SOLAR EPHEMERIS ACCORDING TO SIMON NEWCOMB

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Abstract

The development of Falak cannot be separated from the ephemeris table, one of them i.e Simon Newcomb solar ephemeris. This ephemeris was used in the initial calculation of Abdur Rachim, one of Falak Indonesia's experts. The purpose of this study was to determine the accuracy of the Simon Newcomb ephemeris reckoning algorithm and its strengths and weaknesses. This paper use descriptive analysis as the research methodology. The results of this study are this Ephemeris is quite accurate because because there aremany correction terms and consider aspects of the planet's relative motion to the Earth that can be seen in the formula for perturbation and nutation correction. The advantage of this ephemeris,it has a long period correction which is useful for calculating the Sun ephemeris in years far enough from the epoch used and directly uses UT time in its calculations so there is no need to convert UT to TD. The weakness of this ephemeris is that it cannot be done manually because the formula used is too long and there are many formula corrections.
Keywords: Algorithm, Solar Ephemeris, Simon Newcomb.

Abstrak

Perkembangan ilmu Falak tidak dapat dilepaskan dari tabel *ephemeris*salah satunya adalah *ephemeris* Matahari Simon Newcomb. *Ephemeris* ini pernah dipakai dalam perhitungan awal bulan Abdur Rachim salah satu ahli Falak Indonesia. Tujuan penelitian ini untuk mengetahui akurasi algoritme hisab *ephemeris* Matahari Simon Newcomb serta kelebihan dan kelemahannya. Metode yang penulis gunakan adalah analisis deskriptif. Hasil penelitian ini adalah *Ephemeris* ini tergolong cukup akurat karena jumlah suku koreksi yang banyak dan mempertimbangkan aspek gerak relatif planet terhadap Bumi yang dapat dilihat pada rumus koreksi perturbasi dan nutasi.Kelebihan ephemris ini memiliki koreksi *long period* yang berguna untuk menghitung *ephemeris* Matahari pada tahun-tahun yang cukup jauh dari *epoch* yang digunakan serta langsung menggunakan waktu UT dalam perhitungannya sehingga

tidak perlu melakukan konversi UT ke TD. Kekurangan dari *ephemeris* ini adalah tidak bisa dilakukan perhitungan secara manual karena rumus yang digunakan terlalu panjang dan banyak terdapat koreksi rumus.
Kata Kunci: *Algoritme*, *Ephemeris Matahari, Simon Newcomb.*

A. Introduction

The development of Falak cannot be separated from the ephemeris table which is a collection of calculations of the movement of celestial bodies based on long-lasting observations.[1] The ephemeris made by Islamic Astronomer in 9th century present data on position of the sun, moon and 5 palnets visible to the naked eyes for a certain times. This tbale is called a list of al-sana or taqwim, the ephemeris is calculated for a certain longitudes.[2] The ephemeris in this19th century, one of them is the Solar Ephemeris by Simon Newcomb. This Ephemeris became the basis for the ephemeris used today, namely VSOP87. The Newcomb Solar Ephemeris is used by Indonesian Astronomer Abdur Rachim in the calculation of new month according to the newcomb system.[3] The Ministry of Religion of The Republic of Indonesia also issues the solar and lunar ephemeris every year.[4] Therefore, the author is interested in discussing about the calculation of algorithm used by Simon Newcomb in this Solar Ephemeris.

B. Methode

The method used in this research was library research, which is conducted by reviewing library materials which is the object of the author's research is the book of *Astronomical Papers Prepares for the Use of the American Ephemeris and Nautical Almanac* by Simon Newcomb.[5] In this study, the author uses the type of qualitative research because the research conducted without interference of the author.[6]

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[1] M. Ihtirozun Ni'am, *Al-Murobba': Inovasi Alat Falak Multifungsi* (Semarang: Mutiara Aksara, 2020), iv.

[2] David A King, *Astronomy in the Service of Islam,* (Vermont: Variorum, 1993), page. 235.

[3] Abdur Rochim, *Perhitungan Awal Bulan,* (Yogyakarta: Koleksi Jogja Astronomi Club), page. 4.

[4] Kementerian Agama RI, *Ephemeris Hisab Rukyat 2020,* (Jakarta: Kementerian Agama RI, 2020), page. iii.

