A STUDY ON THE LIGHTING FACTORS AFFECTING RELIEF PRESENTATION

Tzelepis, N. and Nakos, B.

Cartography Laboratory, School of Rural and Surveying Engineering,
National Technical University of Athens. 9, Heroon Polytechniou Str., Zographos,
GR-157 80, Greece. E-mail: niktzel@central.ntua.gr and bnakos@central.ntua.gr

ABSTRACT

The natural relief shades present in earth's surface images are affected by physical lightning procedures that take place along the trace of sunlight from the initial radiation to the final capturing by sensors. Apart from the direct shading based on geometrical functioning between the light and the surface, other important physical phenomena, like the reflections from neighborhood areas or diffused quantities of light, may have a strong influence on the recorded tones. An analysis of all these combined factors is given in the present paper in order to define their qualitative meaning and evaluate their influence on the variation of tones that forms the relief effect. Furthermore, an attempt is made to quantify effectively those components of natural lightning procedure which are considered to be critical for relief shades. This is based on existing research background related to radiometric correction procedures of remote sensing and several lightning models. The existing relations that can be utilized for estimating the influence of natural lightning components on the recorded values of tones are examined, pointing out the most appropriate ones. These efforts are tested both on computational and conceptual level with examples of different lightning conditions on simulated solids. The tests are providing visual results on the functionality of lightning components in the task of: (a) removing existing natural relief shades from digital images and (b) applying cartographic shading into digital images. In addition, the qualitative and quantitative approaches of light components are discussed in the context of suggesting a systematic, practical strategy for the selection of the necessary parameters of relief shading for several cartographic products. These products include either the case of "pure" thematic maps enriched with simulated hill-shading, or the case of satellite images which must first be corrected for the misunderstanding representation of relief due to the usual south-east sunlight. Finally, the paper states the crucial decisions that have to be taken on the choice of the lightning factors evolved in the procedures of elimination or application of relief shading, always depending on the scope of the product and the associated users.

1. THE FUNCTIONALITY OF LIGHT IN VISUAL REPRESENTATIONS OF TOPOGRAPHY

Cartography and map making aim at the effectiveness of graphical communication for describing spatial relationships, which is assured by the use of visual representation of images of these relationships [1]. In the context of the cartographical perception of topography, specific visual cues with physiological or psychological substance are utilized [2], which are able to operate under conditions of radiation emitting from a light source. The design and production of applications using visual representations of topography can be improved, if valuable background of detailed description and examination of natural lighting is provided. The physical procedure of lighting is a complicated mix of various mechanisms that define interaction between light radiation and the lightened surface, resulting in a rich variety of visual effects that form the final image of the application.

Apart from the direct shading based on geometrical functioning between the light and the surface, other important physical phenomena, like the reflections from neighbouring areas or diffused quantities of light, may have a strong influence on the recorded tones. An attempt is made to quantify effectively those components of natural lighting procedure, which are considered to be critical for relief shades. This is based on existing research background related to radiometric correction procedures of remote sensing and several lighting models. The existing relations that can be utilized for estimating the influence of natural lighting components on the recorded values of tones are examined, pointing out the most appropriate ones. Tests providing visual results on the functionality of lighting components are applied in the task of: (a) removing existing natural relief shades from digital images and (b) applying cartographic shading into digital images. The results can indicate several important decisions that have to be taken on the choice and accuracy of the lighting factors evolved in the procedures of elimination or application of relief shading, always depending on the scope of the product and the associated users. These products include either the case of "pure" thematic maps enriched with simulated hill-shading, or the case of satellite images which must first be corrected for the misunderstanding representation of relief due to the usual south-east sunlight.

