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Satellite Laser Ranging in Egypt



Makram Ibrahim^{*}, Y.S. Hanna, S.W. Samwel, Maroof A. Hegazy

National Research Institute of Astronomy and Geophysics, Helwan 11421, Cairo, Egypt¹

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Abstract The paper concerns on the satellite laser ranging (SLR) in Egypt. The three generations which can be loosely defined by their single shot root mean square precision, are discussed. The laser generators used at the Helwan half automatic and full automatic stations are described. The equipments used for the operation of the satellite laser ranging and their upgrading are presented. The observations carried out from Helwan-SLR stations are mentioned. The importance of the satellite laser ranging from Egypt and their contributions to the SLR network are explained. The modification requested for increasing the performance of the Helwan-SLR station is given.

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1. Introduction

This paper deals with the satellite laser ranging in Egypt. By the way, there is a celebration by the passing of 50 years of the SLR. This celebration is carried out at the Maryland, USA, during the 19th International Laser Ranging workshop. The ground stations of the SLR network consist of about 50 stations observing artificial satellites and the lunar retro-reflectors. Almost all SLR stations are unique and developed in an individual way, therefore, operating different devices installed and managed by different software. The SLR station consists of high energy ultra-short pulsed laser, precise timer,

and optionally ultra-stable clocks, photo detector, narrowband filters, and well-mounted telescope (Pearlman, 1981).

As development that progressed laser tracking systems have been categorized into three generations which can be loosely defined by their single shot root mean square (RMS) precisions. The RMS of the first generation is greater than 50 cm, as for the second generation, between 10 and 50 cm and in the third generation, the RMS is better than 10 cm. Differences in instrumentation and approach that also differentiate between the three generations are discussed. Tracking systems in all these categories are still operational in various parts of the world, but many are in the process of upgrading to the 3rd generation specifications, in order to meet the stringent precision requirements being set by current geodynamic and geophysical applications. In this paper, we explain the situation of the three generations of the SLR in Egypt. A brief description of the used laser generators used at the Helwan SLR stations is also given. The atmospheric correction and the system delay are computed from the Helwan SLR station site. The expected upgrading of the station in order to increase its performance is explained.

^{*} Corresponding author.

E-mail address: makikh@yahoo.com (M. Ibrahim).

¹ Affiliation ID: 60030681.

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2. The method used for the satellite laser ranging

The satellite laser ranging (SLR) is an accurate method for satellite tracking. Fig. 1 is a simplified block diagram that shows the principle measurement of the satellite laser ranging. A portion of the outgoing laser pulse is detected by the photodiode, which starts with the time of flight measurements. The remainder of the pulse propagates through the atmosphere to the satellite, where it is reflected by the retro-reflectors back to the receiving telescope. The remainder of the pulse propagates through the atmosphere to the satellite, where it is reflected by the retro-reflectors back to the receiving telescope.

The telescope collects and focuses the returning laser pulse on a photomultiplier, and the resulting signal stops the time of flight measurements. The computer with the epoch time of the measurements and other supporting information stores a digital word representing the round trip time of flight. The system delay is computed and removed from the time of flight measurements (Pearlman, 1984).

The modeling of error sources and the calibration of biases from laser ranging systems (Tapley et al., 1982) may be written, to allow for possible error sources, as

$$R = c(\Delta t/2) + \eta_r + \eta_e + b + \varepsilon \quad (1)$$

where R is the range from the laser reference point to the average satellite retro-reflector position, c is the speed of light in a vacuum, and Δt is the time of flight. η_r is the atmospheric refraction correction (as explained in Section 2.1), η_e is the effect of the systematic and random measurement error (as explained in Section 2.2), b is the system delay as determined by calibration measurement (as explained in Section 2.3), and ε is the un-modeled observation error (Tapley et al., 1982). This is the procedure adopted by most centers currently processing laser ranging observations.

