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# Analysis of Observational Parameters in the Timing Accuracy of Lunar Occultations

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## Abstract

In this observation project named APTO, teams participating, observed the lunar occultations. A total of 9 stars were observed and 20 were reported. The Occult 4 software was used to predict these observations. And we designed SkyTiming 2 application for this project for android smartphones based on GPS. Also, ten of the observational parameters in the project report series were examined. This indicates that, in most cases, the expected results are obtained.

*Keywords: Observation, Timing, Occultation, Moon*

## 1. Introduction

One of the common phenomena at every starry night is the occultation of stars, planets, asteroids and other objects by the Moon is called lunar occultation. Generally, celestial objects are far from us but our Moon is closer so we can conclude that the Moon has a much bigger angular size than other objects in the sky (exception of the Sun) and so it can hide other objects when they passed behind of it. The timing of this kind of phenomenon when an object disappears or even reappears during lunar occultation is prominence for astronomers. Various surveys were done on these phenomena for exploring lunar topography, discovering of exoplanets and binary stars, investigation of the atmosphere planets and their moons, and others that show the importance of these timings for lunar occultation. by considering the situation of the Moon in the sky, every night tens of stars can hide behind the Moon for several minutes (Poro, 2018) and for two last centuries a lot of observations were done for these phenomena but it doesn't show the convenience of this kind of observatories because the apparent magnitude of stars, degree of sky darkness, dust, atmosphere excitation, and etc., definitely have a significant impact on the lunar occultation.

One of the important points to investigate lunar occultation is the reporting of the instant of disappear or reappear of our targets. There are several methods of occultation observation that two of the most common are visual observation and video observation. Our method in this project is visual observation by

using Universal Time (UT). In visual observation, one of the important tools is our eyes and the use of telescope enhances the view of the subject obtained by the eye (Gault, 2017) and by stopwatch we can conclude the instant of intended events. Another prominence issue is the method of timing. There are three common methods of obtaining of UT for the instant of occultation, they are short wave Radio, GPS and NTP time servers. The Global Positioning System (GPS) and Network Time Protocol (NTP) are our time servers.

There are some problems with visual observation and using stopwatch that decrease the accuracy of our results such as observer mistake and delay therefore to express the accuracy there is a factor is called Personal Equation (PE) that is an important parameter for each observer and needs to be developed. Eventually to increase the accuracy and obtaining the exact time, "SkyTiming" is an accurate timing mobile application for visual observation (Lesani, 2017). This application is based on GPS or NTP servers and the observer can record the sound during observation and calculate the event exact time.

Investigation of the lunar surface is an important issue for studying the topography of the Moon. Lunar surface changes during the time by various erosion factors, therefore, plenty of projects and observations concentrate on this problem that one of them is KAGUYA that is the Japanese lunar orbiter spacecraft (another name is SELEN) was successfully launched by H2 rocket on the September 14, 2007 (Manabukata, 2010). KAGUYA has obtained the lunar global topographic data for studying the origin and evolution of the Moon and also studying the Moon gravity (Sasaki, 2009). In our project, our purpose is Data collection in different cities of Iran and comparing them with KAGUYA data. For predicting the exact time of an event, we need the profile of the Moon so we utilize the KAGUYA's lunar profile or LOLA that exists in the Occult4 program. In addition, Watt's profile is older than other ones but it wasn't accurate enough.

This article is based on APTO (Astrophysical Project on Timing Occultation) and its result that was started in November 2019. Nine teams and observatories all over the Iran participated in this project to collect the data of time lunar occultation for eleven stars when they disappear or reappear behind of the Moon in dark or bright limb and compare them with previous results to know how the magnitude of stars or Moon phase and its' brightness and other factors impress our results. For this purpose, we utilized Occult4 software to predict the timing of our targets and calculate O-C (Observed minus Calculated) parameter. All of these timings were done visually by GPS or NTP sources.

This is the second part of the project, known as APTO 2. The results of APTO 1 have already been published (Poro, 2019).

## **2. Prediction and reporting**

The application used in this project is the occult 4.9.3.2<sup>1</sup>. We used it to predict and obtain the first parameters. This software, which was written by David Herald, is based on a great collection of data that big part of which is the information that was obtained from satellites. This software can predict and analyze many astronomical events that were based on occultation, transit and eclipses like lunar occultation, solar and lunar eclipses, asteroid occultation, and occultations of the planetary satellite (Preston, 2019).

