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ATMOSPHERIC ATTENUATION AND SCINTILLATION EFFECTS ON THE RANGE OF EDM INSTRUMENTS

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Abstract

This investigation was aimed to study the range of various Electronic Distance Measurement (EDM) instruments used in surveying engineering assuming different weather conditions and different terrain altitudes, by controlling every parameter influencing the measurements and contrasting the results with the information provided by the manufacturers. The first step consisted in determining the EDM "real" optical wavelength to be used for control against the manufacturers provided values. Consequently, a spectroscopy test of the lasers installed in every EDM instrument was carried out at the ESA-VSC (European Space Agency (ESA) and Val Space Consortium (VSC)) laboratory. The second step was to study the total measurement range of each instrument in different weather conditions and at different altitudes. To answer this question, three experimental tests were carried out at three different locations in eastern Spain, separated by distances of less than 90 km, and altitudes ranging from sea level to about 2000 meters. Due to the influence of atmospheric effects on the EDM ranges, some atmospheric parameters were carefully measured during the process, i.e.: pressure, temperature and humidity.

By the experiments carried out, a large dependence of altitude in the range was detected range. A decrease in range at midday hours was observed in all cases studied. It was found that aerosol scattering causes a reduction of EDM range in all cases. The great influence of atmospheric scintillation on the ranges of the EDMs became evident in all results. Furthermore, as expected, a correlation between laser beam divergence and range, which increased with altitude, was also found.

In certain projects where range in electronic distance measurement is essential, it is advisable to conduct a preliminary study to evaluate the actual range of the particular instrument before it is used.

Subject headings: Experimentation; Distance measurement; Surveys; Instrumentation.

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Keywords: EDM range, Atmospheric turbulence, Free-space optics, Atmospheric attenuation.

Introduction

Over the past 50 years, distance measurement technologies have greatly advanced. The surveying tape was replaced by EDM for long distances, and subsequent improvements in range, accuracy, mass reduction and speed of operation of this technology eventually enabled the EDM to be integrated into electronic theodolites resulting in compact total stations. These total stations, which continued to require retroprisms for distance measurements solved many logistical issues in surveying and lightened the workload of surveyors (Lambrou and Pantazis 2010).

Due to the introduction of GNSS techniques, the use of EDM instruments in survey engineering has decreased in recent years. However, in many cases where GNSS cannot be used because a clear window to the sky is needed for reliable measurements or because it takes too much time to achieve the required accuracy, EDM technology play a vital role in filling this gap. Nowadays, EDMs are universally used to measure large engineering structures such as dams and tunnels, and they still play a key role in establishing position in land surveying in cases where the Global Navigation Satellite System (GNSS) is unable to be used.

Studies regarding the accuracy of the EDM have mainly focused on baseline calibrations. However, little attention has been paid to the comparison of the range of the EDM, in cases where every parameter involved in the measurement is controlled (Burnside 1991).

Essentially, research on laser propagation through the atmosphere involves studying the interaction of the atmospheric medium and laser radiation, i.e., scattering and absorption of radiation by the medium, as well as studying how the laser changes its own properties owing to atmospheric effects (Zhengfang1997).

The aim of this paper was to study the range of different EDMs and the relationship between range and atmospheric attenuation and scintillation, calculated using a specific methodology under controlled conditions.

Theoretical Background

Knowledge of laser beam propagation in the atmosphere is required for many purposes such as optical communication, earth resource remote sensing, laser range finding or EDM measuring, as in the case under study.

The transmission of electromagnetic waves through the atmosphere is governed by attenuation due to both scattering and absorption by all the atmospheric species present in the path of propagation (Salman 2009) and by atmospheric scintillation.

Atmospheric absorption

Absorption results from the loss of a part of the power transmitted as a consequence of energy collection by molecules and particles in the atmosphere. Fundamentally, it is water vapor and decreased carbon dioxide and oxygen molecules that most contribute to this phenomenon, although with the wavelengths used in this work, the absorption effect of the air is irrelevant (Rephaeli *et al*, 2013).