2.1. The atmospheric correction (η_r) as measured from Helwan-SLR station

The simple atmospheric correction calculation is ideal for SLR stations as it only requires local atmospheric measurements to be taken at the ranging site. As a laser pulse propagates through the atmosphere, it experiences a delay due to the troposphere refraction. This has the effect of an increase in the apparent range to the satellite, which varies between nearly 13.5 m at an elevation angle of 10° and 2.4 m at 90° (Sinclair, 1982). Generally, local safety regulations prohibit tracking below 20° at most SLR sites. Since most stations do not range below 20°, as attenuation below this elevation reduces signal intensity significantly, the Marini–Murray model is 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 GFO-1 observed at February 8, 2005 (as an example), and the results are shown in Fig. 2. 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 is measured at the station site. By the way, ϕ and HH are the latitude of the station and its height above mean sea level respectively. It found that, the range correction is about 2.43 m at an elevation angle 90° and increases to nearly 7.05 m at the elevation angle of 20°. As for the Helwan SLR-station, where the minimum elevation angle is 26°, the range correction increases to 5.52 m.

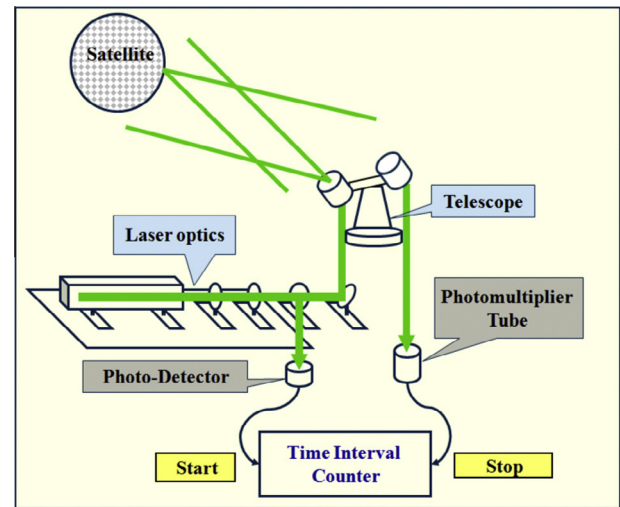


Figure 1 Block diagram of SLR technique.

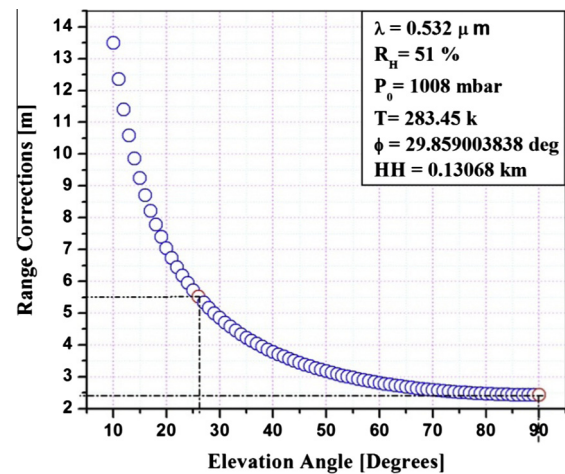


Figure 2 Range correction versus elevation angle as computed from Helwan-SLR station.

2.2. The center of mass correction (η_e)

For all laser ranging satellites the array of corner-cubes, which reflect the transmitted laser signal back to the tracking station, is displaced from the center-of-mass of the spacecraft (Otsubo et al., 1999). Furthermore, the orbit determination is referred to this reference point and so the observed ranges must be corrected accordingly. However, the pulse is not reflected from a single point but is a combination of reflections from all the reflectors facing the station. For spherical satellites (such as Lageos and Starlette) this correction is a simple constant offset and has been determined analytically (Fitzmaurice et al., 1978; Arnold, 1978) and by pre-launched calibration (Fitzmaurice et al., 1978). However, for other satellite the position of the reflector array must be considered, resulting in more complex correction formulae.

2.3. The system delay (b) of Helwan SLR-station

In the satellite tracking, all the ranging data are corrected for calibration constant. In this section we will describe the two methods used at the Helwan SLR stations.