We used "lunar prediction" part of Occult 4 in this project for predicting occultations in specific geographical coordinates, specified period of time, and proper occultations for observation were chosen after checking all the lunar occultations based on observation indicators like the magnitude of a star, Moon phase and altitude, type of occultations (reappear or disappear), weather condition and time of occultations. And then, observation information of selected occultations including estimated time of occultations based on GMT, approximate place of reappearing or disappear on the Moon profile and star information were extracted and is available for the observer (Poro, 2014). After the observation and timing process, the observer entered the observation information including how to timing, correct time

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<sup>1</sup> <http://www.lunar-occultations.com/iota/occult4.htm>

of the occultation, observation location information, observer and observation tools, and weather conditions, along with other information in the “Lunar Observation” section for reporting. Finally, Occult 4 calculates the time difference between the timing of the observer and Kaguya satellite (O-C) of observations.

KAGUYA spacecraft (also known as SELENE), was launched by Japan Aerospace Exploration Agency (JAXA) on September 14th, 2007. Ever since its successful launch, KAGUYA has carried out several scientific observations. For instance, it has used an on-board lunar laser altimeter (LALT) for topography purposes, to generate detailed, stereoscopic images of the lunar surface (Araki, 2013). These images provide information about the lunar limb profile (Pasachoff, 2015).

When an occultation occurs, the “edge of the Moon “is what is being observed from the Earth (Poro, 2019). Therefore, the analysis of occultation observations is limited by our knowledge of the lunar limb profile as seen from the Earth. It is possible that in long periods of time, the profile undergoes a few minor changes due to erosion. It can also change with our different viewing angles of the Moon, called librations, as the Moon moves in its orbit (Nugent, 2007). The amount of these changes can be calculated by the profiles produced by KAGUYA. To compute them, the generated data by occultation observations should be compared to those provided by KAGUYA. This comparison is showed by what we refer to as the O-C parameter (Poro, 2019).

### **3. Timing method**

Lunar occultation timing measurements can be useful when there is an overall accuracy of a few tenths of a second in order to provide confirmation or improvement of knowledge of lunar topography. The methods of timing used by the APTO teams who gathered this data were visual.

The base time that we used for this project are SkyTiming 2 application based on GPS, and Network Time Protocol (NTP). We used two ways for calculating the time that each way has a range of errors depends on each team's experience and abilities. Each team's observation was visually and we had observer's errors too.

Initial preference was to use time based on GPS (SkyTiming 2 or 1), but in times where it was unavailable or when there was a problem, some observations were used the NTP based time.

The GPS is the best time reference base. The whole system's rationale is based on time. Most (but not all) GPS receivers have a feature called One Pulse Per Second (1PPS) referenced to Universal Time (UT) to an accuracy measured in microseconds and that if this signal is used appropriately, a GPS receiver can be used to give times to an accuracy of  $\pm 0.001$  seconds or better (Gault, 2017).

The most important errors in observation and timing are the base time error and the Personal Equation (PE) error. PE is the time the observer takes to react to the occultation. It is required for visual observers. Typical values are 0.3 to 0.5 for a disappearance as the star is first occulted by the Moon. The term D (or d) is used for disappearance and R (or r) for reappearance. Experienced observers always try to improve PE in their visual timing. If the star is not easily visible, or the observer is inexperienced, the value will be at the larger end. A visual observer should enter into the PE field a numerical value, which is the best estimate of their personal reaction time. It is only an estimate and not 100% accurate.

The estimated uncertainty ( $\pm$  time range) in the reported time, after any PE, has been applied. Usually, the uncertainty will be smaller than the PE. The ultimate goal is to decrease PE in visual observations. Initially, for observers to gain experience, they must use visual methods to see an occultation with their eyes as it takes place. This is the reason for understanding the concept of PE since it demonstrates that no matter how 'good' an observer thinks he or she is, there is always a delay in estimating a D or (especially an R) in lunar occultations. To eliminate PE entirely one must transition to a more accurate method that does not require the human eye to interpret when a D or R has taken place. Nowadays, video timing

methods are used with GPS time embedded in each frame. As mentioned here, two reports of this project used a creative approach based on video timing, based on available facilities (Poro, 2018).

