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THE INFLUENCE OF TEMPERATURE AND PRESSURE ON PERFORMNCE OF OPTICAL SURVEYING INSTRUMENTS

Vladimir Pašagić, Tijana Parlić Risović

State Office for Standardization and Metrology, Zagreb, Croatia

Abstract – Althought the surveying instruments grow ever more complex, yet the telescope remains the basic part of modern-day surveying instruments. When considering the problem of measuring with a surveying instrument, that is with the telescope, it is necessary to consider the issue as a whole. In other words it is necessary, alongside the function of the telescope, to take into consideration the object to be measured, atmosphere as the medium transmitting light and physiological and psychological attributes of the sighter. In order to define a complex optical system that would facilitate prediction of measurement's accuracy with the telescope, in dependence on atmosphere conditions, namely different temperature and preassure, it is necessery to provide a description of the atmosphere and telescope as independet optical systems. This is accomplished throught modulation transfer function that provides a complete description of the properties of a considered optical system.

Starting with the fact that surveyors prior to their departure to outdoor measurings have at their disposal only the information on air temperature and pressure, we have conducted suitable theoretical study of the problem. The results of this study provide means to evaluate the limitations of resolution of a considered optical system imposed by the atmospher based on the knowledge of available meteorological parameters..

Keywords: telescope resolution, limitation, atmosphere

1. INTRODUCTION

For optical systems including the telescope the limiting factor of image quality is most often the atmosphere. That is why attempts to theoretically and experimentally determine the dependency of the quality of the optical system upon the parameters of the weather such as temperature, windspeed, atmospheric pressure and relative humidity have been taking place since the second half of this century.

Interdependence-corelation of atmospheric modulation transfer function (MTF) and various metheorological parameters has been summed in works of a scientist N. S. Kopeika and others [1]. In short, MTF of the atmosphere consists of three components: reduction of atmospheric contrast as the background, forward diffusion of atmospheric particles and atmospheric turbulence.

The first component does not depend upon spatial frequency and manifests itself as uniform reduction of MTF. Forward diffusion of atmospheric particles degrdades image quality especially for low spatial frequencies. Higher spatial frequencies change under the influence of atmospheric turbulance while they remain unaffected by the two other above-mentioned atmospheric effects. This difference of atmospheric influences on alteration of spatial frequencies of the image makes it possible to analize the influence of various metheorological parameters such as temperature, relative humidity and wind speed on the image of the object during the spreading of light through the atmosphere. It also makes separating the influences of turbulence, aerosol and background possible.

Optical turbulence can be defined as a fluctuation of index of refraction caused by atmospheric turbulence. Atmospheric turbulences cause a change in the index of refraction of light. Even though the changes are generally small, the cummulative effect on the spreading of the ray of light through the atmosphere may be significant. These are small changes in atmosphere from a metheorological standpoint. The effects of atmospheric turbulences on changes in optical properties of the atmosphere are described via a physical size defined as a structural constant of index of refraction, which is a critical parametre characterizing the effects of the atmospheric turbulence. The effects are amplified in case of discreet sprayers like the aerosol particles, same as the effect of absorption on atmospheric particles (negligible contribution). While the effect of absorption is not taken into consideration becouse of its negligible contribution to choking in the optical part of the electromagnetic spectrum, at the same time there can be a significant absorption on aerosol particles. to calculate the absorption on aerosol partices it is neccesary to know the index of refraction of these particles, that is their chemical composure as well as dimensions. To calculate the spraying on these particles in is imperative to know the distribution of those particles in space. The mentioned sizes are mainly acquired throught corresponding measurings and a number of empirical models applicable depending on the place of measuring are developed [2]. Therefore, for applicable treating of the aerosol effect sizes usually not taken in surveyving measurements should be taken and their effect could not be calculated in actual practice.

2. ATMOSPHERIC MTF

The structural constant of the refraction index C_n^2 determines MTF of the atmosphere which was done by

Fried [3]. Size r_0 is commonly used and is defined as a coherent length and is a measure of maximal resolution of propagation through the atmosphere (it is roughly equivalent to the resolution achieved with a diffraction limited aperture r_0 in diameter), so MTF according to Fried goes [3]:

$$MTF_a(\nu) = \exp[-3.44(\lambda f\nu/r_0)^{5/3}] \qquad (1)$$

where: ν stands for spatial frequency observed in the image plane and expressed in Hz along the length, f - stands for focal length of the optical system and λ stands for wave length of light.

