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An accuracy estimation of the World CCD asteroid observations in the years 1999–2005

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Abstract

The MPC database of the asteroid observations (each position from near 20 millions) was used in analysis of observational accuracy for more than 300 active world observatories both professional and amateur. The values of the "Mean error of a single observation" σ (for α, δ) were derived based on the Pulkovo method of accuracy estimation. These values may be used for observatory weight assignment in the orbital improvement procedures. The accuracy of the best amateur observations is proved to be comparable with professional one ($\sigma = \pm 0''.20$). The detailed results in electronic format are accessible from the first author.

Keywords: Astrometric CCD observations; Asteroids

1. Introduction

Usually an accuracy of positional asteroid and comet observations carried out with various telescopes in the world during different observational campaigns is obtained as a result of orbital improvement for these celestial bodies. The residuals of (O − C), i.e, *observational* minus *calculational* positions for each observatory and each asteroid are published in the Minor Planet circulars together with new system of elements. General accuracy estimations that describe numerically the observations of any observatory, both professional and amateur, are absent in MPC practice. Some advanced amateurs (the number of amateur observatories is strongly increasing now from month to month) want to know a quality of their asteroid observations every night and to compare their own accuracy parameters with the other ones. We are sure that a testing of obtained observations, their accuracy estimation and identification of observed celestial objects must be carried out by observer himself immediately at the place of observation.

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2. MPC database

The Minor Planet Center supported by the International Astronomical Union is the main office for keeping observational data of the solar system minor bodies and their investigations. The MPC circulars that contain the CCD observations obtained by amateurs and professional astronomers all over the world were available due to the courtesy of the Institute of Applied Astronomy, St.-Petersburg (Bykov et al., 2002). We investigated an accuracy of these observations. Our experience of extensive processing of the MPC data allows to conclude that CCD observations of the numbered and unnumbered asteroids have the errors, sometimes very significant. We can also note the systematic errors in presented positions that are usually connected with CCD matrix work in the fixed nights of observations.

Positions of the numbered minor planets (NMP) which have been sent by observers to the Minor Planet Center in the years 1999–2005 were automatically analyzed by means of calculation of (O − C) values with the help of the EPOS software package created at Pulkovo Observatory (L'vov et al., 2001). More than 20 millions individual positions obtained by professional and amateur observatories were taken into consideration.

3. Method of accuracy estimation

For reliable estimation of an accuracy of CCD observations obtained by given observatory we usually consider 10 and more various NMP observed during several months per year (more then 50 positions). It was postulated that the errors of the theory of motion of any numbered asteroid are smaller than the errors of their CCD observations. Therefore, the range of these (O – C) values may be a good characteristic of observational accuracy. The real values of (O – C) may be different but we study just the range of these values during several close nights by computation of the *mean error of a single observation* σ. This value is placed at the last row of the table below the mean of (O – C) values and its mean error. The other notations in the following tables are as follows: Mgn—the visual magnitude, Z—the zenith distance at the moment of observation. We use the EPOS software package for exact asteroid ephemeris calculations based on the latest catalogs of elements (usually ASTORB or MPCORB data) and full account for perturbation.

It is important that one night of observations ought to have three or more positions of the NMP for calculation of the *internal* accuracy, and we use several close nights of observations of the same NMP for deriving the *external* accuracy (the corresponding symbols "int" and "ext" in the Tables 4 and 5). The examples of observational data and processing are given in Tables 1–3. Table 1 corresponds to very good professional positional CCD observations made by Tom Gehrels' group in Arizona University. Table 2 includes very large (O – C) deviations for α and δ during one night. Only observations are responsible for these changes. It is necessary in this situation to test the data by observer himself before sending them to the Minor Planet Center.

As an example there are CCD observations of the same asteroid made by two Spacewatch Telescopes during one night presented in Table 3. These telescopes are situated near to each other. The mean values of (O – C)s for each coordinate are practically the same. Usually the Spacewatch Telescopes give good and similar results for the same asteroid.