Atmospheric scattering

Atmospheric scattering is produced by the interaction of photons with atoms and molecules in the propagation medium. The scattering causes an angular redistribution of radiation, with or without modification of the wavelength.

Atmospheric scattering shows greater variability than absorption. In this case two similar atmospheric phenomena, which act in different ways to produce distinct scattering effects, can be distinguished: molecular and aerosol scattering. These two scattering effects are usually associated with mist and haze.

In the case of molecular scattering (misty conditions) scattering from the gas molecules in the atmosphere (Rayleigh scattering) contributes to the total attenuation of the electromagnetic radiation.

Molecular scattering is negligible at infrared wavelengths, and Rayleigh scattering mainly affects wavelengths ranging from the ultraviolet to the visible spectrum. This type of scattering is responsible for the blue color of the clear sky.

Aerosol scattering (Mie scattering) occurs when the particle size is the same order of magnitude as the wavelength of incident light.

The concentration, composition and size distribution of aerosols vary temporally and spatially; therefore, it is difficult to predict the attenuation caused by aerosols. Although the concentration is closely related to the optical visibility, there is not a unique distribution of particle sizes for a given visibility.

Atmospheric scintillation

The propagation of electromagnetic waves through the atmosphere is severely affected by random fluctuations and discontinuities in the refractive index of air, i.e., resulting in optical turbulence (Sivaslıgil et al. 2013).

As a result of the fluctuating nature of the refractive index in a turbulent medium any laser beam that propagates through the atmosphere experiments deflections. These displacements are always perpendicular to the initial unperturbed direction of propagation, and arise from the beam phase fluctuations. This phenomenon is commonly known as laser beam wandering because of the dancing the beam performs over a screen (Perez and Funes 2012).

Atmospheric scintillation is the result of thermal turbulence within the propagation medium, and is produced by a random distribution of air cells, which vary in size (10 cm - 1 km). The amplitude and frequency of atmospheric scintillation depend on the size of the cells compared to the diameter of the beam. Figure 1 schematically shows the variations in amplitude and frequency of the signal received, as well as the deflection and widening of the beam. A mixture of these heterogeneities causes atmospheric scintillation.

Figure 1. Effect of heterogeneities of different sizes in the propagation of a laser beam (atmospheric scintillation)

Checking Methodology

The range of an EDM system depends mainly on the emission power of the EDM, the EDM detector sensitivity, the reflector used, the beam's divergence and the transmission medium of the electromagnetic radiation. The reflector used in our tests was a total reflection prism. Since its influence has not been studied; the same reflector has been used throughout all the experiments carried out, so it is considered constant. The emission power, beam divergence and detector sensitivity of the EDM is also constant for each instrument. Therefore, the only variable that affects the range for each EDM is the transmission medium.

The first step consisted in choosing the instruments to be checked; the instruments Leica TS02, Trimble S6 DR300, Topcon GPT7500 and SOKKIA NET1 were chosen in order to represent different brands and different nominal accuracies.

The wavelength of a diode laser is determined primarily by the band gap of the semiconductor material though there is also strong dependence on diode temperature and current density (Dobosz 2012). Therefore, the second step was to accurately measure the actual emission wavelengths of the instruments being analyzed.

The last step was to carry out an experiment consisting of series of measurements under different atmospheric conditions in order to obtain the range of each EDM under study.

Thus three experimental tests were carried out in April 2013, in three different locations in eastern Spain, separated by a distance of less than 90 km from each other, and up to a maximum elevation of about 2000 meters namely including:

- Malvarrosa beach in Valencia, located at sea level.
- Albentosa (Teruel province, Autonomous Region of Aragón), located at an altitude of 1000 m.

- Javalambre peak (Teruel province, Autonomous Region of Aragón), located at an altitude of 2019 m.

Laser beam divergence data

A laser beam divergence is a measure for how fast the beam expands far from the beam waist. A low beam divergence can be important for applications such as the use of EDMs. Laser beam divergence influences the range of EDMs. The laser beam divergences according to the technical specifications of each instrument are shown in Table 1.