MTF_a given by the relation (1) where r_0 stands for so-called atmospheric coherent length and it is in fact the most important parametre in these considerations through which we characterize the effects of turbulence on optical system, that is the telescope. Size r_0 is often called Friedman's coherent length after a scientist who applied it for the first time and for horizontal measurements and the situations when we can assume that on that trail the turbulences are homogenous goes

$$r_0 = 2.1\cdot\left[1.46\cdot k^2 C_n^2\cdot L\right]^{-\frac{3}{5}} \qquad (2)$$

The mentioned assumption for homogenity of the turbulence on the measuring trace and does not pose a significant limitation when a single measurement is taken in time of 10 to 20 minutes. This time interval is determined by the dynamics of the change of the structural constant of refraction index on the horizontal paht of spreading of the light.

Therefore, in order to know the MTF_a it is necessary to know the structural constant of refraction index C_n^2. As it is difficult to directly measure C_n^2 it is customary to measure the structural constant of the temperature, and from there according to Lawrence follows [4]:

$$C_n^2 = \left(\frac{\partial n}{\partial T}\right)^2 C_T^2 = (79\cdot 10^{-6}\frac{p}{T^2})^2 C_T^2 \qquad (3)$$

Alongside the research of problems of optical turbulence in the atmosphere numerous experimental measurings were conducted, but whern considering the results a difference should be recognized between socalled borderline layer of the atmosphere and the free atmosphere. The borderline layer of the atmosphere is a term used to describe the layer of the atmosphere where the interchange of temperature between the surface of the earth and the atmosphere is dominant in determining the dynamics of the atmosphere. Dynamics in the layer of the free atmosphere are determined by wind, gravitational waves of the Earth and metheorological conditions. The borderline of the atmosphere is situated 1 to 2 kom above the surface and based on physical processes that dominate in it is divided in three layers which are: surface layer (first few meters above the ground), exchange layer (above the surface layer), and so-called interlayer, that is the layer of the atmospere between the borderline layer and layer of the free atmosphere. The results of many measurings of C_n^2 near surfaceof the ground are knowen. This information is of special interest to us since that surveying measurings are conducted in that part of the atmospere.

Optical turbulence of the atmosphere causes the effect similar to the one of low band filter by filtering high spatial frequencies. Through this the sharpness at the edges is lost and the point object produces a blurred image.

MTF_a in the focal plane of the optical system is calculated using the relations (1) and (2). By describing the properties of the telescope and the atmosphere through MTF we are in position to sight on the telescope and the atmosphere as single complex optical system. MTF of such system is the product of MTF_t (of the telescope) and MTF_a (of the atmosphere) [5].

3. RESOLUTION OF THE SYSTEM TELESCOPE-ATMOSPHERE

Primary evaluation on the possibility of conducting precise enough surveying measurings is achieving the sufficient resolution of the system telescope-atmosphere for metheorological conditions in which the measurings are conducted and the distances of the measured object. To acquire such evaluation it is possible to use an expression for the resolution of that system given by Friedman [1]:

$$R = \int FPM_t(\nu)\cdot FPM_a(\nu)\cdot d\nu \qquad (4)$$

The definition of the borderline frequency (ν_c - "cutoff"), that is the frequency at which the degradation of the resolution occurs, is the frequency at which the value of MTF drops to 1/e. Out of the given graphics of MTF system telescope-atmosphere value of 1/e can be read out. The expression for spatial and angular resolution of the system in the plane of the object is given in the equation:

$$R_s = 2.1\cdot(\lambda/r_0)\cdot L \qquad (5)$$

The evaluation of the limitations of turbulent effects of the atmosphere can be acquired by comparing the limitation of the resolution of the telescope as a result of diffraction and the values obtained through the relation (5). It is known that the limitation of the resolution of the optical system as a result of diffraction is given by the relation :

$$R_t \approx \lambda\cdot L / D \qquad (6)$$

where D stands for aperture.

It is necessary to know the values of R_s in dependency on metheorological conditions, especially temperature and air pressure. Dependency of R_s on temperature and air pressure is a result of dependency of r_0, that is the structural constant of refraction index on these variables.

By inserting (2) into (5) R_s is given in the following way:

$$R_s = 11.3875\cdot\left(C_n^2\right)^{\frac{3}{5}}\cdot L^{\frac{8}{5}}\cdot\lambda^{-\frac{1}{5}} \qquad (7)$$

Out of (7) it is visible that the dependency of R_s on wave length is weak, almost negligible, while the dependency on the distance between the object and the optical system is significant. That is why in further considerations only λ = 588 nm is taken (accuracy is up to ± 3.5 %).