2.3.1. The calibration method as used at the half automatic station

The calibration procedure is to measure the time interval between the transmitted pulse and the received pulse, while the signal is attenuated over the entire dynamic range expected on a satellite pass (Hamal, 1978). In this method, the ranging of the laser system is calibrated on a fixed land-based target at a surveyed distance (nearly 500 m as in Helwan SLR-station). Once an average range time is obtained from a series of target measurements, it is possible to compute the calibration constant. The calibration constant t_c can be given as,

$$t_c = t_s - t_m \quad (2)$$

where t_m is the observed range time which defined as the target range time measured by the laser (average of 20 echoes) and t_s is the range time calculated from the surveyed laser-to-target range and corrected for the atmospheric correction as defined by Eq. (3) (Pearlman et al., 1973).

$$t_s = \frac{d_s}{0.15} [(1 + N * 10^{-6}) + (6.917 * 10^{-4})] \quad (3)$$

where d_s is the surveyed distance to the satellite, and N is the refractivity of the atmosphere which is given by $N = 80.29 * (P/T) - 11.9 * (e/T)$, where P , e and T are the pressure in millibar, humidity and temperature in Kelvin respectively.

2.3.2. The calibration method as used at the full automatic station

In the full automatic station, the calibration is carried out using internal calibration method. It is accomplished by ranging on a fixed target placed at a distance of about 1 m from the laser. The computation of the calibration constant is the average of nearly 100 returns (echoes). For the calibrations, the root mean square value is selected corresponding to 2 sigma (Ibrahim, 2011). Fig. 3 shows a typical histogram of the internal calibration of the system carried out on 2 February 2005. The mean value of the calibration is 86.719 ns and the root mean square value is 0.073 ns \approx 10.94 mm.

3. The generations in the Helwan SLR-stations

A fast rise time and short width laser pulses make the time interval measurements at nanoseconds resolution possible. It is important to mention that, the monochromatic nature of the laser output allows for efficient filtering to improve the signal to noise ratio. Generally, the Helwan satellite laser ranging stations consist of laser transmitter, mount with its emitter and receiver, laser ranging electronics, meteorological station, time base and a computer with advanced software and hardware. By the continuous upgrading of the laser radar systems, the precision of single shot ranging observations has improved from tens of centimeters level to a few millimeters level (Degnan, 1993). In this section, we explain the first, second and third generations of the Helwan SLR-stations.

3.1. The first generation of Helwan SLR-station

In September 1974, Helwan Institute of Astronomy and Geophysics (HIAG) erected a laser tracking station at Helwan observatory which was established in the Interkosmos framework. It was a result of the fruitful cooperation between HIAG, Czech Technical University of Prague – Faculty of Nuclear Science and Physical Engineering, Astronomical Council of the USSR Academy of Science in Moscow and the Smithsonian Astrophysical Observatory (SAO).

The first generation station with visual tracking is a mobile container (20-feet) with ruby laser. The container as shown in Fig. 4, is divided into two parts, the outside telescope room with a sliding roof and the inner room with air condition and instruments. The astronomical mount is of four axes and of aperture of 32 cm. The primary time standard is Loran C and HP Cesium clock 5360. The computer is HP 9830 with capacity 16 Kbytes. The detector is a photomultiplier (PMT) of type RCA 8852. The characteristic of the system and the accuracy of measurements are described (Hamal, 1978). The major systems under the computer control are time gate, range counter and epoch counter. The accuracy of distance measurements of satellites is ranging between 30 cm and 60 cm (Hamal, 1978). In 1978, the time base is upgraded to LORAN C and telex communication channel was established. This mobile station has operated until the end of 1980.

3.2. The second generation of Helwan SLR-station

In 1981, due to the cooperation between the Czech Technical University in Prague and the National Research Institute of Astronomy and Geophysics in Egypt, the second generation SLR station has been completed and activated into another new building.