2. THE FACTORS OF LIGHTING AND THEIR INFLUENCE ON RELIEF PRESENTATION

The procedure of natural lighting takes place in two successive steps. The first step is the traveling of the amount of light emitted from the sun source towards a target location in the lightened surface. The second step that follows is the back traveling of the amount of light that finally reached and reflected from the target location, to the human eye of the observer or an artificial sensor. Along both of these two routes, the initial amount of light is influenced in either a lossy or a beneficial way by the behavior of light radiation in the specific configuration of lighting conditions, defined by various atmospheric attributes and the physical and geometric characteristics of surfaces. Fundamental phenomena like reflection, refraction, scattering and partial absorption can cause the deviation of some quantities of light to other routes that lead to different specific or unspecified destinations, and contrary, the addition of quantities of light deviated from other directions in the current examined route. A full description of the lighting procedure and all the intervening factors that influence the traveling of light, from the time it is emitted by the sun until it is captured by a viewer or sensor, is presented in Figure 1. It is focused on the physical substance of the lighting procedure, leaving out the examination of the parameters related to technical specifications of the various systems used.

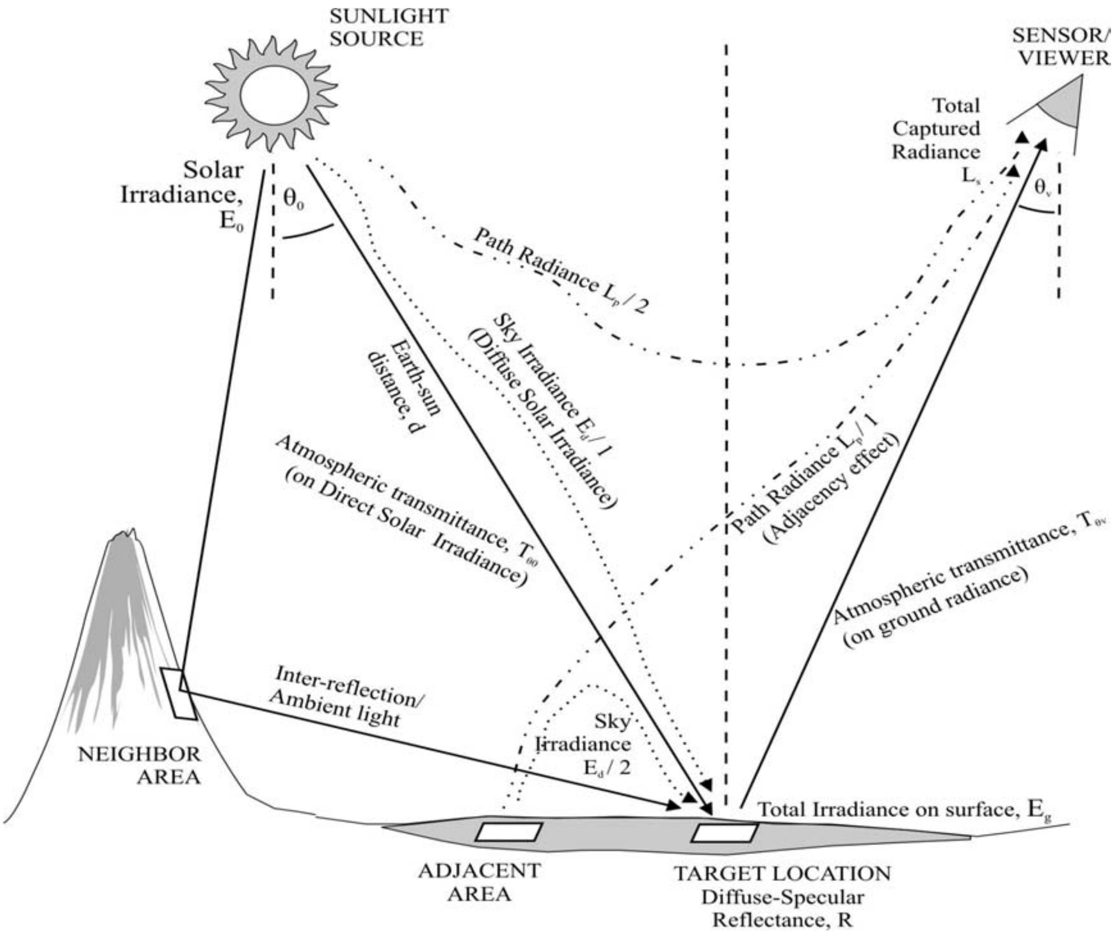

Figure 1. Lighting procedure and intervening factors

In order to understand the following analysis of the lighting factors, some basic terms used need to be explained in a simple way. *Irradiance (E)* refers to the flux of light energy that is incident upon surfaces, while *radiance (L)* is used for the energy transmitted back after reflection and captured by the sensor or viewer [3]. *Atmospheric transmittance (T_θ)* is the main factor representing the way atmospheric conditions affect the transmission of light. It defines the percentage of the initially entered energy that passes through the atmosphere under specific absorption and scattering conditions. The path and the length, covered during the transmission through the atmosphere, are altered by the zenith angle, θ, and the value of T_θ is given by the following equation:

$$T_\theta = \frac{1}{e^{\frac{\tau}{\cos\theta}}} \qquad (1)$$