[5] Simon Newcomb, *Astronomical Papers Prepares for the Use of the American Ephemeris and Nautical Almanac,* Cet. Ke-2, (Wasington: Navy Department, 1898).

[6] Sugiyono, Metode Penelitian, (Pendekatan Kuantitatif,Kualitatif, dan R&D), (Bandung : Alfabeta, cet. Ke 10, 2010), page. 14-15.

The research data that has been collected, then the author analyze that using descriptive analysis method[7] by describing the data systematically and it's possible to draw conclusions. In this case the author describes in general the algorithm of the solar ephemeris by Simon Newcomb to find out the advantages and disadvantages.

C. Discuss and Result

C.1. The Biography of Simon Newcomb

Simon Newcomb was born 12 March 1835 and died 11 July 1909. He is a Canadia-American Astronomer who specialisazing in Applied Mathematics and self-taught learning polymath. He is a mathematics professor in the United States Navy and John Hopkins University.[8]

He was born in Nova Scotia, Canada. His parent is named Emily Prince who son of a judge in New Brunswick. Newcomb taught Mathematics and Physics privately before becoming programmer at Nautical Almanac Office in Cambridge, Massachusees in 1857, in 1857 he graduated as a Bachelor of Science (BSc) at Harvard University.

Newcomb worked in measuring the positions of planets in assisting navigation before he became very interested about theory of planetary motion, he was offered the position of directure at Harvard College Observatory in 1875, but he rejected it because he was more interested in mathematics than observation.

In 1877, he became directure of the Nautical Almanac Office assisted by George William Hill. He insisted that all ephemeris must be based on the calculations he made in his book " Tables of Sun."[9]

His works other than tables of sun are:

- Newcomb, S (1878) Research on the Motion of the Moon, Part I
- Newcomb, S (1879) Astronomy for schools and colleges

[7] Saifuddin Azwar, *Metode Penelitian*Cet. ke-1,(Yogyakarta: Pustaka Pelajar, 1998),page. 91

[8] John Maynard Keynes, *A Treatise on Money,* Vol. 1, (1930), page. 233.

[9] http://www-groups.dcs.st-and.ac.uk/~history/Biographies/Newcomb.html accesed 4 April 2018 at 13.00 WIB.

- Newcomb, S (1890) Elements of Astronomy
- Newcomb, S (1900) His Wisdom the Defender—Science Fiction novel.
- Newcomb, S (1901) The Stars etc

The writings on astronomu, physics an mathematics written between 1882 and 1912 are mentioned in *Astronomical Papers Prepared For The Use Of The American Ephemeris And Nautical Almanac*, U.S. Naval Observatory, The Nautical Almanac Office. In addition, to commemorate his services in astronomy, his nam was immortalized as the name of asteroid 855 Newcombia.

C.2. Algorithm of Newcomb's Solar Ephemeris

There are steps to create the solar ephemeris using data from Newcomb:

a. Specifies the century number (T), calculated from January 0, 1900 hours UT
T = (JD – 2415020[10])/36525

JD = 17020994.5 + INT(365.25*year[11]) + INT(30.6001* (month[12]+1))+ Date + the number of JD[13] + (hours+Minutes/60+second/3600)/24
JD = Julian Days.

b. Calculating the mean Solar Geometric Longitude (L):[14]
$L = 279°41'48.04'' + 129602768.13''T + 1.089T^2$

c. Calculating the mean Sidereal Motion of the Sun (n):[15]
$n = 1295977.4320'' – 0.000403''T$

d. Calculating the Longitude of the Sun's Perigee (Point Closest to Earth) (π) with aberration correction:[16]
$\pi = 281° 13'15'' + 6189.03'' T + 1.63''T^2 + 0.012'' T^3$

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[10] This number is the number of Julian Date on 0 January 1900 at 12 UT

[11] If the month number is less then 3, then the year number is reduced by 1, after that the year number is fixed.

[12] If the month number is less then 3, then the month number plus 12, after that is fixed

[13] Number of JD was formulated:number= 2-the number of century + INT(number of century/4)

[14] Simon Newcomb, *Astronomical,...* page. 9.

[15] Simon Newcomb, *Astronomical,...* page. 9.