#### **4. SkyTiming 2 application for APTO**

In astronomy observational activities, especially observations of the type of occultations, precise timing is the most important pillar of a high-quality observation with reliable result. The results of such accurate observation activities will usually produce reliable observational reports for the usage of astronomy scientific community.

Occultation observations such as APTO project is being done by special observation methods to obtain accurate specifications of small celestial bodies that are not normally observable by conventional observation methods, also to determine the shape and size of asteroids, comets, and dwarf planets that being studied in APTO project (Poro, 2019).

In this method, accurate recording of the location of the observation along with the timing of important events in the occultations, such as disappearance, reappearance, and etc., can allow observers for accurate study of the observed celestial objects. So, it will be important to have a tool or use a method that allows observers to record accurate timing of mentioned events. Therefore, the effort of developing/creating accurate tools for calculating timing of observational events has always been and will be an ongoing and endless endeavor.

Nonetheless, developing software running on smartphones that provide such capability to record occultation events timings along with accurate observer location using GPS facilities of smartphones can be considered as one of the wise, low-cost examples of such efforts compared to other methods (e.g. GPS hardware with timers, etc.); while this way offers permanent expansion and optimization efforts for having an up-to-date timing tool based on project requirements and new capabilities of smartphone software and hardware that comes to market every year.

##### **1.4 The project definition and expected capabilities of the software**

Definition of SkyTiming 2 mobile software project with the aim of improving the visual timing and reporting qualities of an observation (e.g. APTO project) based on a mobile software, started in the last quarter of 2018 by Mr. Attila Poro, Director of The Middle East Occultation Timing Association (IOTA/ME); and has been assigned to Farshid Nasrollahzadeh as mobile software developer of this project.

According to the project definition, this mobile software should work on the most widely used mobile platforms, both Google Android and Apple iOS smartphones. As it had to have the capability of running on both widely used smartphone platforms, the Xamarin mobile app framework was used for this purpose.

In fact, SkyTiming 2 software replaces SkyTiming 1 software (that was just available for Google Android and became a little old for running on new android devices) developed by Lesani and Poro (2017) at the framework of IOTA/ME projects. Users of SkyTiming 2 can use it for precise timing of observation projects, especially observation of various occultations, and record the time of any observation events by recording the observer's voice in the system. Observers can fill observations forms with accurate and complete information they were talking about in their voices by replaying those voices and submit completed observation forms to the IOTA/ME for further review and verification. All the above process steps (voice recording, voice replays, filling observation forms, sending them to IOTA/ME, etc.) can be done thoroughly in SkyTiming 2 mobile app environment. These are similarities between SkyTiming 1 and SkyTiming 2. But, the first different feature of SkyTiming 2 is that the software should run on two widely used mobile platforms, Android and iOS, and be available for almost all versions with adherence to the security requirements of each platform. The next difference is that SkyTiming 2 will include recording both observer voice and her/his physical location coordinates, plus visual displaying of the time; and finally,

playback of the recorded voice of the observer in the same app environment. Using SkyTiming 2, the observer can record important moments of events related to occultation or any other type of events using visual time display (like a stopwatch) accompanied by her/his voice.

As with Timing Sky 1 software, it should also be able to prepare an observation form in digital format and submit it online to IOTA Middle East as an email. The app should also be able to read the time from the GPS Satellite Clock Source. Therefore, where there is no Internet access or the accuracy of the internal clock of the mobile device is in doubt, the GPS Satellite Clock is a reference to the time recorded. Also, software should allow the user to determine the accuracy of GPS information based on the accuracy radius around observer physical location in the meter unit. Another expected functionality is the ability to allow the observer to select the source used in time recording. This means that the observer can choose between the GPS time source or the mobile device's internal clock system. The software is expected to predict the time display accurately for a hundredth a second in displaying the time taken from any source (GPS Clock or Internal Timer).

## 2.4 Operating SkyTiming 2

SkyTiming 2 APK file is sufficient to install this software in the Android environment, and using this APK file, SkyTiming 2 can be installed on any smartphone running Android 6 or higher. Also, it would be available on google play store for those who want to install it from validated application sources like Google play store and Apple AppStore for iPhone smartphones.

Once installed, just in the first run, the app will ask the user for the minimum required permissions to access to device resources like file system, microphone, and GPS hardware. After receiving these permissions, the software environment is loaded and ready to use.