Table 1
CCD observations of NMP 82499 made by Spacewatch Telescope with normal values of the mean errors of a single observation σ

Date 2006 08	α 22^h14^m	(O – C)	δ $-4°28'$	(O – C)	Mgn	$Z°$
29.20449	$32^s.403$	$-0''.17$	$28''.62$	$0''.26$	17.6	48
29.22185	$31^s.649$	$-0''.15$	$35''.40$	$0''.20$	17.5	45
29.23927	$30^s.897$	$-0''.06$	$42''.08$	$0''.27$	17.5	41
Normal place						
29.22187	$31^s.650$	$-0''.13$	$35''.37$	$0''.24$		
Its error:		$\pm0''.03$		$\pm0''.02$		
σ		$0''.06$		$0''.04$		

Table 2
CCD observations of NMP 78728 made by LONEOS (code 699) with large values of the mean errors of a single observation σ

Date 2006 08	α 23^h13^m	(O – C)	δ $+7°04'$	(O – C)	Mgn	$Z°$
27.43577	$25^s.900$	$-0''.40$	$44''.78$	$0''.55$	19.0	40
27.44487	$25^s.561$	$1''.38$	$42''.39$	$-1''.25$		42
27.45397	$25^s.021$	$0''.19$	$43''.31$	$0''.24$		45
27.46310	$24^s.311$	$-3''.52$	$44''.22$	$1''.74$		47
Normal place						
27.44943	$25^s.199$	$-0''.59$	$43''.68$	$0''.32$		
Its error:		$\pm1''.04$		$\pm0''.62$		
σ		$2''.09$		$1''.23$		

Table 3
One night CCD observations of NMP 69262 made by two Spacewatch Telescopes (codes 691 and 291)

Code 691						
Date 2006 08	α 22^h54^m	(O – C)	δ $-3°25'$	(O – C)	Mgn	$Z°$
19.33121	$36^s.464$	$-0''.27$	$00''.40$	$0''.18$	17.0	36
19.34852	$35^s.635$	$-0''.24$	$00''.29$	$0''.17$	17.3	35
19.36586	$34^s.806$	$-0''.17$	$00''.19$	$0''.16$	17.3	35
Normal place						
19.34853	$35^s.635$	$-0''.23$	$00''.30$	$0''.17$		
Its error:		$\pm0''.03$		$\pm0''.01$		
σ		$0''.05$		$0''.01$		
Code 291						
Date 2006 08	α 22^h54^m	(O – C)	δ $-3°24'$	(O – C)	Mgn	$Z°$
19.41532	$32^s.416$	$-0''.35$	$59''.93$	$0''.12$		40
19.41901	$32^s.249$	$-0''.20$	$59''.93$	$0''.09$		41
19.42277	$32^s.061$	$-0''.31$	$59''.94$	$0''.07$		42
Normal place						
19.41904	$32^s.242$	$-0''.29$	$59''.93$	$0''.09$		
Its error:		$\pm0''.04$		$\pm0''.02$		
σ		$0''.08$		$0''.03$		

So we see that the (O – C) values may be very different for various objects but their mean error shows a reliability of the system "atmosphere + telescope+ CCDcamera + catalogue +method of astrometric reduction" altogether atmean observational conditions. They are an indicator of accuracy of the CCD positional observations for a given observatory.

4. Results

We are analyzing the sets of such *mean error of a single observation* σ derived from all NMP observed at selected observatory during specified observational period. Then we calculate an average value for each set of these data. It may be considered as an accuracy of the

Table 4
The best results of CCD asteroid observations from MPC database for some professional observatories

MPC Observatory		Year	Total asteroids	Total positions	σ_α	σ_δ	Type
Code	Telescope						
Professionals							
673	USA, table	2004	135	1344	0″.07	0″.06	int
	Mountain,		127	1703	0.07	0.06	ext
	$D = 0.61$ m,	2005	125	559	0.08	0.04	int
	FL = 9.0 m,		152	1015	0.06	0.05	ext
	FOV = 22 × 22′,						
	Scale = 0″.3						
691	USA,	1999	1114	5823	0.23	0.26	int
	Kitt Peak,		458	3408	0.40	0.34	ext
	Spacewatch,	2000	1898	10540	0.20	0.21	int
	$D = 0.88$ m,		635	5261	0.34	0.31	ext
	FL = 4.6 m,	2001	4697	19194	0.22	0.20	int
	FOV =		787	5389	0.38	0.34	ext
	390 × 30′,	2002	3856	14934	0.21	0.22	int
	Scale = 1″.1		680	4440	0.33	0.38	ext
		2003	20954	101722	0.20	0.18	int
			7553	50350	0.33	0.38	ext
		2004	28212	154523	0.18	0.17	int
			12397	93942	0.25	0.23	ext
		2005	35133	219848	0.23	0.23	int
			18707	154816	0.26	0.26	ext
644	USA,	2001	11187	103709	0.19	0.19	int
	Palomar		6397	73522	0.45	0.50	ext
	Mountain/	2002	36079	309180	0.20	0.20	int
	NEAT,		24683	239812	0.30	0.37	ext
	$D = 1.2$ m,	2003	33113	190096	0.18	0.18	int
	No data		12776	100669	0.23	0.29	ext
		2004	35558	183967	0.18	0.16	int
			10630	77005	0.23	0.19	ext
		2005	39172	260419	0.16	0.15	int
			15508	134088	0.18	0.16	ext
422	Australia,	1999	20	144	0.16	0.15	int
	Loomberah.		6	98	0.19	0.20	ext
	$D = 0.45$ m,	2000	11	52	0.05	0.07	int
	FL = 2.4 m,		4	24	0.05	0.12	ext
	FOV = 17 × 17′,	2001	17	135	0.12	0.10	int
	Scale = 2″.		4	68	0.12	0.11	ext
		2002	25	219	0.12	0.10	int
		2003	7	89	0.09	0.07	int

