DOI 10.5162/SMSI2020/D3.3

Analysis of accuracy requirements to the meteorological sensors used to compensate for the influence of the Earth’s atmosphere in high precision length measurement

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Summary:
The influence of the Earth’s atmosphere on the results of high precision distance measurement on the baselines of up to 5 km can be taken into account due to the information on the mean integral refractive index of air along the baseline being measured, obtained with temperature, air humidity and pressure sensors. The ways on improving the accuracy of such an account, as well as the requirements to the characteristics of the respective sensors for various approximations by quadrature formulas of the mean integral refractive index are discussed.

Keywords: length measurement, meteorological sensors, refractive index, gradient method, GeoMetre

Background, Motivation an Objective

Meteorological sensors (temperature, air humidity, pressure) are widely used to obtain the measurement information necessary to determine corrections that compensate for the effect of the Earth’s atmosphere on the results of distance measurement on near-Earth baselines. Instrumental (dispersion) methods for accounting the influence of the atmosphere [1] for baselines of up to 5 km still have not found practical application. For this reason, the correction of the atmosphere’s influence on the results of length measurement on such baselines is currently grounded on the use of traditional methods for determining corrections using data on the mean integral refractive index of air ($\overline{n}$). Measurement of meteorological parameters for calculating $\overline{n}$ are carried out using temperature, humidity, pressure sensors located at discrete points of the path being measured.

Increasing the accuracy requirements for length measurement leads to the need to improve the accuracy of methods and instruments of determining $\overline{n}$ including the meteorological sensors.

In this paper, the results of research carried out within the GeoMetre project (under EMPIR), in terms of the development of methods and means of taking into account the influence of the Earth’s atmosphere to achieve the distance measurement uncertainty of not more than 1 mm on the baselines of up to 5 km, are discussed.

The research has been performed using the gradient method for determining the mean integral refractive index of air. The gradient method for determining the mean integral refractive index of air is the common name of methods based on the use of quadrature formulas with summands depending on the values of the gradient of the refractive index of air at discrete points on the integration interval along the baseline being measured by the range finder.

Description of the New Method

The analysis of the measurement equation shows that the fulfillment of the above requirements is possible using modern high precision laser rangefinders, if the measurement uncertainty of the mean integral value of the refractive index of air on the trace being measured is not more than $5 \cdot 10^{-7} \cdot L^{-1}$ (L in km).

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The exact value of the mean integral refractive index of air $\overline{n}$ is determined by the relation

$$\overline{n} = \frac{1}{L}\int_0^L n(\sigma)\,d\sigma\,, \qquad (1)$$

where σ is the ray coordinate, measuring along the electromagnetic radiation propagation path; L is the path length; $n(\sigma)$ is a function describing the change in the refractive index along the baseline (trajectory of the radiation).

In the process of research, possible options for representing the integral (1) by quadrature formulas satisfying the accuracy requirements formulated above are considered. With this, the main attention is paid to the analysis of the relations for $\overline{n}$ obtained using the trapezoidal method (valid for a uniform distribution along the path of measuring points of local values of the refractive index of air, determining $\overline{n}$ through the quadrature formula), Euler-Maclaurin method (for a uniform distribution of the above points) and Hermite polynomials (for a non-uniform one) [2-4].

It is shown that the potential accuracy of the widely used in practice relation for $\overline{n}$ obtained by representing the integral (1) by the quadrature formula using the trapezoidal method is significantly lower than the potential accuracy of the corresponding quadratures obtained using the Euler-Maclaurin representation and Hermite polynomials. This result is due to the appearance of additional summands in the Euler-Maclaurin and Hermite quadratures, taking into account the contribution of the gradients of the refractive index of air and the angles of arrival of the signal at the end points of the baseline. Therefore, the method using the $\overline{n}$ representation by quadrature formulas according to Euler-Maclaurin or Hermite was called gradient method of $\overline{n}$ determination [2-4].

Results

The accuracy requirements for the meteorological sensors necessary for the practical implementation of the above methods for determining the mean integral refractive index of air are formulated taking into account the number of points, their location on the baseline being measured and weather conditions.

In the calculations, the most accurate relation was used, connecting the local values of the refractive index of air with the meteorological parameters of the atmosphere – Ciddor's formula [5].

As a result of the research, it was shown that the instrumentation capabilities available at the linear geodetic polygon of the National Scientific Centre "Institute of Metrology" for measuring pressure, temperature, air humidity at the points of determining local values of the refractive index, as well as the visible zenith angles and gradients of the refractive index at the end points of the baseline (that is, all the input quantities necessary for the implementation of the analyzed methods) allow to obtain the mean integral refractive index of air with the uncertainty of not more than $5{\cdot}10^{-7}{\cdot}L^{-1}$ (L in km).

References

[1] M.T. Prilepin, A.N. Golubev, Instrumentalnyye metody geodezicheskoy refraktometrii [Instrumental methods of geodetic refractometry]: *Itogi nauki i tekhniki, Ser. Geodeziya i aerofotosyemka [Findings of Science and Technology. Series Geodesy and Aerophotography],* M.: VINITI, Vol. 15, 91 (1979) (In Russian).

[2] P. Neyezhmakov, A. Prokopov, V. Skliarov, On the accounting for the influence of the Earth's atmosphere on the results of distance measurement realized by lasers, *Journal of Physics: Conf. Series* 1065 (2018) 142008; doi:10.1088/1742–6596/1065/14/142008

[3] P. Neyezhmakov, A. Prokopov, I. Trevogo, K teorii gradiyentnogo metoda opredeleniya sredneintegral'nogo pokazatelya prelomleniya vozdukha pri dal'nomernykh izmereniyakh na prizemnykh trassakh [On the theory of the gradient method for determining the mean integral refractive index of air in distance measurement on near-Earth traces], *Suchasní dosyagnennya geodezychnoi nauky ta vyrobnytstva – Modern achievements of geodesic science and industry*, II (36), 28–31 (2018) (in Russian).

[4] P. Neyezhmakov, A. Prokopov, Analiz tochnosti hradiyentnoho metodu vyznachennya serednointehralnoho pokaznyka zalomlennya povitrya [Accuracy analysis of the gradient method for determining the mean integral refractive index of air], *Ukrainian Metrological Journal*, 4, 43-48 (2018) (In Ukrainian); doi:10.24027/2306-7039.4.2018.155754

[5] P.E. Ciddor, Refractive index of air: new equations for the visible and near infrared, *Applied Optics*, 35(9), 1566-1573 (1996); doi:10.1364/AO.35.001566

Acknowledgement

This study was performed under the European joint research project named EMPIR 18SIB01 GeoMetre Large-scale dimensional measurements for geodesy. This project has received funding from the EMPIR programme cofinanced by the Participating States and from the European Union's Horizon 2020 research and innovation programme.