Figure 1 shows some screenshots of the SkyTiming 2 App environment.

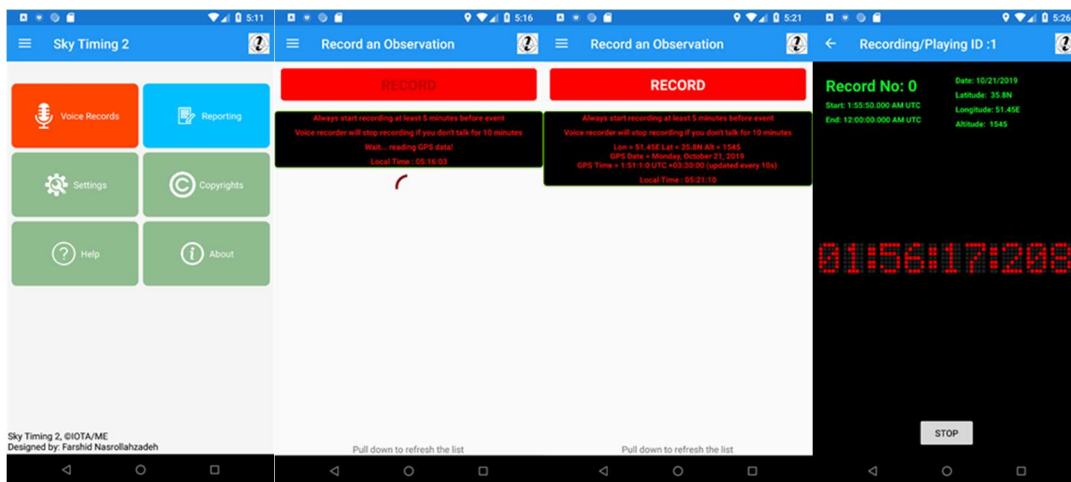


Figure 1. Left to right: Main screen, recording screen waiting for GPS data, recording screen after received GPS data, recording screen in action

## 3.4 Developments that are in progress

The expected capabilities of this software that will allow the observer to have a very accurate timing is Sound Spectrum or spectrum charting. Using this feature, the observer won't need to play/pause and repeatedly backward/forward the corresponding audio file to find the exact time of an observation event that is recorded in the audio file with speech or audio signals. And only by finding the peak points of the sound spectrum that indicate the presence of an audio mark in the range of the audio spectrum can she/he perform more accurate timing based on software calculations and avoid try and error to find the exact time of events. This capability is currently in the development phase, and due to the complexities

involved in implementing this capability, it requires more time to implement, test and finalize. Other features that can be added to the software in the future are as follows:

- A) In future upgrades, it is better to code all the information in the same format as the Occult4 software so that the Occult4 can also read SkyTiming 2 data.
- B) Add a night sky map section to the app.
- C) In the future, other forms may be provided for other events that require accurate timing.

## 5. Observation and data sets

The following targets for the APTO 2 observations are: SAO 190065, SAO 165276, SAO 128710, SAO 93034, SAO 165127, SAO 93716, SAO 128787, SAO 93954, SAO 79042.

These targets and their occultation opportunities were selected given the following limitations: The stars are defined to be single star (Table 1); the lunar phase for predictions is between 10% to 90% and -90% to -10%; lunar elevation above the local horizon during the occultation period should be more than 25 degrees; star visual magnitudes are until +8 based on the size of group's telescopes.

Based on these limitations, predictions and observations for the 9 target stars by the teams and observatories from November 2019 to February 2020 were made in different places of Iran. A total of 20 observations were reported in the APTO 2 (Table 2).

**Table 1. Details of all observed stars collected from the Simbad database<sup>2</sup>**

SAO	GSC	RA.	Dec.	Spect.	Distance (pc)
190065	06354-00402	21 09 15.43	-20 11 35.41	K0	161.941
165276	05818-00590	22 45 27.11	-13 00 25.00	F3	144.103
128710	04668-00448	00 21 13.12	-03 18 42.57	F6	85.55
93034	00642-00472	02 39 03.45	+10 38 13.28	K0	148.588
165127	05817-01280	22 30 17.35	-14 35 08.64	B8	197.141
93716	01254-00501	04 00 36.88	+17 17 47.97	A0	193.117
128787	04668-00082	00 29 39.06	-02 50 25.51	K4	212.698
93954	01273-01104	04 28 36.99	+19 10 49.54	G9	44.964
79042	01895-01643	07 05 18.36	+22 38 14.85	B8	142.481