Table 1. The laser beam divergence according to the technical specifications of each instrument. Sources: (Leica, 2013), (Trimble, 2013), (Topcon, 2013)

Aerosol scattering occurs when the particle size is the same order of magnitude as the wavelength of incident light. Aerosol absorption also depends on the incident wavelength; the wavelength of the instruments was accurately measured.

Spectroscopy techniques were used for the optical study of the laser installed in every EDM instrument. The experiments were performed in the ESA-VSC High Power Space Material Laboratory.

Test procedure

Optical spectroscopy is a non-destructive technique that measures radiation intensity as a function of the photon's wavelength (λ). The light from the laser installed in the EDM instrument was focalized by using a lens for visible light, and an optic fiber was placed on the lens focus in order to lead the collected light into a Newport spectrometer with a focal length of 54 mm. The setup of the experiment is shown in Figure 2. This spectrometer is provided with gratings that allow the wavelength to be resolved in the range between 190 and 1000 nm with a resolution of 0.5 nm. The detector used is a 1024 element silicon NMOS photodiode array. The gratings of the spectrometer separate the different wavelengths of the incident light and their intensity is recorded by the photodiode array which is finally represented as a function of the photon's wavelength.

Figure 2. Diagram of the optical spectroscopy setup.

Results and discussion

After the calibration of the set up with the well-known mercury line at 365 nm of a Hg-Xe lamp, the spectra of the laser from the stations under study were recorded. The background was subtracted and the emission was fitted using Gaussian functions. Our attention was focused on the highest intensity, since it is the intensity most likely to be detected by the EDM instrument. Figure 5 shows the normalized optical intensity for each EDM instrument. The spectra were normalized due to the difficulty involved in comparing the intensity between them. The maximum emission (λc) of two of these, Trimble and Leica, was close to 660 nm while the Topcon and Sokkia emitted around 680 nm. On the other hand, Timble and Topcon had the minimum full width at half maximum (FWHM). This parameter is related to the monochromaticity of the emission. In the figure, λc and FWHM are depicted with arrows in the Topcon's spectrum. Table 2 presents for each EDM the wavelength measured in the laboratory and the nominal one which is given by the manufacturer.

Figure 3. Normalized optical emission from the EDM instruments under study.

Table 2. Measured and nominal Wavelengths of the EDMs

The experiment

Study of molecular scattering

In order to study this phenomenon, observations were made in the three selected areas on three separate days, taking care that atmospheric turbulence was minimum. A clear day with light west wind was chosen, which helped in ensuring the highest visibilities for these areas. The relative humidity was around 20% and the levels of aerosols in the atmosphere were low. The observations were made at intervals of two hours from 7:00 am to 21:00 pm.

The experiment was designed to determine and quantify how the decrease in atmospheric molecular concentration (correlated with increasing altitude), and the temperature, affected the range of EDMs studied.

Regarding the results of the observations, Figures 4, 5 and 6 show the results of the one day observations at sea level, an altitude of 1000 meters and an altitude of about 2000meters (specifically 2019 m), respectively. Figure 7 shows the range in function of altitude for every instrument checked.

Figure 4. The range of EDM analyzed at sea level (Valencia)

Figure 5. The range of EDM analyzed at an altitude of 1000 meters (Albentosa)

Figure 6. The range of EDM analyzed at an altitude of about 2000 meters, actually 2019 meters (Javalambre)

Figure 7. Variation of the range of each EDM in relation to the altitude

Study of scattering by aerosols

In order to study this phenomenon, two sets of observations were made on two different days at the Malvarrosa beach in Valencia. The observations were made at intervals of two hours from 7:00 am to 21:00 pm and atmospheric conditions where constant throughout every observation period, and the results are shown in Figure 8.

On the first day, the atmospheric conditions were as follows: Northeast wind (marine origin) of 15 km / h and 91% relative humidity. Under these conditions, the amount of aerosols, and especially sea foam and sand, was very high.