[16] Simon Newcomb, *Astronomical,...* page. 9.

e. Calculating the Asensiorect of the Mean Pseudo Motion of the Sun (r) including the aberration correction:[17]

r = 18h 38m 45.836s + 8640184.542s + 0.0929sT^3

f. Calculating the Average Earth Anomaly Longitude (g):[18]

g = 358° 28' 33"+ 129596579.10" T – 0.54 "T^2 – 0.012" T^3

g. Calculating the Eccentricity of Earth's orbit (e):[19]

e = 0.01675104 – 0.00004180T – 0.000000126T^2

h. Calculating the Ecliptic Tilt (equal to the tilt of the Earth's axis) (ε):[20]

ε = 23° 27' 8.26"

ε = 23° 27' 8.26" – 46.845"T – 0.0059T2 + 0.00181T3

i. Calculating ta'dil asy-Shams (Equation of Center) (C):[21]

Sin g x 6910.057" – 17.240"T – 0.052"T^2 + sin 2g x 72.338 – 0.361T + sin 3g x 1.054 – 0.001T+ sin 4g x 0.018

j. Calculating the Radius Vector Logarithm (a):[22]

0.00003057 – 15T + cos g x -0.00727412 + 1814T + 5T^2 + cos 2g x -0.00009138 + 46T + cos 3g x -0.00000145 + 1T + cos 4g x -0.00000002

Note that each coefficient of T and T^2 is divided by 10^8

k. Calculating the Perturbation Correction for Longitude (Δλ) and the Logarithm of the Radius Vector (Δ log r), the general formula is:[23]

S cos (K – jg' – ig)

The "g" is the longitude of the planetary anomaly, while g is the longitude of the solar anomaly.

The following is a table of Anomaly Longitudes for each planet:

Planet	General values of g_1	Values for	Motions in anomalistic years	Unit of Arg.	Period and designation

[17] Simon Newcomb, *Astronomical,...* page. 9.
[18] Simon Newcomb, *Astronomical,...* page. 9.
[19] Simon Newcomb, *Astronomical,...* page. 9.
[20] Simon Newcomb, *Astronomical,...* page. 10.
[21] Simon Newcomb, *Astronomical,...* page. 10.
[22] Simon Newcomb, *Astronomical,...* page. 10.
[23] Simon Newcomb, *Astronomical,...* page. 13.

		1900.0	In degree	In units of Arg.		of Argument
Mecury	248.07° + 1494.7235° t'	102.2°	1494.7630°	99.6509	15°	24 I
Venus	114,50° + 585.17493 t'	212.45°	585.1904°	292.5952	2°	180 II
Mars	109.856° + 191.39977 t'	319.58°	191.4048°	95.7024	2°	180 III
Jupiter	148.031 + 30.34583 t'	225.28°	30.3466°	15.1733	2°	180 IV
Saturn	284.716 + 12.21794 t'	175.6°	12.2183°	2.0364	6°	60 V

Table C1. Longitude Anomaly for Each Planet[24]

For the second column it is calculated from the epoch of January 1, 1850 at 12 UT and t' is the Julian year number. For the third column it is calculated from 0 January 1900 at 12 UT. The fourth and fifth columns are the coefficients in the anomalistic year. In the calculations that the author uses, the coefficients are used. T 'in the second column and a constant in the third column.

Following are the perturbation correction tables for each planet. For the logarithm of the radius vector the coefficient s must be divided by 10^9

Longitude						Log. Radius Vector			
j	i	Vc	vs	s	K	Pc	ps	s	K
-1	+1	-0.006"	-0.011"	0.013"	243°	+26	-12	28	335°
	2	-0.003	-0.003	0.005	225°	-4	+5	6	130°
	3	0.015	-0.001	0.015	357°	-1	-18	18	267°
	4	0.019	-0.013	0.023	326°	-2	-4	5	239°

Table C2. Correction of Perturbation by Mercury[25]

[24] Simon Newcomb, *Astronomical,...* page. 21.
[25] Simon Newcomb, *Astronomical,...* page. 13.

