Journal scientific and applied research, vol. 22, 2022
International Journal

Original Contribution

ISSN 1314-6289

THE INFLUENCE OF AIR DENSITY ON RECEIVED LASER SIGNALS

Kiril Yanchev

DEPARTMENT OF GEODESY, FACULTY OF TECHNICAL SCIENCES, KONSTANTIN PRESLAVSKY UNIVERSITY OF SHUMEN, BULGARIA

E-mail: k.yanchev@shu.bg

ABSTRACT: *The subject of the research is to make a correct assessment of the atmospheric parameters and to choose a model for their removal, achieving the required accuracy and high productivity with minimal material costs when conducting laser measurements.*

KEYWORDS: *results, measurements, horizontal movements.*

1. Introduction

The values measured by the terrestrial laser system (TLS) (distance, horizontal and vertical angles, intensity and actual color of the surface of the objects from which the signal is reflected) are adversely affected by the atmosphere, especially its surface layer. In this layer there are significant changes in air density, movement and fluctuations of air masses, which leads to a decrease in the speed of light propagation and change in the direction of radiation (refractive phenomenon), as well as to reduce the intensity of the reflected signal and incorrect color reproduction (so-called "fog" effect) [6]. As a result of the influence of the refraction of light rays, the rangefinder measures the optical length of the line. Its length exceeds the geometric length.

2. Errors caused by air tightness and ways to eliminate

The refractive index *n* for specific environmental conditions is usually presented as a function of air density, the arguments of which are air pressure, temperature and humidity, measured using a barometer and hygrometer [6]. Since the principle of measuring distances with light rangefinders and TLS is similar, the formula can be used to calculate the refractive index of electromagnetic waves, taking into account meteorological data when scanning an object:

$$n_R = 1 + \frac{n_G - 1}{1 + \alpha(T + 273.16)} \frac{p}{760} - \frac{55^e}{1 + \alpha(T + 273.16)} * 10^{-9}, \quad (1)$$

where:

α − gas constant equal to 1 / 273.16;

p − atmospheric pressure, in mm of mercury;

e − water vapor pressure in air, in mm of mercury. This parameter is related to the absolute humidity by the Mendeleev-Klaiperon equation;

T − air temperature in kelvin;

n_G − refractive index of standard air calculated by the formula.

$$(n_{G-1} - 1) * 10^{-7} = 2876.04 + \frac{16.288}{\lambda^2} + \frac{0.136}{\lambda^4}, \quad (2)$$

where:

λ - wavelength of the emitter.

The rate of propagation of electromagnetic oscillations in a dense medium (especially in air), as can be seen from formulas (2.7) and (2.8), depends on the physical properties of the medium and the length of the electromagnetic wave. The refractive index of electromagnetic waves under normal environmental conditions for a given wavelength can be calculated by the formula:

$$(n_R - 1) * 10^{-8} = A + \frac{B}{C - \sigma^2} + \frac{D}{E - \sigma^2} + \frac{F(G - \sigma)}{K + (G - \sigma)^2}, \quad (3)$$

where:

A, *B*, *C*, *D*, *E*, *F*, *G*, *K* − coefficients;

σ − the reciprocal wavelength in vacuum, c μm^{-1}.

Depending on the TLS model, expression (1) or (2) is used in measurements to determine the range to exclude the influence of atmospheric conditions.

In theory, the integral index of refraction of electromagnetic radiation in air is usually calculated by the formula:

$$n_R = \iiint F(R, T, p, E) dT dP dE, \quad (4)$$

where:

F(R,T,p,E) − stochastic function of the integral value of the refractive index, depending on the meteorological parameters of the environment and the length of the path of propagation of electromagnetic radiation, where R is the distance from the radiation source to the reflecting surface and E is the absolute humidity g/m^3.

Based on expressions (1), (3) and (4), a formula can be obtained for residual errors in range measurements caused by environmental influences

$$\delta R(T, p, E) = \frac{c \times \tau}{2}[(\iiint F(R, T, p, E)dTdPdE) - u], \qquad (5)$$

where:

u − refractive index value calculated by formula (1) or (2).

Since formulas (1) and (3) are determined on the basis of empirical data, it can be concluded that in addition to the average integral refractive index, they also take into account the curvature of the laser beam.

Refractive errors lead to distortion of the direction of light rays when the refractive index changes. When measuring horizontal angles, main effect is the lateral refraction.