investigated CCD observations. Of course we must have a lot of NMP observations for each observatory under consideration. As an advise for observers we would like to underline: if it is possible try to observe three positions per night and do not neglect to observe the Numbered Minor Planets in your telescope field of view as a "by product" of current observational programs. They are a good test for every-night estimation of your accuracy. We think such estimations ought to be produced every morning after CCD observations of the moving celestial objects by observer himself. Our analysis can find these errors too late. Obviously, it is desirable to test each asteroid's position before sending results to the MPC.

Tables 4,5 present an accuracy estimation for some professional and amateur telescopes carrying out the programs of observations of potentially hazardous asteroids.

Finally, a difference between "int" and "ext" estimations may be explained by the influence of the reference star positions used for astrometric reduction. Usually one night asteroid images are processing with the same stars but several nights images demand other catalog's stars from night to night. We also noted that our accuracy parameters for the fast moving celestial bodies, such as NEO, are two times worse as compared to the usual objects.

More detailed results can be found via Internet (www.accuracy.puldb.ru).

Table 5
The best results of CCD asteroid observations from MPC database for some amateur observatories

MPC Observatory		Year	Total asteroids	Total positions	σ_α	σ_δ	Type
Code	Telescope						
Amateurs							
621	Germany,	1999	17	125	0″.21	0″.15	int
	Bergisch		17	134	0.22	0.21	ext
	Gladbach,	2000	22	152	0.14	0.12	int
	$D = 0.6$ m,		19	156	0.22	0.15	ext
	FL = 3.1 m,	2001	73	480	0.24	0.20	int
	FOV = $11 \times 10'$,		55	455	0.28	0.21	ext
	Scale = 1″.2	2002	102	649	0.30	0.22	int
			61	493	0.30	0.22	ext
		2003	241	1416	0.36	0.41	int
			101	872	0.37	0.33	ext
		2004	183	897	0.32	0.29	int
			83	593	0.31	0.31	ext
		2005	262	1106	0.32	0.28	int
			83	556	0.33	0.28	ext
127	Germany,	1999	8	36	0.14	0.08	int
	Bornheim,		12	61	0.37	0.48	ext
	$D = 0.19$ m,	2000	7	38	0.08	0.15	int
	FL = 0.8 m,		6	34	0.37	0.41	ext
	FOV = $30 \times 20'$	2001	19	106	0.16	0.15	int
	Scale = 2″.4		21	147	0.40	0.35	ext
		2002	32	186	0.12	0.12	int
			34	230	0.50	0.39	ext
		2003	55	447	0.12	0.14	int
			45	424	0.35	0.36	ext
		2004	29	204	0.12	0.12	int
			15	150	0.21	0.21	ext
		2005	31	285	0.13	0.12	int
			26	262	0.26	0.19	ext
A34	Grossha-bersdorf,	2003	35	153	0.23	0.15	int
	Germany	2004	95	494	0.22	0.24	int
	$D = 0.2$ m,		7	64	0.18	0.14	ext
	FL = 2.0 m,	2005	111	594	0.17	0.16	int
	FOV = $20 \times 15'$		4	43	0.15	0.15	ext
	Scale = 1″.4						

5. Conclusions

As we can see the accuracy of modern CCD asteroid observations is rather high. The best amateur astronomers work like the professionals. They could participate at the scientific observational campaigns to the benefit of Celestial Mechanics and Astrometry. We hope that the Pulkovo software package EPOS (http://neopage.nm.ru) will be useful for this work.

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