Longitude						Log. Radius Vector			
j	i	Vc	vs	S	K	pc	Ps	S	K
-1	+0	+0.033"	-0.067"	-0.075"	296.6°	-85	-39	94	205°
	1	2.353	-4.228	4.838	299° 6.1'	-2062	-1146	2359	209°4.8'
	2	-0.065	-0.034	0.074	207.9°	+68	-14	69	348.5°
	3	-0.003	-0.008	0.009	249°	+14	-8	16	330°
-2	+0	-0.003	+0.001	0.003	162°	0	+4	4	90
	1	-0.099	+0.060	0.116	148.9°	+84	+136	160	58.4°
	2	-4.702	+2.903	5.526	148° 18.8'	+3593	+5822	6842	58°19.1'
	3	+1.795	-1.737	2.497	315° 56.6'	-596	-632	869	226.7°
	4	+0.030	-0.033	0.044	311.4°	+40	+33	52	38.8°
-3	+2	-0.013	+0.001	0.013	176°	0	+21	21	90
	3	-0.666	+0.027	0.666	177.71°	+44	+1044	1045	87°34.2'
	4	+1.508	-0.397	1.559	345°15.2'	-381	-1448	6842	255°15'
	5	+0.763	-0.684	1.024	318.15°	+126	+148	869	49.5°
	6	+0.012	-0.012	0.017	315°	+14	+13	52	43°
-4	+3	-0.003	-0.001	0.003	176°	0	+21	21	90
	4	-0.188	-0.093	0.210	177.71°	+44	+1044	1045	87
	5	-0.139	-0.038	0.114	345°15.2'	-381	-1448	1497	255
	6	+0.146	-0.042	0.152	318.15°	+126	+148	194	49
	7	+0.005	-0.004	0.006	315	+14	+13	19	43

-5	+5	-0.047	-0.069	0.084	235.6°	-134	+93	163	145.4°
	6	-0.028	-0.025	0.037	221.8°	-39	+43	59	132.2°
	7	-0.119	-0.033	0.123	195.3°	-37	+136	141	105.2°
	8	+0.154	-0.001	0.154	359.6°	0	-26	26	270°
-6	+6	-0.047	-0.038	0.038	264.1°	-80	+8	80	174.3°
	7	-0.028	-0.013	0.014	253°	-24	+7	25	164°
	8	-0.119	-0.007	0.010	230°	-10	+10	14	135°
	9	+0.154	-0.003	0.014	12°	+3	-12	12	284°
-7	+7	+0.008	-0.018	0.020	294°	-38	-17	42	203.5°
	8	+0.001	-0.006	0.006	279°	-12	-3	12	194°
	9	+0.001	-0.003	0.003	288°	-4	+1	4	166°
	10					-3	+3	4	135°
-8	+8	+0.009	-0.007	0.011	322°	-14	-19	24	234°
	9					-5	-4	6	218°
	12	-0.008	-0.041	0.042	259.2°	-43	+8	44	169.7°
	13					-9	-8	12	222°
	14	+0.021	+0.024	0.032	48.8°	-25	+22	33	138.7°
-9	+9	+0.006	-0.001	0.006	351°	-2	-13	13	261°
	10					-1	-4	4	256°
-10	+10	+0.003	+0.001	0.003	18	+3	-7	8	293°

Table C3. Correction of Perturbation by Venus[26]

Longitude						Log. Radius Vector			
j	i	Vc	vs	S	K	pc	ps	S	K
+1	-2	-0.005"	-0.004"	0.006"	218°	-5	+6	8	130°
	-1	-0.216	-0.167	0.273	217.7	-92	+119	150	127.7°
	0	-0.008	-0.047	0.048	260.3	+27	-6	28	347°
+2	-3	-0.040	-0.010	0.041	346°	-13	-50	52	255.4°
	-2	+1.963	-0.567	2.043	343° 53.3'	-573	-1976	2057	253°49.7'
	-1	+1.659	-0.617	1.770	200° 24.1'	+64	-137	151	295°
	0	-0.024	+0.015	0.028	148°	-18	-25	31	234.3°
+3	-4	+0.001	-0.004	0.004	284°	-6	0	6	180°
	-3	+0.053	-0.118	0.129	294.2°	-154	-67	168	203.5°
	-2	+0.396	-0.153	0.425	338.88°	-77	-201	215	249°
	-1	+0.008	+0.001	0.008	7°	0	+6	6	90°
+4	-4	+0.001	+0.032	0.034	71	+46	-17	49	339.7°
	-3	-0.131	+0.483	0.500	105.18	+461	+125	478	15.17°
	-2	+0.526	-0.256	0.585	334.06	+43	+96	105	65.9°
	-1	+0.007	-0.005	0.009	325	+6	+8	10	53°
+5	-5	-0.007	+0.001	0.007	172°	0	+12	12	90°
	-4	+0.049	+0.069	0.085	54.6°	+87	-62	107	324.6°

[26] Simon Newcomb, *Astronomical,...* page. 14.

