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Analytical Studies of Laser Parameters for Ranging and Illuminating Satellites from H-SLR Station

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ABSTRACT

In this study, the laser system used at the Helwan Satellite Laser Ranging Station (H-SLR) will be used in satellite's illumination as well as for satellite ranging. The estimated model which describes the energy and number of photons as well as the number of photoelectrons are investigated from the received signals of laser beam. For the ranging purposes, the equipment used at the H-SLR is described and also the method used for its calibration. "The Range corrections due to the effect of the atmosphere on the laser beam is also discussed and applied for some satellites observed from Helwan". The ranging and illuminating space satellites are modeled and computed from the H-SLR parameters. "The numbers of photons, of photoelectrons are then computed from the ranging data".

Key words: Satellite laser ranging, calibration of the Helwan-SLR station, radar equation, atmospheric correction

INTRODUCTION

Laser ranging is considered to be one of the most accurate techniques available for tracking the artificial satellites. It measures the time intervals required for pulses emitted from laser transmitter to travel to a satellite and return back to the transmitting site. The "range" or distance between the satellite and the tracking site, is approximately equal to one half of the two-ways travel time multiplied by the speed of light. The Helwan SLR-station is one of the international laser ranging services (Cech *et al.*, 1999; Prochazka *et al.*, 1997).

The technique requires satellites which carrying retro-reflectors on their surfaces. The returned signals are characterized from the range equation, in which the optical parameters of the reflectors are taken in consideration. The space objects have reflectors with specified reflectivity and size. The optical cross section of the illuminated space satellite is taken as an element for the description of the range equation. As well as the parameters of transmission and receiver laser system are more efficient for studying and determining the numbers of photons, in addition to the number of photoelectrons (Lukesh *et al.*, 2000, 2001; Chandler and Lukesh, 2006).

In this study, the laser of the Helwan SLR station is used for satellites illumination as well as for ranging. For that purpose, basic relations and formulas concerning laser ranging, energy photons and number of photons received to ground telescope will be given. The first group of relations explains the principle of range measurement and some factors influencing the magnitude of the received signals. The relations describe the energy returned and photons from the satellite

laser retro reflector array to receiver are useful to understand some basic principles of the used laser system. The calculations are applied for Helwan Satellite Ranging (SLR) station under the effect of device parameters and conditions in our laser system. For that purpose, some information of the (H-SLR) system, are given.

HELWAN SLR-STATION

The basic function of laser ranging technique is the measurement of the range of the satellite. It can be determined as the time required for pulses emitted by a laser transmitter to travel to a satellite and return back to the transmitting site. In this section, A description of the Helwan Satellite Laser Ranging Station (SLR) and its possibility for observing the artificial earth satellites are given. The method used for calibrating the station is also considered. The model used for computing the atmospheric effect on the laser beam is discussed and applied at the meteorological conditions of the time of satellite observations as an example.

Description of Helwan SLR-station: The Mount configuration is of Azimuth/Elevation mode with a code system of mirrors for the transmitted beams as shown in Fig. 1. The movement drive is consisting of 2 step drive motors and the maximum tracking rate is 2 deg sec^{-1}. Its pointing accuracy is almost 30" deduced from receiver microscope The guiding of the mount is a computer controlled. The receiving system is consists of spherical mirror lens of diameter 40 cm and optical filter of 6 nm with 80% transmission. The type of the detector is a Photomultiplier (PMT) manufactured by Hamamatsu model H6533. The quantum efficiency of this PMT is 10% at 532 nm and of normal gain equal 5.6 millions. The mode of the PMT is single photoelectron detection.

