche photoreceiver can register separate photons, but it must have proper interval of time after each pulse, when it's sensitivity is too low. Because of it, when during these intervals can be photons from the star, system will not be able to register them. This leads to decreasing of sensitivity from the one side and to increasing of inaccuracy in measuring of flux intensiveness from the other side. All this leads to increasing of inaccuracies in measuring.

Coming out of given before condition concerning accuracy of pointing, it is possible to offer to use for construction and correction of model of telescope position angles values, which can be read from sensors during tracking of satellite during location.

PRINCIPE OF INACCURACY MODEL CONSTRUCTION OF OBSERVATIONS OF SATELLITES:

1. During SLR, at the beginning of every second data of angle sensors are saved in separate file (1);
2. After SLR observation, to do processing SLR files and create the file of time moments when was return signal, so when telescope were really pointed at satellite (file (2)).

3. Based on the searching ephemeris data (3) is calculated positions of satellite. Interpolated data of file (1) and (3) at the moments of reflected signal receiving (2), we can find the difference O-C.

But these O-C will have the ephemeris inaccuracy. Therefore ephemeris inaccuracies we can compensate by simple shift of “ephemeris” time, so that by ephemeris Time Bias, that is why this displacement we can include as unknown parameter for each appearance of satellite during model parameters determination. If we use precise ephemeris, so in this case we don’t need to determine ephemeris Time Bias.

From the general considerations it is possible to make quality comparison of methods of telescope inaccuracy model construction of stars and satellites observations:

Model, constructed by stars observations data

Advantages:

- High accuracy of stars observation (outgoing information) (1-2 arcsec);
- Model is reduced to PMT sensitivity center.

Disadvantages:

- time loss for stars observations;
- small quantity of points on the sky (about 100 for the night);
- it is needed previous preparing for observations.

Model, constructed by SLR observations

Advantages:

- no time loss for observations;
- big quantity of points on the sky;
- possibility of model operative control and it’s correction
- independence of photoreceiver type;
- there is no need in additional devices and additional preparing for observations.

Disadvantages:

- not high accuracy of telescope position individual measurement
- model is reduced to the center of laser ray, not to the photoreceiver sensitivity center.

These disadvantages we can consider not important, because of:

- model accuracy we can improve statistically, because quantity of observations points is too big and increases constantly;
besides, coming out of set target (model must be not worse then a half of laser ray width) this disadvantage in general we can not take into account, because this condition is done automatically.
- Lead to the photoreceiver sensitivity center to the laser ray center is done by system adjustment.

Software and devices for task solving

Control of telescope is done with 486DX100 computer under operating system DOS. Given computer has 24Mb of RAM. As you know, DOS uses only 640 Kb of RAM. Rest of RAM is used for electronic disc, on which data during observations are saved. This is done to decrease time loss for information recording. Because access time to RAM is much less then to hard disk and telescope control requires continuous control of system, that is why we need to take as possible as less processor time of computer for other tasks. After SLR observation session the file (1) is automatically copied to hard disk.

For model parameters calculating is used program of method of the least squares for NDP FORTRAN compiler.

RESULTS

There were used results of 40 observation sessions, general quantity is about 14 000 points. As the first step, we taken model parameters of the formula [1] and were determined coefficients of it's parameters. All model parameters (for height and azimuth) were determined at the same time, because part of them physically presents in both components (for example slope of vertical axle).

Laser beam width during observation was in limits 20 arcsec. This parameter is controlled and can be changed by simple moving of intermediate lens during system addjustment.

Figure 1 shows covering of sky by points, in which were made measurement. On the figures 2 and 3 are presented outgoing data O-C. It is easy to see, that some satellites positions are not "entered" in the general picture. These are cases of not accurate ephemeris (Time Bias ephemeris).

Fig. 1. Sky Covering

Fig. 2. Dependence of azimuth differences O-C on azimuth

Fig. 3. Dependence of height differences O-C on height

Figures 4 and 5 presents final distribution of residual O-C after model computing, that is made according satellites observations. And on 6 and 7 figures their distribution.

Azimuth, degrees
Fig. 4. Azimuth residual

Height, degrees
Fig. 5. Height remainders

Fig. 6. Azimuth residual distribution

Fig. 7. Height residual distribution

Having numerous enough numbers of observations, it was done investigation on “stability” of model parameters. Part of parameters of model [1], includes merely mathematical parameters, that don’t have physical basis, but they are mathematical results, as for example, frequency of Nikewist in spectral analysis. Taking different combinations of outgoing files and their different quantity, were determined stable parameters. So such parameters, which don’t change their value or sign. And how it was found, unstable parameters don’t influence on the final model accuracy.

The parametrical dependences are presented in table 1, they accepted in the new model and also their coefficients according satellites observations.

Table 1a. Model parameters and coefficients (part one)