	-3	-0.038	+0.200	0.204	100.8°	+87	+17	89	11°
	-2	+0.003	+0.001	0.003	18°	-1	+3	3	108°
+6	-6					-4	-3	5	217°
	-5	-0.020	-0.002	0.020	186°	-3	+30	30	95.7°
	-4	-0.104	-0.113	0.154	227.4°	-102	+94	139	137.3°
	-3	-0.011	+0.100	0.101	96.3°	-27	-4	27	188°
-7	-6	+0.003	-0.005	0.006	301°	-9	-5	10	209°
	-5	-0.049	+0.003	0.049	176.5°	+4	+60	60	86.2°
	-4	-0.078	-0.072	0.106	222.7°	-26	+28	38	132.9°
+8	-7	+0.001	+0.003	0.003	72°	+5	-1	5	349°
	-6	+0.006	-0.008	0.10	307°	-12	-9	15	217°
	-5	+0.051	-0.010	0.052	348.9°	-8	-44	45	259.7°
	-4	-0.017	-0.012	0.021	215.2°	+5	-6	8	310°
+9	-7	+0.002	+0.003	0.004	57°	+5	-3	6	329°
	-6	+0.013	-0.025	0.028	298°	-30	-16	34	208.1°
	-5	+0.060	-0.015	0.062	346°	-4	-17	17	257°
+10	-7	+0.002	+0.005	0.005	68°	+7	-3	8	337°
	-6	-0.007	+0.018	0.019	111°	+14	+6	15	23°
	-5	+0.005	-0.002	0.005	338°				
+11	-7	+0.009	+0.015	0.017	59°	+17	+10	20	330°
	-6	-0.012	+0.042	0.044	105.9°	+8	+3	9	21°

+12	-7	-0.004	-0.005	0.006	232°	-4	+3	5	143°
+13	-8	-0.013	-0.001	0.013	184°	-1	+15	15	94°
	-7	-0.30	-0.033	0.045	227.8°	-4	+3	5	143°
+15	-9	+0.013	-0.016	0.021	309°	-17	-14	22	220°
	-8					-1	-6	6	261°
+17	-10	-0.002	-0.004	0.004	243°	-4	+2	4	153°
	-9	-0.010	+0.024	0.026	113°				

Table C4. Correction of Perturbation by Mars[27]

Longitude						Log. Radius Vector			
j	i	Vc	vs	S	K	pc	ps	S	K
+1	-3	-0.003"	-0.001"	0.003"	198°	-2	+5	5	112°
	-2	-0.155	-0.052	0.163	198.6°	-78	+193	208	112°
	-1	-7.208	+0.059	7.208	179°31.9'	+56	+7067	28	89° 32.7
	0	-0.307	-2.582	2.600	263°1'3	+227	-89	52	338.6°
	+1	+0.008	-0.073	0.073	276.3°	+79	+9	7067	6.5°
+2	-3	+0.011	+0.068	0.069	80.8°	+102	-17	103	350.5°
	-2	+0.136	+2.728	2.731	87° 8.7'	+4021	-203	026	357° 6.5'
	-1	-0.537	+1.518	1.610	109° 29.6'	+1376	+486	459	19° 28'
	0	-0.022	-0.070	0.073	252.6°	-1	-8	8	263°
+3	-4	-0.005	+0.002	0.005	158°	+3	+8	9	69°

[27] Simon Newcomb, *Astronomical,...* page. 15.