Errors related to the action of lateral refraction are systematic, especially in a calm image, i.e. the stable location of the air layers passed by the sighting beam [6]. To calculate the corrections for the effect of lateral refraction along the path of the specified distance, we have to measure the horizontal gradients of temperature and humidity. The formulas for calculating the corrections for lateral refraction in the case of the uniform refractive field are [6]:

− for temperature

$$\delta_{\ddot{\Gamma}} = -10.9\frac{P}{T^2}S\frac{\partial T}{\partial y}, \qquad (6)$$

− for humidity

$$\Delta\delta_{\ddot{\Gamma}} = -1.40\frac{P}{T}S\frac{\partial T}{\partial y}, \qquad (7)$$

where:

$\delta_{\ddot{\Gamma}}$ − correction in the measured direction due to a change in temperature along the measured distance;

$\Delta\delta_{\ddot{\Gamma}}$ − correction in the measured direction related to the change of humidity along the route of the measured distance;

$\frac{\partial T}{\partial y}, \frac{\partial E}{\partial y}$ – horizontal gradients of temperature and humidity;

S − measured distance;

T − absolute temperature;

P − pressure, millimetre of mercury.

Horizontal humidity gradients affect the refractive angle much less than temperature gradients. The effect of the pressure gradient on the angle of lateral refraction is insignificant (thousandth of a second) [6].

From the experimental studies presented in [6], we can conclude, that the daily course of errors due to refraction is sinusoidal. Therefore, the correction values of the angular measurements related to the influence of lateral refraction will change over time. Since the duration of measurements at a station can reach 1.5–2 hours, the correction value of the angular measurements must be set as a function of time. There is a relationship between temperature and humidity gradients: when there is a significant temperature gradient, there is significant humidity gradients and vice versa due to the very nature of the gradients. On a wetter surface, the amount of evaporation is higher, so more heat is used, and the air temperature above this surface is lower. As a result, gradients of humidity and temperature appear above the surface boundary. If two equally humid surfaces absorb different amounts of heat, then the evaporation from the hotter surface is more significant and along with the temperature gradient above the limit, humidity gradient also appears. This means temperature and humidity gradients are accompanied [6].

The observation time, which is the most optimal in terms of the influence of refraction, is the most favorable in terms of the influence of turbulence. These two phenomena result from the same physical preconditions; which also proven by experimental studies. Therefore, it can be concluded that when measurements are made during still images, errors due to both refraction and turbulence are minimized simultaneously. The errors obtained correspond to the conditions of low turbulence [6].

In the physical sense, horizontal refraction is a function of the refractive index of electromagnetic waves in different layers of the atmosphere. This functional dependence is particularly difficult to describe mathematically for local inhomogeneities of the atmosphere. In order to take into account the horizontal refraction, a formula is used that includes integral indicators of the atmosphere (temperature, pressure and humidity). Studies carried out by various experts show that significant distortion in the measured direction can be introduced by the intrinsic refractive fields of the structures (in some cases up to 20″ at horizontal angles when the rays pass close to structures at a distance of 1.5 m).

The most studied of all phenomena is vertical refraction, which requires temperature and pressure measurements to be taken into account [1].

In conclusion, the errors in the measured angles caused by the influence of meteorological properties of the environment can be recorded as:

− for horizontal corners

$$\delta\varphi_{T,p,E} = G(R_{XY}, T_{XY}, p_{XY}, E_{XY}); \quad (8)$$

− for vertical angles

$$\delta\theta_{T,p,E} = G(R, T_Z, p_Z, E_Z), \quad (9)$$

where:

$G(R_{XY},T_{XY},p_{XY},E_{XY})$ and $G(R,T_Z,p_Z,E_Z)$ − stochastic functions describing the distortions of the measured horizontal and vertical angles depending on the meteorological properties of the environment;

$\delta\varphi_{T,p,E}$ and $\delta\theta_{T,p,E}$ – error values in horizontal and vertical angles caused by the influence of meteorological properties of the environment.

3. Conclusion

Oscillations attenuation of electromagnetic waves caused by the atmosphere is particularly characteristic of the optical range used in all TLS. This type of atmospheric influence leads to a reduction in the range of scanners in the first place and incorrect determination of the reflectivity of the object during ground-based laser imaging.

References

[1] Ivanov S. „Spatial data models“. Journal scientific and applied research. Volume 20. Шумен 2021. Университетско издателство „Еп. К. Преславски“. ISSN: 1314-6289. Стр. 40 - 46.

[2] Merzenin, AV Symmetric model of weakening of the influence of lateral refraction in azimuthal measurements [Text] / AV Merzenin // Izv. universities. Geodesy and aerial photography. - 1981. - № 4. - P. 25–29.

[3] Selikhanovich, VG Geodesy [Text]: textbook for universities / VG Selikhanovich. - M .: Nedra, 1981. - 544 p.– 2 h.

[4] Sudakov, SG Basic geodetic networks [Text] / SG Sudakov. - M .: Nedra, 1975. - 368 p.

[5] Yunoshev, LS Lateral refraction of light when measuring angles [Text] / LS Yunoshev. - M .: Nedra, 1969. - 96 p.

[6] Yanchev K., Laser Scanning - Achievable Precision in Photogrammetry, Remote Sensing and Geodesy, ISBN 978-619-201-573-2.