№	Coefficient	In azimuth model*	In height model*	Coefficients according satellites going	
				Amplitude, arcsec	Inaccuracy, $\pm$ arcsec
1.	1.	+	–	400606.81	3.03
2.	$1/\cos(h)$	+	–	-303.56	4.11
3.	$\tan(h)$	+	–	39.67	3.13
4.	$\sin(2\pi \cdot A/360)$	+	–	-94.08	0.95
5.	$\cos(2\pi \cdot A/360)$	+	–	-260.06	2.88
6.	$\sin(2\pi \cdot A/290)$	+	–	-81.81	1.77
7.	$\cos(2\pi \cdot A/290)$	+	–	-56.55	1.98
8.	$\sin(2\pi \cdot A/170)$	+	–	38.44	0.62
9.	$\cos(2\pi \cdot A/170)$	+	–	-28.14	0.61
10.	$\sin(2\pi \cdot A/105)$	+	–	0.00	0.00
11.	$\cos(2\pi \cdot A/105)$	+	–	0.00	0.00
12.	$\sin(A-h)$	+	+	-109.52	0.73
13.	$\cos(A-h)$	+	+	4.99	0.68
14.	$\cos(2\pi \cdot A/312) \cdot \sin(A)$	$\cdot \tan(h)$	+	-65.11	0.89
15.	$\sin(2\pi \cdot A/312) \cdot \cos(A)$	$\cdot \tan(h)$	+	132.47	0.82
16.	$\cos(2\pi \cdot A/209) \cdot \sin(A)$	$\cdot \tan(h)$	+	0.00	0.00
17.	$\sin(2\pi \cdot A/209) \cdot \cos(A)$	$\cdot \tan(h)$	+	19.43	0.55
18.	$\cos(2\pi \cdot A/121) \cdot \sin(A)$	$\cdot \tan(h)$	+	7.15	0.48
19.	$\sin(2\pi \cdot A/121) \cdot \cos(A)$	$\cdot \tan(h)$	+	-8.27	0.50
20.	$\cos(2\pi \cdot A/105) \cdot \sin(A)$	$\cdot \tan(h)$	+	12.86	0.41
21.	$\sin(2\pi \cdot A/105) \cdot \cos(A)$	$\cdot \tan(h)$	+	0.00	0.00
22.	$\cos(2\pi \cdot A/85) \cdot \sin(A)$	$\cdot \tan(h)$	+	-13.59	0.27
23.	$\sin(2\pi \cdot A/85) \cdot \cos(A)$	$\cdot \tan(h)$	+	0.00	0.00
24.	$\cos(2\pi \cdot A/71) \cdot \sin(A)$	$\cdot \tan(h)$	+	4.07	0.35
25.	$\sin(2\pi \cdot A/71) \cdot \cos(A)$	$\cdot \tan(h)$	+	7.37	0.44
26.	$\cos(2\pi \cdot A/65) \cdot \sin(A)$	$\cdot \tan(h)$	+	3.82	0.23

Table 1b. Model parameters and coefficients (part two)

№	Coefficient	In azimuth model*	In height model*	Coefficients according satellites going	
				Amplitude, arcsec	Inaccuracy, $\pm$ arcsec
27.	$\sin(2\pi \cdot A / 65) \cdot \cos(A)$	$\cdot \tan(h)$	+	5.47	0.33
28.	$\cos(2\pi \cdot A / 50) \cdot \sin(A)$	$\cdot \tan(h)$	+	6.92	0.30
29.	$\sin(2\pi \cdot A / 50) \cdot \cos(A)$	$\cdot \tan(h)$	+	6.11	0.31
30.	$\cos(2\pi \cdot A / 45) \cdot \sin(A)$	$\cdot \tan(h)$	+	9.35	0.22
31.	$\sin(2\pi \cdot A / 45) \cdot \cos(A)$	$\cdot \tan(h)$	+	10.30	0.30
32.	$\cos(2\pi \cdot A / 40) \cdot \sin(A)$	$\cdot \tan(h)$	+	0.00	0.00
33.	$\sin(2\pi \cdot A / 40) \cdot \cos(A)$	$\cdot \tan(h)$	+	-6.97	0.29
34.	$\cos(2\pi \cdot A / 35) \cdot \sin(A)$	$\cdot \tan(h)$	+	0.00	0.00
35.	$\sin(2\pi \cdot A / 35) \cdot \cos(A)$	$\cdot \tan(h)$	+	-4.26	0.25
36.	$\cos(2\pi \cdot A / 31) \cdot \sin(A)$	$\cdot \tan(h)$	+	4.91	0.18
37.	$\sin(2\pi \cdot A / 31) \cdot \cos(A)$	$\cdot \tan(h)$	+	0.00	0.00
38.	$\cos(2\pi \cdot A / 29) \cdot \sin(A)$	$\cdot \tan(h)$	+	0.00	0.00
39.	$\sin(2\pi \cdot A / 29) \cdot \cos(A)$	$\cdot \tan(h)$	+	0.00	0.00
40.	$\cos(2\pi \cdot A / 25) \cdot \sin(A)$	$\cdot \tan(h)$	+	0.00	0.00
41.	$\sin(2\pi \cdot A / 25) \cdot \cos(A)$	$\cdot \tan(h)$	+	5.86	0.22
42.	$\sin(A)$	$\cdot \tan(h)$	+	-104.44	0.47
43.	$\cos(A)$	$\cdot \tan(h)$	+	60.04	0.77
44.	1.	—	+	23640.42	3.32
45.	h	—	+	-427.93	2.55
46.	$1 / \tan(h)$	—	+	56.36	1.05

- + means, that given coefficient presents in model, and “-“ – absent.

Not taking into account, that received results were based only on the part of observations, which were taken place only during five nights (40 goings of satellites), it is possible to make such conclusions.

CONCLUSIONS

1. It is offered the new way for determination of telescope inaccuracy model, that satisfies set task.
2. Satellites observations with use of telescope model that was got by the new method confirmed relevancy of this method. Accuracy of pointing at object is really in limits 15 arcsec.
3. The model, constructing on stars observation [1], is reduce to the sensitivity center of photoreceiver. But the model, constructing on satellites observation, is reduced to the center of laser ray, not to the photoreceiver sensitivity center.
4. In 2003 –2004 we used a high precision model. The number of successful ranging satellite passes were more then 1000, a big part of satellite passes was invisible.

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