	-3	-0.162	+0.027	0.164	170.5°	+43	+278	281	81.2°
	-2	+0.071	+0.551	0.556	82.65°	+796	-104	803	352.56°
	-1	-0.031	+0.208	0.210	98.5°	+172	+26	174	8.6°
+4	-4	-0.003	-0.016	0.016	259°	-29	+5	29	170°
	-3	-0.043	+0.009	0.044	168.2°	+13	+73	74	79.9°
	-2	+0.017	+0.078	0.080	77.7°	+110	-24	113	347.7°
	-1	-0.001	+0.023	0.023	93°	+17	+1	17	3°
+5	-5					-1	-3	3	252°
	-4	-0.001	-0.005	0.005	259°	-10	+2	10	169°
	-3	-0.007	+0.002	0.007	164°	+3	+12	12	76°
	-2	+0.003	-0.009	0.009	71°	+13	-4	14	343°

Table C5. Jupiter's Correction of Perturbation[28]

Longitude						Log. Radius Vector			
j	i	Vc	Vs	S	K	pc	ps	S	K
+1	-2	-0.003"	+0.011"	0.011"	105°	+15	+3	15	11°
	-1	-0.077	+0.412	0.419	100.58°	+422	+79	429	10.6°
	-0	-0.003	-0.320	0.320	269.46°	+8	-1	8	353°
	+1		-0.008	0.008	270°	+8		8	
+2	-3					-3	-1	3	198°

[28] Simon Newcomb, *Astronomical,...* page. 16.

	-2	+0.038	-0.101	-0.101	290.6°	-152	-57	162	200.6°
	-1	+0.045	-0.103	-0.103	293.6°	-103	-44	112	203.1°
	0	+0.002	-0.017	-0.017	277°				
+3	-2	+0.007	-0.020	-0.020	289°	-30	-11	32	200.1°
	-1	+0.006	-0.016	-0.016	291°	-16	-6	17	201°
+4	-2	+0.001	-0.003	-0.003	288°	-4	-1	4	194°

Table C6. Saturn Perturbation Correction[29]

Pertubations produced by Venus					
j	i	β_1	B_2	S	K
+1	+ 0	-0.024”	+0.017”	0.029”	145°
	1	+0.004	-0.003	0.005	323°
	2	-0.006	+0.092	0.092	93.7°
	3	-0.001	-0.007	0.007	262°
-2	+1	-0.023	+0.003	0.023	173°
	2	-0.010	+0.006	0.012	149°
	3	-0.037	+0.056	0.067	123°
	4	-0.005	+0.013	0.014	111°
-2	+2	-0.013	-0.005	0.014	201°

[29] Simon Newcomb, *Astronomical,...* page. 16.

	3	-0.008	-0.001	0.008	187°
	4	-0.185	+0.100	0.210	151.8°
	5	-0.006	+0.003	0.007	153°
	6	+0.002	-0.004	0.004	296°
-4	+3	-0.004	-0.005	0.006	232°
	5	+0.031	+0.001	0.031	1.8°
	6	-0.012		0.012	180°
-5	+6	+0.008	+0.004	0.009	27°
	7	+0.018	0.006	0.019	18°
-6	+5	+0.002	-0.006	0.006	288°
	7	+0.002	+0.003	0.004	57°
	8	+0.002	+0.003	0.004	57°
-8	+12	+0.005	+0.009	0.010	61°
Pertubations produced by Mars					
j	i	β1	B2	S	K
+2	- 2		+0.008”	0.008”	90°
	0	+0.008	-0.002	0.008	346°
+4	-3	-0.007	-0.001	0.007	188°
Pertubations produced by Jupiter					
j	i	β1	B2	S	K
+1	-2	-0.007”		0.007”	180°
	-1	+0.001	-0.017	0.017	273°

	0	-0.016		0.016	180°
	+1	-0.001	-0.023	0.023	268°
+2	-1	-0.013	-0.166	0.166	265.5°
+3	-2	-0.006	+0.001	0.006	171°
	-1	-0.001	-0.018	0.018	267°
Pertubations produced by Saturn					
j	i	β_1	B_2	S	K
+1	-1	-0.001"	-0.006"	0.006"	260°
	+1	+0.001	-0.006	0.006	280°

Table C7. Ecliptic Latitude Perturbation Correction[30]

For the correction of perturbation affected by the Moon with sufficient accuracy, it can be formulated:[31]

$\Delta\lambda=\mu_1\pi/\pi_1 \cos \beta_1 \sin (\lambda_1 - \lambda)$

$\Delta\log r= M\ \mu_1\ \pi/\pi_1 \cos \beta_1 \sin (\lambda_1 - \lambda)$

$\Delta\beta= \mu_1\ \pi/\pi_1 \sin \beta_1$

μ1 is the ratio of the mass of the Moon to Earth, which is formulated:[32]

$\mu_1 = \mu/1+\ \mu$

$\mu = 1 / 81.45$[33]

π1, λ1, β1 are the Horizontal Parallax, Ecliptic Longitude and Moon Ecliptic Latitude, respectively.