The accuracy of measurements was ranging about 20 cm, obtained during the preliminary MERIT campaign by using 5 ns ruby laser. To obtain better accuracy of the measurements below 10 cm, a psec mode locked train laser is adopted to the station (Jelinkova, 1984). The mount shown in Fig. 5, is of azimuth elevation type and with aperture of 40 cm. The primary time standard is Loran C and HP Cs clock 5360. The type of the computer is HP 2100S with capacity 64 kByte (Novotny and Prochazka, 1984). The detector (PMT) type is RCA 8852 (Hamal et al., 1989). A new time interval counter of type HP-5360 is used (Prochazka, 1989a,b). A new software package is developed for the HP 2100 computer. The major systems under the computer control are time gate, range counter, epoch counter and the laser mount. It was the first full blind tracking SLR station in the world. During the period from 1984 to 1986, a new start detector and HP-5370B time interval counter are used in order to improve the performance and the accuracy. The accuracy of measurements was ranging below 10 cm (between 6 cm and 8 cm). This station has operated until the end of 1986.

3.3. The third generation of Helwan SLR-station

In 1987 the laser system changed again as shown in Fig. 6 to mode-locked Nd:YAG with coudé beam delivery system, as explained in the next section. In 1989 a control electronics

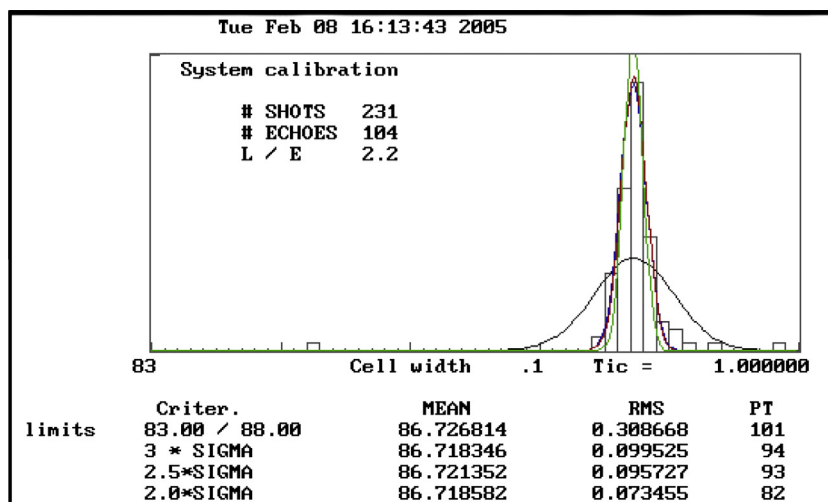


Figure 3 The system calibration of Helwan-SLR automatic station.

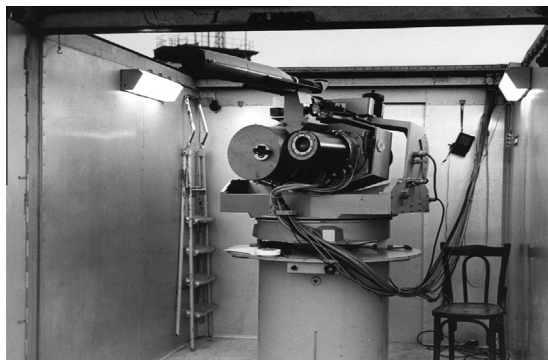


Figure 4 The container of the half-automatic tracking station.

was completely upgraded and SLR station at Helwan was the first fully personal-computer-controlled one in the world. Moreover, a photomultiplier tube (PMT) receiver, amplifiers and discriminator chain were optimized in 1988.

In 1989, the control system based on HP-2100s computer was removed and all operations were carried out using PC (Cech and Novotny, 1989). The laser was rebuilt in order to transmit either a single pulse or semitrain pulses, which is the second part of the mode-locked train (Hamal and Jelinkova, 1989). The output energy at 0.53 μm for a single

pulse is 30 mJ while 80 mJ for semitrain pulses. The pulse duration is 20 ps. The laser radar electronics had been modified to access the PC. The average accuracy estimated for the satellites ranging was 2.8 cm for Lageos, 2.4 cm for Starlette, and 3.2 cm for Ajisai.