**Table 2. Details of lunar occultation observations during APTO 2**

Date	Team	Tel. (cm)	SAO	Mag.	D/R	Limb	Moon		Timing	PE	O-C
							Alt.	ill%			
2019-11-04	Bushehr1	41	190065	6.7	D	D	41	52	NTP	0.4	0.04
2019-11-04	Bushehr2	30	190065	6.7	D	D	41	52	NTP	0.3	-0.42
2019-11-06	Kashan	15	165276	7.8	D	D	43	70	GPS	0.4	-0.17
2019-11-08	Tangestan	20	128710	7.4	D	D	40	87	GPS	0.4	-0.02
2019-11-11	Ardebil	31	93034	6.7	D	D	62	99	NTP	0.4	0.10
2019-12-03	Ardebil	150	165127	6.4	D	D	33	44	NTP	0.3	-0.07
2019-12-03	Shiraz	20	165127	6.4	R	B	26	44	NTP	0.4	-0.07
2019-12-10	Ardebil	31	93716	6.3	D	D	67	98	NTP	0.3	0.00
2019-12-10	Kashan	15	93716	6.3	D	D	69	98	GPS	0.3	-0.35
2020-01-02	Ardebil	31	128787	6.9	D	D	42	45	NTP	0.3	-0.31
2020-01-02	Kashan	15	128787	6.9	D	D	42	45	GPS	0.3	-0.76
2020-01-02	Pasargad	30	128787	6.9	D	D	42	45	NTP	0.6	0.11
2020-01-02	Tangestan	20	128787	6.9	D	D	42	45	GPS	0.5	-0.42

<sup>2</sup> <http://simbad.u-strasbg.fr/simbad/>

2020-01-07	Bushehr2	31	93954	3.5	D	D	34	88	NTP	0.3	-0.37
2020-01-07	Kashan	15	93954	3.5	D	D	34	88	GPS	0.3	0.15
2020-01-07	Pasargad	30	93954	3.5	D	D	34	88	NTP	0.4	-0.13
2020-02-03	Ardebil	30	93716	6.3	R	B	73	65	GPS	0.4	-0.15
2020-02-03	Tangestan	20	93716	6.3	R	B	73	65	GPS	0.5	-0.74
2020-02-06	Ardebil	30	79042	6	D	D	35	92	GPS	0.4	-0.12
2020-02-06	Kashan	15	79042	6	D	D	35	92	GPS	0.3	-0.86

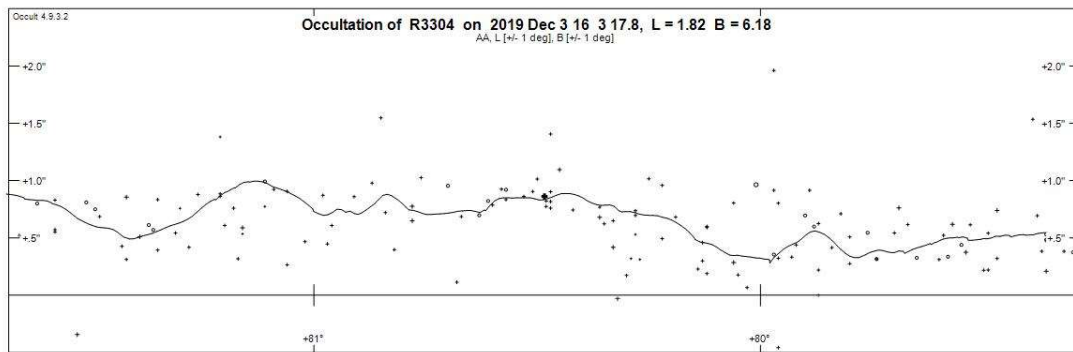
**6. Analysis and conclusion**

The most important problem in the visual observation part of the project was the reduction of the PE for each observer. This error can occur for a variety of reasons. Some of the things that have been reported to have caused this error, according to observers, are: Effect of cold temperatures lowering the timing accuracy, response of the eye/brain to an occultation impacted by the age of the observer, observer’s hands are not free for controlling the telescope, observer cannot comment on some conditions concerning the observation directly., eye fatigue and lack of consistent focus, other problems which reduce the accuracy of timing such as instrumentation issues.