[30] Simon Newcomb, *Astronomical,...* page. 17.
[31] Simon Newcomb, *Astronomical,...* page. 17.
[32] Simon Newcomb, *Astronomical,...* page. 17.
[33] Simon Newcomb, *Astronomical,...* page. 17.

Π, λ, β are the Sun's Horizontal Parallax, Ecliptic Longitude and Sun's Ecliptic Latitude, respectively.

the formula for calculating the Horizontal Parallax of the Sun:[34]

$\pi = 8.790''/r$

If the above formula is developed into sine and cosine terms, the formula becomes:[35]

$$\Delta\lambda = 6.454'' \sin D + 0.013 \sin 3D + 0.177 \sin (D+g_1) - 0.424 \sin (D - g_1) + 0.039 \sin (3D - g_1) - 0.064 \sin (D+g) + 0.172 \sin (D - g) - 0.013 \sin (D - g_1 - g)^* - 0.013 \sin 2u'^*$$

$$\Delta \log r = 1336 \cos D + 3\cos 3D + 37 \cos (D+g_1) - 133 \cos (D - g_1) + 8 \cos (3D - g_1) - 14 \cos (D+g) + 36 \cos (D - g) - 3 \cos (D - g_1 - g)^* + 3 \cos 2u'^*$$

$$\Delta\beta = 0.576'' \sin u + 0.0016 \sin (u+g_1) - 0.047 \sin (u - g_1) + 0.021 \sin (u - 2u') + 0.005 \sin (u - 2u' - g_1)^* + 0.005 \sin (u+g)^* + 0.005 \sin (u - g)^*$$

Δ log r in the order 10^{-9}

D, the Moon's Average Elongation from the Sun or the Difference in Average Ecliptic Longitude

g, g_1 respectively, the Average Anomalous Longitude of the Sun and Moon.

u, the Moon's Mean Latitude Argument.

u', the Sun's Average Distance from the Moon's Ascending Vertex, the value of u' is equal to g1 minus **Ω**.[36]

The terms marked (*) are used for high accuracy calculations.

The formula for calculating D is:[37]

$350°.737486 + 1236 * 360° * T + 307°.1142167 * T - 1°.436 * 10\text{-}3 * T^2$

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[34] Simon Newcomb, *Astronomical,...* page. 18.

[35] Simon Newcomb, *Astronomical,...* page. 18

[36] See Wayne H. Wilson, *Solar Ephemeris Algorithm,* (Sandiego: University of California, 1980), page. 3-6. Compare with formula in Simon Newcomb, *Astronomical,...* hlm. 18.

[37] Wayne H. Wilson, *Solar,...*, page. 3-4.

The formula for calculating g_1 is:[38]

$296°.104608 + 1325 * 360° * T + 198°.8491083 * T + 0°.00919167 * T^2 + 1°.4388 * 10\text{-}5 * T^3$

The formula for calculating u is:[39]

$11°.250889 + 1342 * 360° * T + 82°.02515 * T + 0°.003211 * T^2$.

The formula for calculating **Ω** is:[40]

$259°.183275 – 5 * 360° * T – 134°.14200 * T + 2°.0778 * 10\text{-}3 * T^2$

If needed, calculate the Mean Longitude Inequality for the Long Time period in which the first 2 terms are affected by the mass of the planet affecting the Earth:[41]

$\delta L = +(1.882'' – 0.016''T) \sin (57.24° + 150.27°T) + 0.202'' \sin (315.6° + 893.3°T) + 6.40'' \sin (231.19° + 20.20°T) + 0.266'' \sin (31.8° + 119°T) + 1.089''T^2 + 7''$

