DETERMINATION OF THE REFRACTIVE INDEX OF AIR WHEN MEASURING LINES WITH LIGHT SENSORS IN GEODETIC NETWORKS

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Abstract

This article presents about the refractive index which is equal to the speed of a specific wavelength of light in vacuum space divided by that same wavelength's speed in an object. This contribution focuses on geodetic sensor systems and sensor networks for positioning and applications. The key problems in this area will be addressed together with an overview of applications. Global Navigation Satellite Systems (GNSS) play a central role in many applications like engineering, mapping and remote sensing.

Key words: refraction, geodetic observations, air temperature, the length of line.

Introduction. Refractive index, commonly known as the index of refraction, is a measurement of how much a light beam bends when it passes through one medium and into another. The refractive index n is defined as the ratio of the sine of the angle of incidence to the sine of the angle of refraction, i.e., n = sin I / sin r, where I is the angle of incidence of a ray in vacuum (angle between the incoming ray and the perpendicular to the surface of a medium, called the normal) and r is the angle of refraction (angle between the ray in the medium and the normal). The refractive index is also equal to the speed of a specific wavelength of light in vacuum space divided by that same wavelength's speed in an object. This contribution focuses on geodetic sensor systems and sensor networks for positioning and applications. The key problems in this area will be addressed together with an overview of applications. Global Navigation Satellite Systems (GNSS) play a central role in many applications like engineering, mapping and remote sensing. These techniques include precise positioning, as well as applications of reference frame densification and geodynamics, to address the demands of precise, real-time positioning of moving platforms. In this paper, we try to determination of the refractive index of air when measuring lines.

Materials and methods. To measure the lengths of lines of polygon metric moves, the basic sides of triangulation, as well as networks for various purposes (tethering, surveying, etc.), rangefinders of the ST, SM-3, TD-2, Kristall, etc. series are used.

The basic formula for calculating the distance measured by the range finder is

$$D = \frac{\upsilon\tau}{2} = \frac{\upsilon\varphi}{4\pi f}$$

Differentiating this expression and passing to the relative mean square errors, we obtain

$$\frac{m_D}{D} = \sqrt{(\frac{m_\vartheta}{\vartheta})^2 + (\frac{m_\varphi}{\varphi})^2 + \left(\frac{m_f}{f}\right)}. \qquad (1)$$

From formula (1) it can be seen that the accuracy of measuring distances with a light range finder depends on the errors in determining the operating speed of light m, frequency m, phase difference m_φ. In addition, it depends on the errors in determining the rangefinder constant and geometric corrections (centeringme and reduction m.) [4]. The influence of these errors on the accuracy of the measured distances is different. The errors in the operating speed of light and frequency act in proportion to the length of the line.

In triangulation of I and II categories, the lengths of the sides are 2000-5000 and 500-3000 m, the accuracy of measuring the basic sides is 1:100,000 and 1:50,000, respectively, 360 and 190 m. When constructing reference geodetic networks in cities and industrial sites, the mean square error of distance measurements should be ⩽ l cm [1].

The influence of individual errors on the accuracy of distance measurements should be evaluated taking into account the lengths of the lines and the accuracy of their measurements. As is known, the error in the operating speed of light depends on the error in determining the speed of light in vacuum and the error in the refractive index of air. The speed of light in vacuum is known with a relative accuracy of 1:750,000, so its error can be neglected.

The error of the refractive index of air depends on the error due to the dispersion of light waves and due to inaccurate accounting for temperature, pressure and air humidity. Since the errors for the dispersion of light waves and air humidity do not exceed ±10^(-6) [2], they can be neglected.

The refractive index of air for light waves is calculated according to the well-known empirical formula of Barell and Sears, which for a wavelength of light 2 = 0.56 µm can be represented as follows

$$(n-1)\cdot 10^6 = \frac{1}{T}(109.22P - 15{,}02e) \ , \qquad (2)$$

where T is the air temperature in degrees Kelvin (T=273° + t, where t is the temperature in degrees Celsius); P and e - atmospheric pressure and water vapor pressure in mm Hg. Art.

Let us analyze the effect of errors in measuring air temperature and pressure on the accuracy of determining the refractive index. To do this, we find the partial derivatives

$$\frac{\partial n}{\partial T} = -\frac{1}{T^2}\,(109{,}22P - 15{,}02e)\cdot 10^{-6} \qquad (3)$$

$$\frac{\partial n}{\partial P} = \frac{109{,}22}{T}\cdot 10^{-6} \qquad (4)$$

Replacing the differentials with finite increments, we get:

1) from equation (3) for Δt=±1°C in the range -10°C⩽t⩽+30°C, 760 mm Hg. Art. ⩾P⩾660mmHg St.: ±1.2 10^{-6}⩾Δn (t)⩾0.9·10^{-6}, or on average Δn (t) ≈ ±1·10^{-6};

2) from equation (4) for Δp=±1 mm Hg. Art. in the range -10°C⩽t⩽+30°C, we find: Δn (P) ≈ ±0.4 · 10^{-6}