The laser Transmitter is a composed of Nd: YAG oscillator, Pulse selector, three amplifiers system and a Second Harmonic Generator (SHG); it produces a semi train of pulses (Cech *et al.*, 1999; Prochazka *et al.*, 1997). The wavelength of the laser is 0.53 μm, the output energy of the laser is 80 mJ, the pulse width is 17 psec and its repetition rate is nearly 5 Hz. The divergence of

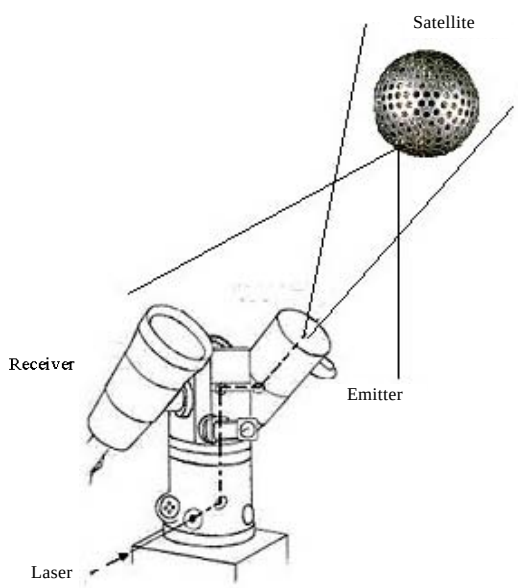

Fig. 1: Block diagram of the Helwan-SLR for ranging and illuminating satellites

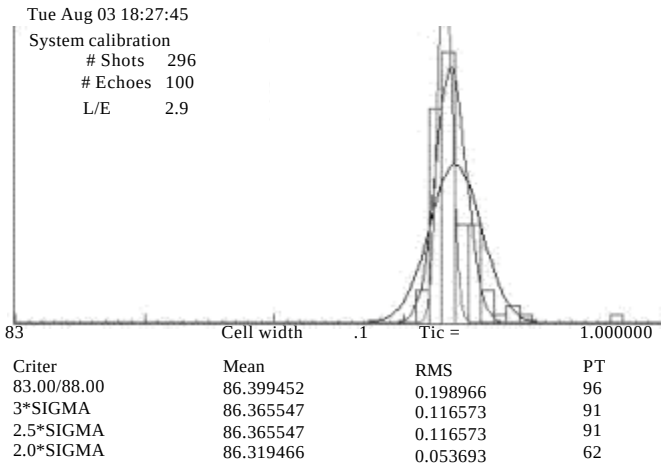

Fig. 2: The system calibration of Helwan-SLR station

the laser beam is adjustable and can reach to 0.1 mrad. The laser transmitter is placed outside the mount and then the laser beam is directed to the satellite through the mount via a four coude mirrors.

The Meteorological station (MET-3) installed to improve temperature, humidity and atmospheric pressure s' measurements. It measures with accuracy of 0.1 mbar for the pressure and with accuracy ~0.5°C and 2% at 25°C for the temperature and humidity respectively stored in a file after observing a satellite, the satellite laser ranging data which represent the distance between the satellite and the station are measured and stored in a file. The data are analyzed in three steps and the final form of the data is given as a part of the data presented by Ibrahim *et al.* (2001) and Ibrahim (2005).

Calibration of Helwan SLR-station: The Helwan-SLR station is calibrated using internal calibration method (Ibrahim *et al.*, 2001; Ibrahim, 2005).

Figure 2 shows a typical histogram of the internal calibration of the system carried out on 3 August 2004. The mean value of the calibration is ~ 86.319 ns and the Root Mean Square (RMS) is ~ 0.054 nsec.

Range correction due to the effect of the atmosphere on the laser beam: The simple atmospheric correction calculation is ideal for SLR stations as it only requires local atmospheric measurements to be taken at the ranging site. Since most stations do not range below 20°, as attenuation below this elevation reduces signal intensity significantly, the Marini-Murray model is still useful (Marini and Murray, 1973). For the purpose of the computation of the correction in the range of the satellite, the Model is applied at the same meteorological condition during the observation of the satellite starlette observed at November 22, 2005 (as an example) and the results are shown in Fig. 3.