Despite the low experience of observers at the beginning of this project, the average PE for the observations is calculated: 0.381. This error rate is within the range of 0.3 to 0.6 on visual timing in this project.

Once we have found that the PE of reports was acceptable for this project, we proceeded to comparative study of O-C. As mentioned earlier, O-C can be an indicator of timing accuracy, according to the KAGUYA satellite profile. If this parameter’s range for visual timing is between +0.1 to -0.1 it means that the observer has done an accurate time measuring (Poro, 2019).

Figure 1 shows an example for profile the Moon and location of the occultation timing calculated. This calculation did for all observations.



**Figure 1. An example of the location of the result in a project observation (+ in the middle of the image) based on the LOLA**

After tabulating observations and obtaining observation parameters such as O-C and PE, they can be compared. The purpose of this study is to obtain results to improve future observations as well as an accurate picture of the observational parameters in a set of observations at different locations. These results are shown in Table 3. Descriptive results are also provided in the subtitles of each of the Figures 2-11.

**Table 3. Comparative results between different observation parameters**

Parameters	Value (the slope)	Error ( $\pm$ )
------------	-------------------	-----------------



Date, O-C	-0.002742	0.000326
O-C, Tel	22.941429	22.432653
O-C, Limb	-0.165020	0.288426
O-C, ill	8.840551	17.344918
O-C, Alt	-4.709061	11.586726
O-C, Based time	-0.693564	0.373308
O-C, DR	-0.165020	0.288426
O-C, Mag	-0.328725	0.974358
O-C, PE	0.0544089	0.066353
Tel, PE	-0.000486	0.000680

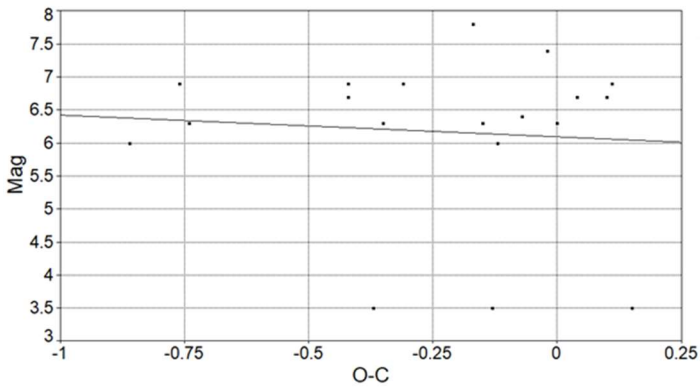


Figure 2. Comparison between the magnitude of the stars and the O-C. The higher the magnitude of the stars, the lower the O-C, so the brighter stars in these observations set showed better timing accuracy.

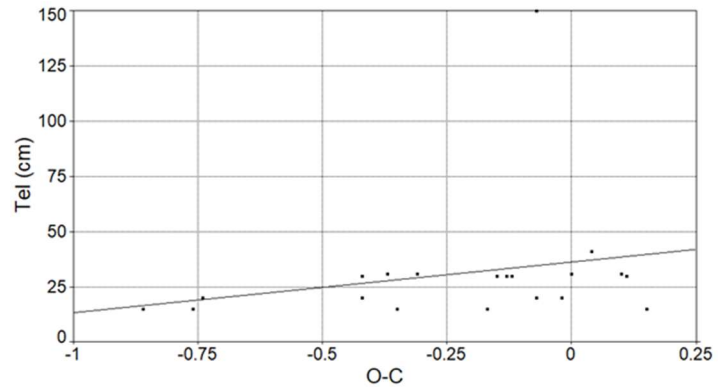


Figure 3. Comparison between telescope size and O-C value. The larger the telescopes, the closer the value is to zero for O-C. So bigger telescopes have a better O-C value.

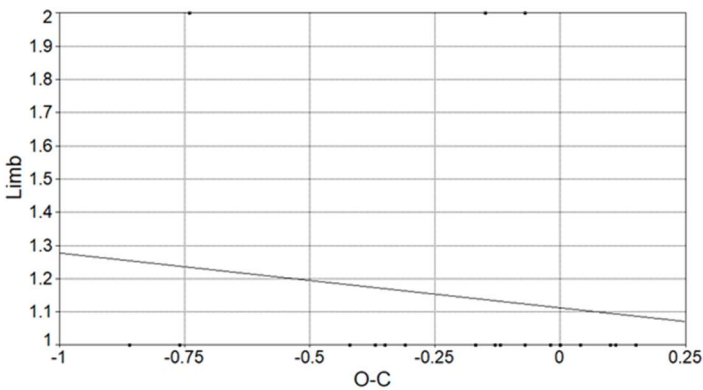


Figure 4. Comparison between dark or bright limb of the Moon and O-C value. It shows dark limb is better for observation and O-C is better.