By comparision of corresponding values from table 1. we can see that for $r_0 < 50$ mm $\Rightarrow R_s > R_t$, which leads to a situation where the atmospheric influence makes the measuring with the tested telescope impossible. The use of size r_0 is of interest since great number of experimentally acquired values exist but here it is not essential for we must not egnore that r_0 depends also on L with exponent - 3/5.

Table 1.: The values of R_s and R_t for determined velues of r_0

L (m)	R_s (cm)			R_t (cm)
	λ = 588 nm			
	$r_0 = 10$	$r_0 = 50$	$r_0 = 100$	
300	1.77	0.35	0.18	0.39
500	2.94	0.58	0.29	0.65
1000	5.88	1.17	0.59	1.31
3000	17.64	3.53	1.76	3.92
5000	29.40	5.88	2.94	6.53
10000	58.80	11.76	5.88	13.07

Therefore, for each of the values of r_0 used pairs of L and C_n^2 exist, that are p (pressure) and T (air temperature). Since it is interesting to determine the estimate of R_s in direct corelation with p and T let us analize the values of r_0 in the interval from 10 mm to 50 mm using the experimental results for structural constant of temperature (C_T^2) in functional dependency on the difference of the temperatures of the surface and air (table 2.).

Table 2.: The experimental results for structural constant of temperature

ΔT	-5	-4	-3	-2	-1	1	2	3	4	5
$C_T^2 \cdot 10^3$	3.2	3.7	4.1	4.6	5.1	6.0	6.5	7.0	7.6	10

Using the relation (7) to calculate R_s and expressing the C_n^2 over a relation (3) we acquire the resolution of the system in the focal plane of the object and in dependency on ait pressure and temperature as well as the difference in temperature between the ground and air.

Since R_s depends on five parameters it is obvious that it is not possible to graphically present the changes of R_s in dependency of all the parameters at the same time.

Calculation of the values of R_s for optional values of p and T uses an expression for approximate value through partial derivations of R_s by p and T, that is:

$$R_s \approx R_{s_0} + \frac{\partial R_s}{\partial p}(p - p_0) + \frac{\partial R_s}{\partial T}(T - T_0) \qquad (8)$$

In (8) p_0, T_0 and R_{so} are optionally chosen referent values (R_{so} is a value for λ_0). Using the relations (3) and (8) we can conclude that efects the changes of R_s mainly depends on changes of air temperature. Let us chose as an example air pressure p_0 of 1000 mbar, T_0 temperature of 300 °K and λ_0 wave lenght of light 588 nm.

Using the relation (8), values of R_{s0} given out of relation (7), values of C_T^2 out of table 2. and the values of R_t out of table 1. grafic presentations of R_s with the amplification of L have been acquired out of which it is easy to notice the limit of distance object-telescope determined by optical properties of the atmosphere and the resolution of the telescope being analized.

In table 3. are presented, for example, the values of R_s for T = 280 K, L = 1000 m and compared with the value of R_t = 131 cm (D = 45 mm).

Table 3.: The values of R_s for T = 280 K, L = 1000 m

ΔT p	-5	-4	-3	-2	-1	1	2	3	4	5
900	77	85	88	95	102	103	116	123	130	151
960	92	99	106	106	111	130	137	144	152	180
990	99	106	103	103	130	144	152	159	166	194
1000	102	109	116	123	133	148	155	162	169	201
1020	102	113	120	127	134	148	155	166	173	204

The limitation of the distance object-telescope that is conditioned by optical properties of the atmosphere and the resolution owend by the analysed telescope is illustrated in table 3. by sheding the values R_s that are smaller than the values R_t of the considered telescope.

4. CONCLUSION

The aim of this research was to make it possible to evaluate the limitations of resolution of the optical system caused by the atmosphere based on the knowledge of aforementioned metheorological parameters.

The explained procedure of calculating the resolution of system telescope-atmosphere makes it possible to make an assessment of the resolution of the system depending on the distance between the telescope and the measured object and air pressure and temperature. This lends the article practical value.

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Authors:
D.Sc., Vladimir Pašagić, Division of Metrology, State Office for Standardization and Metrology, www.dznm.hr (Ul. grada Vukovara 78, 10000, Zagreb, Croatia), phone 3707924, fax 3773238, vpasagic@inet.hr.
B.Sc., Tijana Parlić Risović, Division of Metrology, State Office for Standardization and Metrology, www.dznm.hr (Ul. grada Vukovara 78, 10000, Zagreb, Croatia), phone 6106027, fax 61092332, tijana-pr@inet.hr