Where, λ is the wavelength of the used laser, R_H is the relative humidity, P_0 is the atmospheric pressure and T is the temperature, each of them are measured at the station site. By the way, the parameters HH and ϕ represent the height above the mean sea level and the latitude of the station,

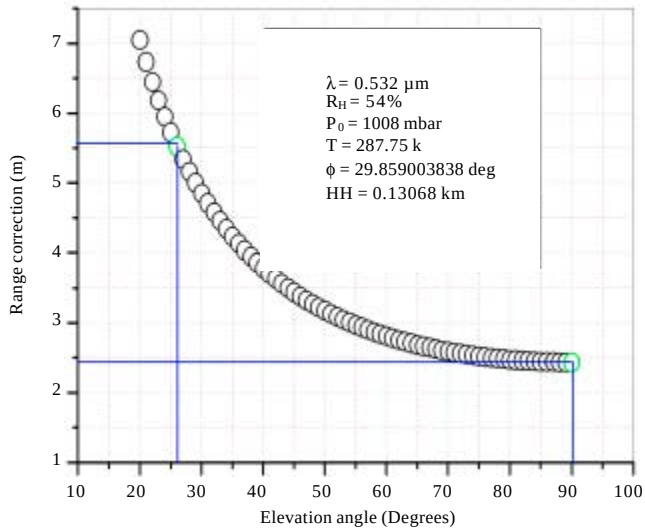

Fig. 3: Range correction versus elevation angle as computed by marini murray model

Table 1: Optical cross section and other characteristics for some spherical satellites

Sat name	Cosper ID	Hight (km)	σ ($\times 10^6$ m^2)	Sat. Diam (m)	No. of retro reflectors
Stella	9306102	950	0.65	0.24	60
Starlette	2501001	950	0.65	0.24	60
Ajisai	8606101	1400	12.00	2.14	1436
Lageos	7603901	6000	7.00	0.60	426
Etalon	8900103	19000	60.00	1.294	2134

respectively. The range correction is about 2.43 m at an elevation angle 90^0 and increases to about 7 m at the elevation angle of 20°. As for the Helwan SLR-station, it increases to about 5.52 m at the elevation angle of 26° which is minimum elevation angle at Helwan SLR station.

Modeling of ranging and illuminating space satellites

Range equation of transmitted and received signals: For laser illumination, the range equation is used to estimate the received photon based on some parameters such as laser energy, receiver and transmitter diameters and atmospheric effects. This equation is commonly used to predict strategic laser system performance (Degnan, 1993). Modern geodetic satellites are designed to be spherical in shape, in order to avoid the large pulse spreading caused by flat panel arrays when viewed at non-normal incidence. For circular entrance aperture, the far field diffraction pattern is the familiar Airy pattern (Born and Wolf, 1975; Ibrahim *et al.*, 1997). Typical values of the optical cross section σ for some of spherical satellites, used in the studying of SLR system, from Helwan station, are given in Table 1. It is clear also from the table that the satellites array size is largely determined by the satellite altitude. Science more retro reflectors are required to achieve reasonable signal to noise ratios over longer slant ranges.

Number of photons and photoelectrons

Calculation of returned photons: The expected number of counted signals per pulse is determined by developing a link equation which includes the losses that the signal encounters while traveling to the target and back (Lipinski *et al.*, 1994).

Calculation of the number of photoelectrons: The calculation of the number of photoelectrons N_{pe} is performed according to the known Radar link equation (Lipinski *et al.*, 1994) as given by Eq. 1:

$$N_{pe} = \eta_q E_T \frac{\lambda}{hc} \eta_T G_T \sigma \left(\frac{1}{4\pi R^2}\right)^2 A_T \eta_R T_A^2 T_C^2 \quad (1)$$

where, η_q is the quantum efficiency of the photo multiplier, E_T, λ, h, c, σ and A_T are defined previously. η_T and η_R are transmitted and received path efficiency. T_a^2, T_c^2 are the transmission properties of the atmosphere and circus cloud. G_T is the transmitter gain which defined for a Gaussian beam as:

$$G_t(\theta) = \frac{8}{\theta^2} \exp\left[-2\left(\frac{\theta_P}{\theta_t}\right)\right]$$

where, θ_t, is the far field divergence half angle between the beam center and the $1/e^2$-intensity point and θ_P is the beam pointing error. As θ_P pointing error generally far smaller than the beam wander induced by atmospheric turbulence, θ_P is often replaced by θt when determining the transmitter gain. Then the, transmitter gain can be replaced by $8/\theta_t^2$. The data are applied on different satellites ranging and configurations and the results are discussed in details in the next section. Table 2 shows the parameters used and estimated for the Helwan SLR station.

RESULTS AND DISCUSSION

The analytical model is applies for satellite configuration and the parameters of laser system as given in Table 1 and 2, respectively. The obtained results for the observed and estimated data are discussed and interpreted in the following relations:

Figure 4 shows the data that plotted for satellite named AJISA. Figure 4a describes the relation between the satellite ranging and energy received at the surface of ground telescope at different

Table 2: Parameters used and estimated for the Helwan SLR station

Parameters	Value
λ	0.532 μm
E_{tran}	80 mJ
E_{ph}	~3.74×10-19 J
Pulse width	17 Psec
Repetition rate	Up to 5 Hz
θ_t	0.1 mard
D_T	2.5 cm
D_R	40 cm
K_T	0.6
K_{LRA}	~0.9
K_R	0.3
T	~0.7
ρ	0.9
θ	45°
θ_{LRA}	0.1 mard
D^{LRA}	~3 cm
η_q	10%

time of laser shots. While Fig. 4b shows the relation between the number of photon received at the surface of ground telescope and the number of photoelectrons produced from the Photomultiplier Tube (PMT). It is seen from Fig. 4a that, as the satellite ranging decreases, the energy returned to ground telescope increases. This is confirmed also from the Eq. 1 in which the general trend of the received energy due to the R^4 effect. The very small values of the received energy results from the very small value of the surface dimension of the used ground telescope (40 cm receiver diameter).

In Fig. 4b, the behavior is different. The photons returned at the surface of ground telescope N_p and the number of photoelectrons of PMT detector N_{pe} have the same behavior for all time of laser shots which also that each of N_p and N_{pe} has a considerably great values but the data of N_p is still approximately the greatest one. This is shown nearly in the middle of the time of laser shots. This is evidence that, the decreasing of N_{pe} values is as a result of the characteristic and properties of the detector devise, such as the parameters response for the sensitivity, conversion from photons to electric signals (conversion factor) and the efficiency of the PMT detector as given in E. 6. In addition, the dependence of N_{pe} values on the transmitted beam divergence led to the need of very narrow transmitted beam of the used setup (~ urad).