Since 1990 the time subsystem is based on GPS system, and since 1991 the communication and data transfer are provided by EARN/Bitnet computer network, later on internet. In 1992, the station of the satellite laser ranging at Helwan has been included into the European Laser Consortium (EUROLAS). The station has been involved in numerous international scientific projects such as MEDLAS and WEGENER. A new PMT of type Hamamatsu H6533 with new package of amplifiers and discriminator is used (Cech, 1994; Cech et al., 1998) instead of the previous one due to its long operating time. In 1999, a high precision meteorological station (MET-3) has been installed to improve the temperature, pressure, and humidity percentage. Moreover, the SR620 time interval counter had been installed (Ibrahim, 2005). The accuracy of measurements below 1 cm becomes available (Ibrahim, 2011).

In 2000 the station has been added to the International Laser Ranging Services (ILRS) and still now. In 2004 two step motors' driver for vertical and horizontal movements has been added. In 2005 with the help of the Czech side, the roof of the station has been motorized. In 2006, the Czech side has been provided the station with a high power supply to use in the station for laser pumping. In 2007 the satellite position prediction software had been modified to use the CPF-formats instead of the IRV formats (Blazej et al., 2008).

4. Laser generators used at Helwan-SLR station

A laser transmitter system consists of a laser active material with its excitation source arranged through an optical system triggered by an electric power supply and controlled by a cooling system. Different types of laser generators are used in the half-automatic and full-automatic laser tracking stations. In the half-automatic station, a Q-switch ruby laser is used. In the full-automatic station, a Nd:YAG laser with different

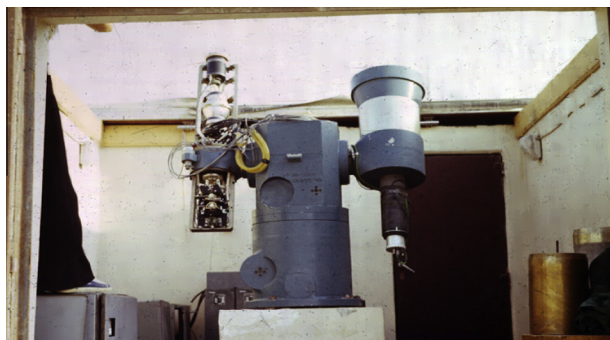


Figure 5 The second generation of Helwan SLR station.

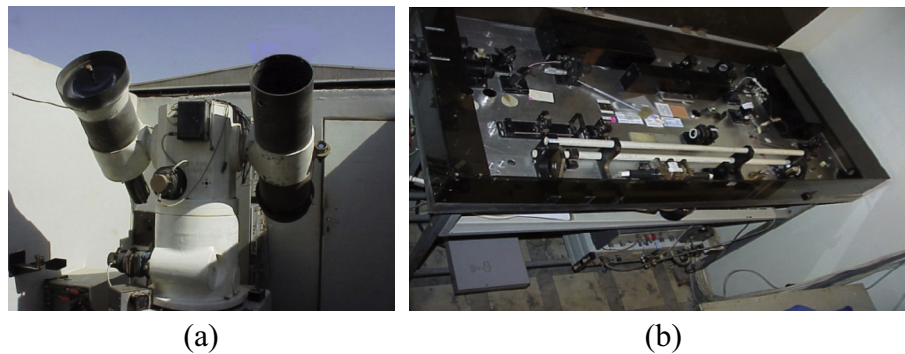


Figure 6 The telescope of the blind tracking station in (a) and the laser system in (b).

output modes of operations is used. The purpose of this section is to give short notices about all the laser transmitters used in Helwan SLR stations.

4.1. The *Q*-switch ruby laser transmitter

The ruby rod that is used in the half-automatic station is of diameter 1.5 cm and of length 12 cm. It is placed in an ellipsoidal pumping cavity at one of its foci. At the other focus a linear flashlamp is placed. The inner surface of the ellipsoidal cavity is coated by silver. The coated ellipsoidal shape of the cavity concentrates the light emerging from the flashlamp on the ruby rod (Masevitch and Hamal, 1975). It produces a laser beam of pulse width of 20 ns and with energy 1 J at the wavelength of 0.6943 μm .