Apart from the zenith angle, the computation of atmospheric transmittance includes the *total normal atmospheric optical thickness, τ,* which is the sum of partial corresponding values for scattering and absorption attenuating coefficients, each of them depending on a variable power of the wavelength [4]. The relative contributions of the coefficients of *τ,* are changing for different levels of height from the ground, and thus transmittance is influenced also by surface elevation [5].

The first stage of lighting procedure is related as already mentioned to the amount of light reaching the target location on the ground, and it incorporates the illumination process.

It is initiated by the emission of *solar irradiance,* E_0, and it is influenced on the way of its traveling to the surface by the following factors:

- *Solar zenith angle* and *earth-sun distance,* which define the initial solar irradiance by a proper normalization ratio of the cosine of sun's zenith angle, $\cos\theta_0$, with the distance of sun from earth, d^2 [6].
- Atmospheric transmittance at the solar zenith angle, $T_{\theta 0}$, which attenuates the part of solar irradiance that is directly transmitted by the atmosphere toward the target location.
- *Sky irradiance* or *skylight*, E_d, that increases the incident irradiance, mostly originating from part of solar irradiance that is scattered in the atmosphere and reached at target diffusely (*diffuse solar irradiance*), and secondarily from part of the reflected radiance of surrounding areas that is scattered by the atmosphere back to the ground [7]. Its computation is very complex and depends on the different combinations of atmospheric gases, the neighboring topography and elevations. Representative configurations can be filed in a database and recalled [8,9].

The value of the *total irradiance incident on the surface*, E_g, for a given spectral interval $\Delta\lambda$, is computed by the above factors using this relation:

$$E_g = E_0 \frac{\cos\theta_0}{d^2} T_{\theta 0} \Delta\lambda + E_d \tag{2}$$

In the case of mountainous and quite rugged terrain, additional irradiance exists by the inter-reflection of light from neighboring terrain, which is accurately simulated and computed with ray tracing algorithms. However, this is a very time-consuming process and an alternative solution is the approximation of it by *ambient contribution*, a constant amount of background light illuminating every location of the surface.

The second stage of lighting is related to the actual image-formation process by the values of radiance reflected by the ground, and modified by factors that affect radiance during the transmission by the atmosphere until capturing.