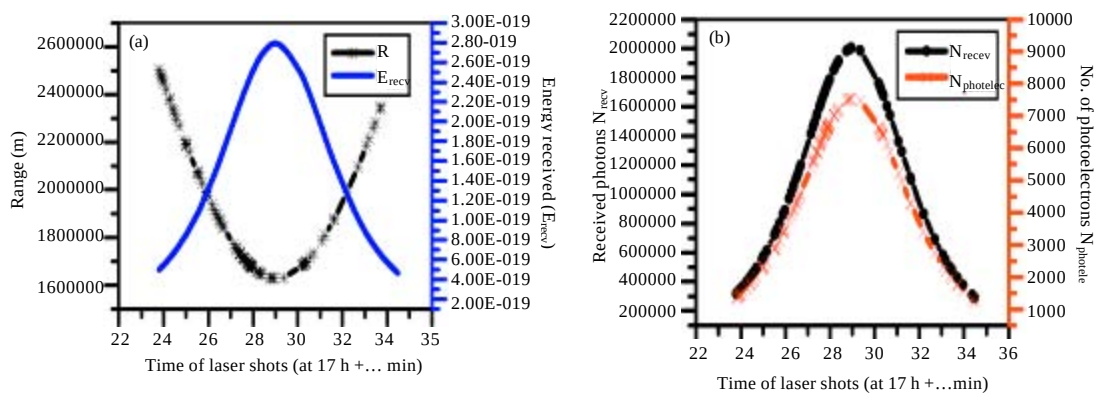

Fig. 4: The data plotted for satellite Ajisai, versus R and ET in (a) and versus N_p and N_{pe} in (b)

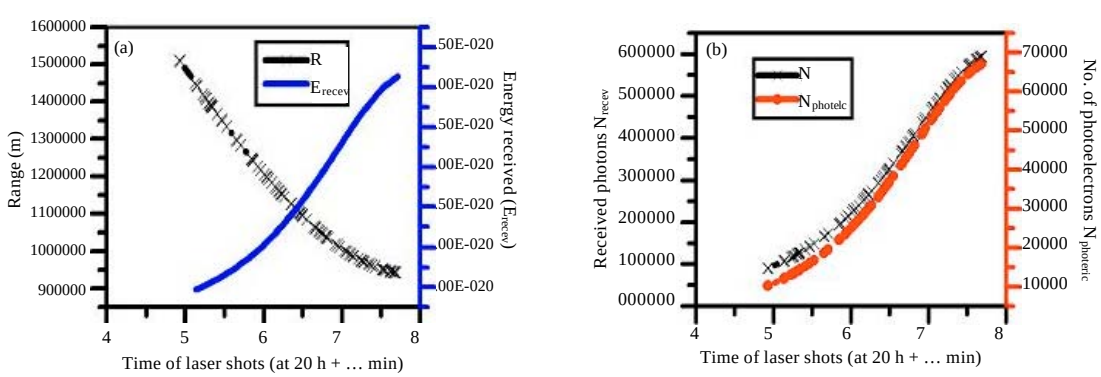

Fig. 5: The data plotted for satellite Starlette versus R and E_T in (a) and versus N_p and N_{pe} (b)

For more clarification of these behaviors, the dependence of these parameters on the conditions observed and estimated is pointed out. So, the same relations obtained in Fig. 4 are applied and plotted for different satellite configurations and ranging at different time of laser shots. These satellites are Topex, ERS-2 and Starlette. and the results are shown In Fig. 5 for satellite starlet as another example. These relations will be clarified in details in the following graphs.

Figure 5 illustrates the data obtained for the satellite Starlette at different laser shots. In this case, it is noticed that the data is observed at Helwan station in a one satellite path called a (path sector). At this period of observation, the graphs show approximately the same behavior given by the satellite Ajisai.

CONCLUSION AND FUTURE WORK

The possibility of using the Helwan SLR station for illuminating as well as for ranging satellites are studied. The Marini-Murray model is used for the computation of the range correction due to the effect of the atmosphere on the laser beam. It shows a correction in the range of about 2.43 m at an elevation angle 900° and increases up to about 5.52 m at the elevation angle of 260^0 which is minimum elevation angle at Helwan SLR station. The model used for the description of the energy, number of photons and the number of photoelectrons is studied and investigated from the received signal of the laser beam. The laser ranging data that obtained from the Helwan SLR station for different ranging and configuration satellites are applied for the analysis. The results produced from the analytical studies clarify the effect of the parameters of the space objects. A comparison between the data obtained for N_p and that of N_{pe} show the dependence of these parameters on the receiver characteristic and the properties of the used photo detector. It is clear from the results that there are two main parameters required for the laser to be able to reach very high satellites. Those parameters are the divergence angle of the laser should be very narrow (to be in the order of ìrad) and the receiver diameter should be sufficiently large. By that method the Helwan-SLR station can be able to use in satellites illumination.

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