4.2. The mode locked train Nd:YAG laser transmitter

The mode locked Nd:YAG laser transmitter system is consisting of oscillator, single pass amplifier and a frequency doubler. It produces a train of pulses from 2 to 3 pulses per train of wavelength 0.53 μm with output energy 20 mJ/train (Jelinkova, 1984). A saturable dye cell containing ML 51 dissolved in dichloroethane is used to insulate the oscillator from the amplifier. The potassium dihydrogen phosphate (KDP) crystal of type II, is used behind the amplifier as a frequency doubler. The beam passes through the output Galileo (adjustable) telescope which allows achieving an output beam of divergence up to 0.2 milliradian. A He-Ne laser is incorporated into the system for easy alignment of the oscillator/amplifier chain and for pointing services.

4.3. The mode locked single pulse/semirain laser transmitter

This laser transmitter is composed of Nd:YAG oscillator, pulse selector and three amplifiers system (Jelinkova, 1989). The oscillator head consists of Nd:YAG crystal rod placed with the flashlamp in an elliptical silver coated cavity. The beam from the oscillator passes through a pulse selector (Cech, 1989). It is a small solid electrical switching device of two-mode operations, either a single pulse or semi-train of pulses. The amplifier chain consists of three amplifiers of Nd:YAG crystals. As explained before the potassium dihydrogen phosphate (KDP) crystal type II works as the frequency doublers. Finally, the laser beam is directed to the emitter of the mount via four coude mirrors. The output

telescope is used for controlling the divergence angle of the output laser beam up to 0.1 mrad.

The output energy of the laser beam at 0.53 μm is 30 mJ in the single pulse mode, but the energy is 80 mJ for the semi-train of pulse modes. Generally, to distinguish for all the laser generators that are used at Helwan-SLR stations, we summarized their main characteristics as shown in Table 1.

5. Scientific contributions of the Helwan-SLR stations into the SLR network

The measurements from the Helwan SLR stations are accurate and useful for many studies. The data obtained from the Helwan in the period from 1974 to 2011 are discussed (Hamal et al., 1981, 1989; Ibrahim et al., 2001; Ibrahim, 2011). On the other hand, these data are useful in connection with other SLR stations in the network for the study of many applications (Bosworth et al., 1993).

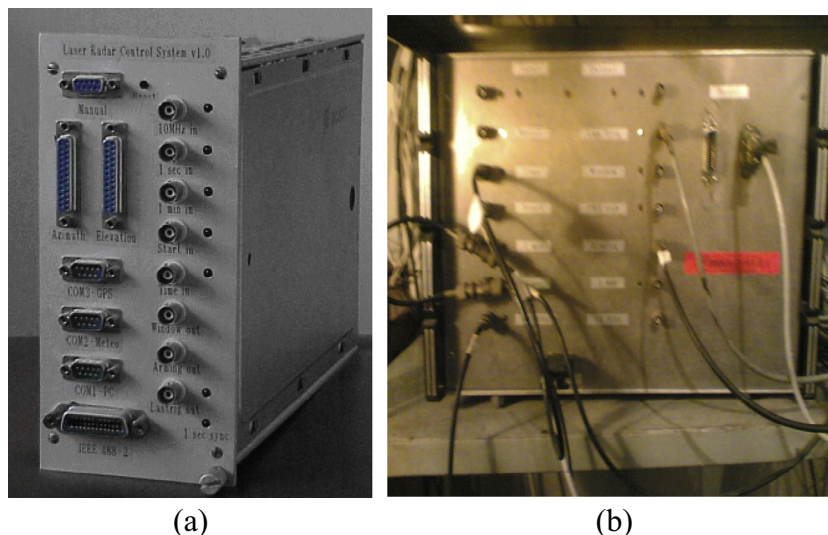
It helps strengthen the reference frame for defining tectonic motion and enhancing the basic models which are used to define crustal deformation at the boundaries of the African plate with European and Arabian plates (Smith et al., 1994a,b). This helps to the monitoring of deformation at the boundaries of the Adriatic, Aegean, Anatolian and Red Sea regions. Measurement of internal deformation of the African plate will also be facilitated in combination with observations from the satellite laser ranging stations at South Africa with other geodetic techniques such as GPS in the region. This deformation would help identify areas of potential earthquake hazard within the African continent (Tapley et al., 1982, 1993).