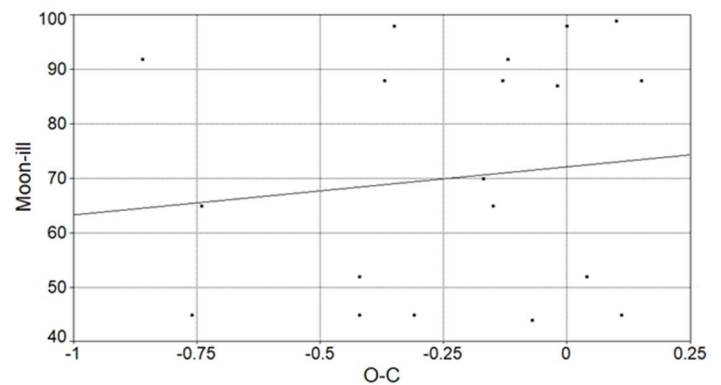


Figure 5. Comparison between the Moon ill (%) and O-C value. It is very clear that as the brightness of the Moon has increased, the amount of O-C has increased, which means more error in the timing (O-C) for more ill.

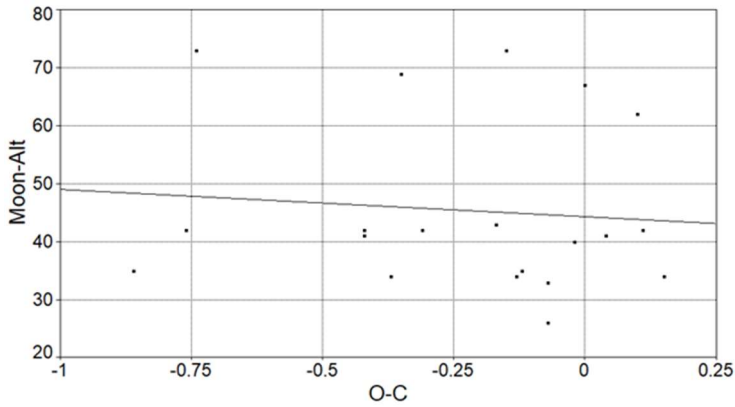


Figure 6. Comparison between the Moon altitude in each observation places and O-C value. The results seem a bit strange! The lower the altitude, shows the lower the observation error (O-C); which we usually do not expect. At about 45 degrees, the O-Cs were better.

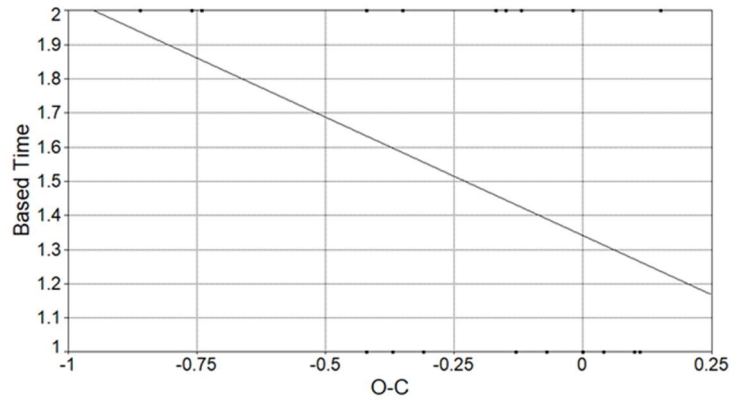


Figure 7. Comparison between Based time (NTP or GPS) and O-C value. It is very clear that the GPS method is significantly better than the internet base time.