Calculating Nutation Corrections for Ecliptic Longitude (Δψ) and Ecliptic Tilt(Δε): the Nutation for the Ecliptic Longitude (Δψ) which is influenced by the Moon.[42]

$\Delta\psi = -(17.234'' – 0.017''T) \sin \Omega + 0.209 \sin 2\Omega + 0.067 \sin g_1 + 0.015 \sin (2D – g_1) + 0.006 \sin 2D$

Action of the Moon

$-0.034'' \sin(2☾ - \Omega) + 0.012 \sin (2☾ - g_1) – 0.204 \sin 2☾ - 0.026 \sin (2☾ + g_1) + 0.012 \sin (2L – \Omega)$

Meanwhile, Nutation for Ecliptic Longitude (Δψ) which is influenced by the Sun.[43]

Action of the Sun

$\Delta\psi = +0.021'' \sin (2L – g) – 1.257 \sin 2L – 0.049 \sin (2L + g) + 0.127 \sin g$

[38] Wayne H. Wilson, *Solar*,... page. 3-4.
[39] Wayne H. Wilson, *Solar*,... page. 3-6.
[40] Wayne H. Wilson, *Solar*,... page. 3-4.
[41] Simon Newcomb, *Astronomical*,... page. 24.
[42] Simon Newcomb, *Astronomical*,... page. 19-20.
[43] Simon Newcomb, *Astronomical*,... page. 20

Meanwhile, the nutation for the ecliptic tilt ($\Delta\varepsilon$) is influenced by the moon.[44]

$$\Delta\varepsilon = +9.214'' \cos \Omega - 0.090 \cos 2\,\Omega + 0.018 \cos (2\,☾ - \Omega) - 0.005 \cos (2\,☾ - g_1) + 0.088 \cos 2\,☾ + 0.011'' \cos (2\,☾ + g_1) - 0.007 \cos (2L - \Omega)$$

Meanwhile, the nutation for the ecliptic tilt ($\Delta\varepsilon$) is influenced by the sun.[45]

$$\Delta\varepsilon = -0.009'' \cos (2L - g) + 0.546 \cos 2L + 0.021 \cos (2L + g)$$

C.3. Analysis of the Accuracy of the Newcomb Solar Ephemeris Calculation Algorithm

Ephemeris is included in contemporary calculations because this ephemeris was issued in the early 20th century. In addition, this ephemeris is quite accurate because of the large number of correction terms and considering aspects of the planet's relative motion to Earth which can be seen in the perturbation and nutation correction formulas.

This ephemeris is calculated using the epoch of January 0, 1900 due to observations made from the end of the 19th century to the end of the 20th century. In addition, this ephemeris uses the base date as Julian Day and does not use dynamic time (TD) but universal time (UT), so it does not need to convert time from UT to TD if you want to find ephemeris data. This can make it easier for ephemeris users to do calculations and this is an advantage of Newcomb ephemeris. This ephemeris is similar to the ephemeris made by the Indonesian Ministry of Religion. Calculating the direction of the Qibla, prayer times, the beginning of the lunar month or the calculation of the eclipse by Islamic organizations, falak institutions and observers of rukyat reckoning.[46] The Newcomb ephemeris can also be used for the same thing as the Indonesian Ministry of Religion's ephemeris reckoning.

The disadvantage of this ephemeris is that it cannot be calculated manually because the formula used is too long and there are many formula corrections. However,

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[44] Simon Newcomb, *Astronomical,...* page. 19-20

[45] Simon Newcomb, *Astronomical,...* page. 20.

[46] Alfan Maghfuri, Akurasi Data Perhitungan Gerhana Matahari dengan Data Ephemeris Hisab Rukyat, *Al-Afaq: Jurnal Ilmu Falak dan Astronomi* (2020).

this shortcoming can be overcome by calculating using a computer, so that the work can be done more quickly and efficiently

D. Conclusion

The Newcomb calculation ephemeris algorithm is classified as an ephemeris which has high accuracy with a large number of corrections and has a long period correction which is useful for calculating the ephemeris of the Sun in years far from the epoch used. In addition, users in performing calculations can directly use UT time so they don't need to convert UT to TD. The disadvantage of this ephemeris is that it cannot be done manually because the formula used is too long and there are many formula corrections. However, this deficiency can be overcome by calculating using a computer.

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