Since the errors of temperature and air pressure are independent, according to the rules of error theory, we write

$$m_n\cdot 10^{-6} = \sqrt{(\frac{\partial n}{\partial t})^2 m_t^2 + (\frac{\partial n}{\partial P})^2 m_P^2} \ ,$$

or taking into account the obtained coefficients

$$m_n \cdot 10^{-6} = \sqrt{m_t^2 + 0{,}16\, m_P^2} \qquad (5)$$

The error in determining the refractive index m_n affects the distances measured by the range finder as follows [2]:

$$\frac{m_{D_n}}{D} = \frac{m_n}{n} \quad ,$$

Because

$$n \approx 1\,,$$

That

$$\frac{m_{D_n}}{D} \approx m_n$$

When measuring the distance, the basic sides of the triangulation by the error due to the error while due to the refractive index must be ⩽±5·10^{-6}. In the case of measuring the lengths of lines of polygonometric moves, it is enough to know the refractive index with an error of ±10^{-5}.

Analyzing formula (5), taking into account the accepted values m_n, we can draw the following conclusions:

1) when measuring the basic sides of the triangulation of the 1st category, the errors in determining the air temperature can be ± 3 °, and the pressure - ± 10 mm Hg. Art.;

2) in the case of measuring the lengths of the lines of polygonometric moves and the basic sides of the triangulation of the II category, the root-mean-square errors in determining the temperature can be ± 5 °, pressure - ± 10 mm Hg. Art.

Analysis of Literature. When studying the influence of meteorological factors on the accuracy of light and radio range measurements, the main thing is to study the nature of the distribution of temperature, pressure, and air humidity in the lower layers of the atmosphere, depending on the state of the weather, measurement time, properties of the underlying surface, etc. Significant information about the distribution of temperature in the lower layers of the atmosphere are available in general courses in atmospheric physics [6] and in the literature on meteorology and climatology [5], as well as in [3], [7], [8], [9], etc.

According to research by M. T. Prilepin [8], the average air temperature along the beam can be determined from the results of measurements at the end points of the line with an error of ±0.1 to ±1°5C. According to M.V. Ratynsky [9], for average conditions, this error is ±0.7 °.

Studies have been carried out [10] on the accuracy of determining the air temperature based on the results of its measurement at one point. The root-mean-square value of the difference between the average of the air temperature values at two points and the temperature at one of them turned out to be ±0.9 for clear, calm weather: the line lengths were from 5 to 11 km; measurements were made on signals with a height of 16–30 m.

L.S. Yunoshev [11] studied the correlation between the line length and the absolute value of the temperature difference at its ends. The correlation coefficient turned out to be +0.3, which indicates a weak dependence of the modulus of the temperature difference on the distance between meteorological posts. The modulus of the temperature difference at the ends of the lines varied from 0° to 3.3° and averaged 0.65; measurements were made in the steppe flat terrain: thermometers were installed at a height of 1.4 m; distances between meteorological posts - 4-6 km.

The presented research results allow us to conclude that the average air temperature along the beam, according to the results of measurements at one of the end points, can be determined with an accuracy of ±1°C. Since when measuring lines in polygonometric passages, the air temperature must be known with an accuracy of ±5°C, we have analyzed the daily temperature variation. The dependence of temperature t on time T of the day can be represented in the following form

$$t = c_0 + c_1 T + c_2 T^2 \;. \qquad (6)$$

The coefficients c_0, c_1, c_2 are determined by the least squares method. In a coordinate system with origin at a point

$$\begin{cases} t_0 = \dfrac{[t_i]}{n} = +21°{,}9 \\ T_0 = \dfrac{[T_i]}{n} = 14{,}5 \text{ час} \\ (i = 1{,}2, \dots, n). \end{cases}$$

Function (6) for t=+25° in clear weather in summer takes the form (see Fig.1).

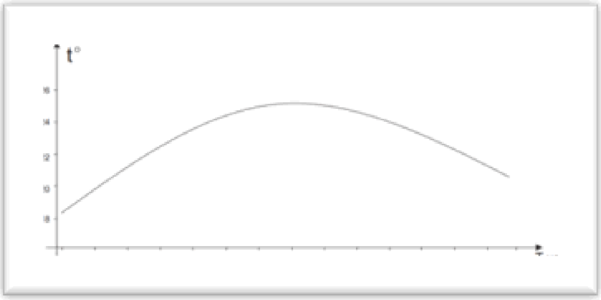

Figure 1. Connection between temperature and time.

$$\eta_i = 3{,}2 + 0{,}209\xi_i - 0{,}120\xi_i^2 \qquad (7)$$

Where

$$\begin{cases} \xi_i = T_i - T_0 \\ \eta_i = t_i - t_o \\ (i = 1{,}2, \dots, n) \end{cases}$$

Conclusion:

The word used to describe how the atmosphere affects geodetic observations is geodetic refraction. The inhomogeneities of the atmosphere's refractive index have an impact on an electromagnetic wave, the object of the geodetic measurement. Variations in refractive index have an impact on the wave's amplitude, phase, and frequency as well as its velocity and direction while it travels through the atmosphere. Consequently, all geodetic observations other than those based on gravity, with the exception of horizontal and vertical angles, electronic distance measurements (EDM), leveling, laser ranges, Doppler and GPS observations, and very long baseline interferometry (VLBI), are subject to refraction.

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