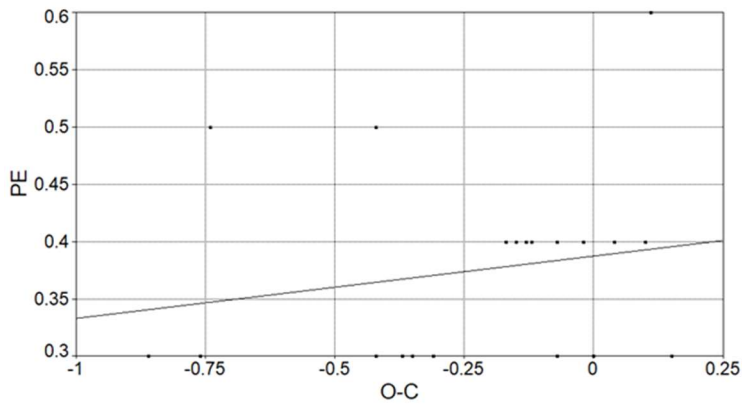


Figure 8. Comparison between PE and O-C value. The higher the human error rate (PE), the greater the O-C expectation. This is a normal result.

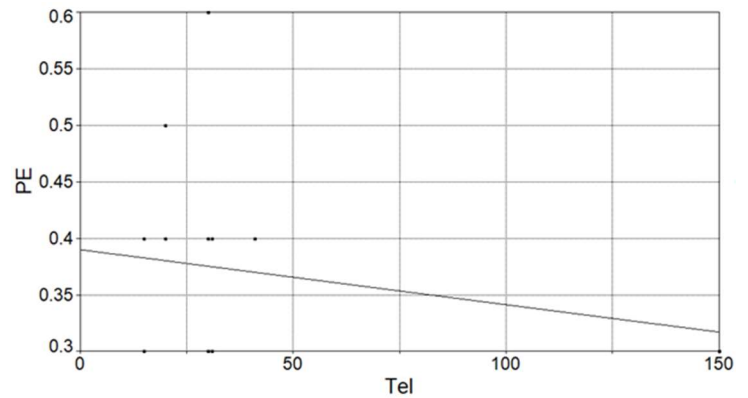


Figure 9. Comparison between PE and telescope size. It shows that the larger the telescope's size, the lower the human error rate (PE).

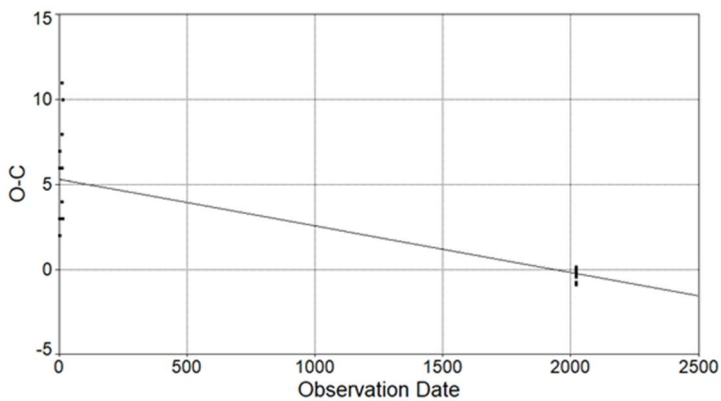


Figure 10. Comparison between O-C and Observation date. It is a great pleasure that the observations have become more accurate over time. The diagram shows the proper slope to increase the accuracy of the observations.

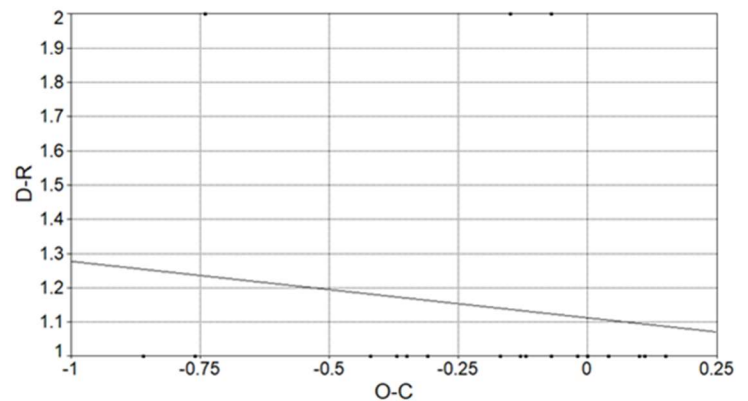


Figure 11. Comparison between disappear and reappear occultations, and O-C value. This figure shows that the disappearing observations were more accurate, due to less moonlight.

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