Data from Helwan station help to improve the resolution of polar motion and to aid in the separation of the forces that drive the polar motion. These include the processes deep in the Earth's core, as well as climate variations and large earthquakes. Accurate measurements of the Earth's rotation rate help to identify the influences of atmospheric variations on the rotations, which are now known by El Nino events.

Global climate features also affect the motion of the geocentric, as it is driven by variations in atmospheric pressure, as well as the forces generated by ocean circulation and global surface water redistribution, including the melting of the ice caps. The inclusion of data from Helwan station improves the ability to identify the relative contributions from the atmosphere, the oceans, and groundwater storage to the behavior of the whole Earth.

Table 1 Characteristics of the laser transmitters used at Helwan SLR-stations.

Laser generator	Ruby laser Q-switched	Nd:YAG ML-train	Nd:YAG single pulse	Nd:YAG semi-train
Wavelength (λ)	0.6943 μm	0.53 μm	0.53 μm	0.53 μm
Energy	1 J	20 mJ	30 mJ	80 mJ
Pulse width	20 ns	70 ps	20 ps	20 ps
Rep. rate	15 pulse/min	2.5 Hz	2.5 Hz	Up to 5 Hz
Beam div.	4 mrad	0.2 mrad	0.1–1 mrad	0.1–1 mrad

**Figure 7** A new laser radar control in Camac unit in (a) and the old LRE in (b).

Laser ranging data on radar altimeter satellites from the Helwan station also support the direct observation of ocean circulation and sea level variations. Altimeter measurements of the topography of the ocean surface depend upon precise knowledge of satellite height relative to the center-of-mass of the Earth. The Helwan station directly supports the measurements in the Mediterranean and Southern Indian Ocean, and in addition, through strengthening geographic coverage of the orbit, it also strengthens altimeter measurements everywhere.

6. Prospective modifications of new laser radar control (LRC)

The total numbers of passes observed during 2007, 2008, 2009 and 2011 are, 54, 21, 6 and 2 (Ibrahim et al., 2011). It shows that, although the precision of the measurements of the Helwan SLR-station is good, its performance became bad especially during the recent years. That is the reason why the observations from H-SLR station are reduced. That performance is referred in fact to some reasons; one of them is the old Laser Radar Electronics (LRE) unit which installed at the station 20 years ago. There is upgrading of new LRC of the satellite laser ranging station at Helwan. It is expected to improve the performance of the Helwan SLR-station in the near Future.

The new laser radar control system is completely redesigned. It is based on powerful 80C188EB microprocessor operating with 1 MB memory. Special circuits for range and epoch reading are included. The control system is connected to the main station computer via fast RS232C interface based

on 16550 chips. A second serial port is used for high accurate meteorological station MET-3. Two DC servomotors (for azimuth and elevation) are controlled in closed loop feedback. Special microchips HP HCTL-1100 are used. HCTL-1100 is a high performance, general purpose motion control IC. A very precise time interval counter (resolution 20 ps) SR620 is connected via HP-IB interface based on second generation of HP-IB microcontroller Ines i7210. The control system consists of two printed boards in Camac unit with a size $14 \times 22 \times 30$ cm, as shown in Fig. 7. A firmware is written in C language and Assembler and it is very flexible. Firmware is compatible with old LRCS system on command level (Mirosalv Cech, private information). A computational power of microprocessor is sufficient to implement simple real time operating system (in future). This system will increase the reliability of the station; unfortunately, it is not installed yet.

7. Conclusions

We discussed the satellite laser ranging in Egypt from the period 1974 up to now. We studied the three generations of the Helwan-SLR stations from the point of view of the accuracy of the measurements. It is found that, the accuracy of measurements is ranging between 30 cm and 60 cm in the first generation, 10 cm and 20 cm in the second generation and less than 5 cm in the third generation. We also found that the precision below 1 cm is possible from the Helwan SLR-station. We discussed all the laser generators that used at the Helwan SLR

stations for increasing the power and the precision of the range measurements. We showed the importance of the satellite laser ranging from Egypt and their contributions. We also explained the requested modification for increasing the performance of the Helwan-SLR station in the near future.

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