On the second day, the meteorological parameters were very different from on the first day: with west wind (continental origin) of 20 km / h and 15% relative humidity. Under these conditions, the amount of aerosols was very low, and visibility was very high.

The experiment was designed to determine and quantify how the amount of aerosols affects the range of EDM studied.

Figure 8. The influence of the scattering by aerosol over one day period to the range of each EDM.

Study of atmospheric scintillation

In order to study this phenomenon, two sets of observations were made on two different days at Albentosa in Teruel, at an altitude of 1000 m. The observations were made at intervals of two hours from 7:00 am to 21:00 pm and atmospheric conditions were constant throughout each observation period.

On the first day, weather conditions not favoring atmospheric turbulence were chosen: with a west wind of 15 km / h and temperatures around 10 ° C maximum.

The second day was hotter (maximum temperature around 25 º) and there was no wind, meaning that the conditions were suitable for the generation of atmospheric turbulence.

The design of the experiment aimed to determine and quantify how much atmospheric turbulence affects the range of each EDM studied.

Figure 9 shows the influence of the atmospheric scintillation to the ranges of each EDM over the second day, in which atmospheric turbulence was intense. The ranges measured for each of the EDM used to study atmospheric scintillation over the first day, in which atmospheric turbulence was low, are shown in Figure 5.

Figure 9. The influence of the atmospheric scintillation to the range of each EDM over one day period.

Conclusions

The wavelength values offered by different manufacturers are almost exactly the same as the values measured in the laboratory (differences not exceeding 1%).

Based on the study of molecular scattering two basic aspects can be pointed out:

- On the one hand, the graphs clearly show a large dependence on altitude in the range for each of the EDM studied. Specifically, for the Leica TS02 EDM, which has the highest variation depending on height, the range increased by 41.5% at an altitude of 2000 meter. This is due to the decrease in the altitude of the molecular concentration, especially water vapor, carbon dioxide and oxygen.
- Furthermore, as shown in Figures 6, 7 and 8, a decrease in range averaging 3% at midday hours was observed in all cases studied. These values are higher at sea level (6%) and hardly noticeable at an altitude of 2000 meters (0.5%). This phenomenon responds to increased spectral absorption lines due to the Doppler Effect, as the molecules are moved with respect to the incident wave, and due to the collisions caused by the interaction between molecules. This phenomenon reaches its peak at the maximum temperature during the midday hours. On the other hand, this phenomenon decreases with altitude due to decreases in molecular concentrations and atmospheric pressure as altitude increases.

The aerosol scattering is evidenced in both sets of observations, causing a 12% average reduction of range for the EDM studied, with a great abundance of sand particles, sea foam and high humidity. It is worth noting that the decrease in the range is not the same for every instrument checked. The reduction in range is 9% for the Topcon GPT7500 EDM and 16% for the Leica TS02 EDM.

The great influence of atmospheric scintillation on the range of EDM has become evident in tests. Atmospheric turbulence is the most influential phenomenon in reducing the range. Decreases and increases of 51% were recorded in tests carried out over a one day period for Topcon GPT7500 EDM. The tests showed that the range could be decrease up to 40% in a one-hour interval.

As expected, a correlation between laser beam divergence and range was found and increased with altitude, as shown in Figure 7. In general, Leica TS02 Total Station, which has the smallest beam divergence angle, has the greatest range. On the other hand, Topcon GPT7500 Total Station, which has the largest beam divergence angle, has the least range.

Therefore, it can be concluded that in certain surveying engineering projects where range in electronic distance measurement is essential, it is advisable to conduct a study to evaluate the actual range of the particular instrument to be used and, above all, to plan meteorological conditions as carefully as possible, given that the nominal precisions offered by manufacturers are not always accurate. With a calibration procedure in place and proper planning prior to the execution of a project, one can save time, money and negative surprises.

Although, theoretically speaking, aerosol scattering depends on the incident wavelength, no relation has been found between incident wavelength and range in the tests carried out.

Since weather conditions have a significant influence on the range of EDM, in a future study it would also be interesting to study how accuracy is influenced by weather conditions.

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