These factors are:

- *Reflectance (R)* of the surface, which is the proportion of irradiance reflected by the target location, depending on the surface material and the surface orientation with respect to the light source and the viewer. In order to calculate reflectance, a wide variety of shading models is available, implementing the simplifying assumption of Lambertian ideal *diffuse reflection*, or encountering also a component of *specular reflection* behavior of the lightened surface [10]. Whether a surface behaves only as a diffuse reflector or it has partly specular behavior, it is a matter of rough or smooth surface micro-structure respectively. For total accuracy on reflectance calculation, a *Bidirectional Distribution Reflectance Function (BDRF)* is used, that takes into account the particular geometry of viewing and illumination distribution applied on the surface.
- Atmospheric transmittance at the viewing zenith angle, $T_{\theta v}$, which attenuates the part of ground radiance that is transmitted toward the viewer (*Direct Solar Irradiance*).
- *Path radiance* (L_p), which is included in the recorded radiance of target location. It is created by incoming sun radiation that never reaches the earth's surface because it is scattered by the atmosphere towards the sensor, or by part of the reflected radiance of nearby targets which is scattered into the returning signal of the current examining target, also called as the "*adjacency effect"* [7]. Its computation is equally complex with the computation of the *Sky Irradiance* factor [8,9].

The *total captured radiance,* L_s, is calculated then by the contribution of the above factors as follows:

$$L_S = \frac{R}{\pi} T_{\theta v} E_g + L_p \tag{3}$$

There is one last factor of lighting which is not actively adding any contribution of energy, but in fact it passively blocks the total direct solar irradiance to reach the ground surface. This is the visual effect of *cast shadow*, resulting from the topographic protrusions of surrounding land surfaces [11]. Nevertheless, some radiance value is finally captured even for these locations, as light may reach them during illumination indirectly, through sky irradiance and inter-reflections, or it may be added after the reflection with path radiance. The recorded values of locations that should be totally dark because of cast shadowing are utilized by various quantitative methods of remote sensing processing to empirically define the contribution of path radiance.

3. EXAMINATION OF DIFFERENT LIGHTING CONDITIONS

The above synoptic presentation of theoretical concepts of lighting can be used for the modeling and computation of the tones presenting the relief of a surface, which prompts for practical examination of these relationships with experimental tests. One issue that could benefit from such tests and their relative outcomes is the *topographic normalization,* a pre-processing radiometric correction applied for the elimination of inborn relief shading in images of earth's surface. The goal of this procedure is to remove the contribution of relief from the tones of the image through shading, in order to clear out the actual values of tone that relate to the identity of the surface's material. In a lot of research work in remote sensing area related to the problem, the proposed methods for solution have adopted a quantitative approach by using image-based techniques (C-correction, statistical-empirical method), definitely requiring available ground reference information. A method that deals with the issue in a more qualitative sense, is that of *Minnaert's correction*, where the basic Lambertian surface assumption is utilized, and the parameter of *Minnaert constant, k,* -ranging between 0 and 1- controls the extent to which a surface behaves diffusely [12]. For *k*=1, the method degenerates to the simpler *cosine method,* where the surface is assumed to be a perfect diffuser. The form of the relation after appropriate adjustment for common vertical viewing is:

$$L_h = L_s \left[\frac{1}{\cos i} \right]^k \tag{4}$$

where i is the *sun incidence angle* in relation to the normal of the surface, L_s is the captured radiance value and L_h is the successive value corrected for relief contribution.

In the context of this work, apart from the basic assumption of diffuse reflection, two factors were included in the production of artificial images of illuminated surfaces, which are present in most of the several commercial software platforms that implement lighting capabilities. These are the specular component of reflectance and the amount of ambient contribution, which are applied separately with a variable contribution. The surfaces of two simulated solids, a cone and a hemisphere, are used as examples of earth's topography. They are characterized by common shape but different behavior on the slopes of their surfaces, since the cone has a standard value whereas the hemisphere's slopes fluctuate. Their models are illuminated and visually captured under a vertical, above viewing direction, for acquiring artificial images of illumination. Then, by using the Minnaert's method, appropriate corrections are analytically computed, based on geometric information given by the digital models. Finally, the corrections are multiplied with the corresponding tones of the simulated images of illumination to produce normalized, relief-corrected images of their surfaces.

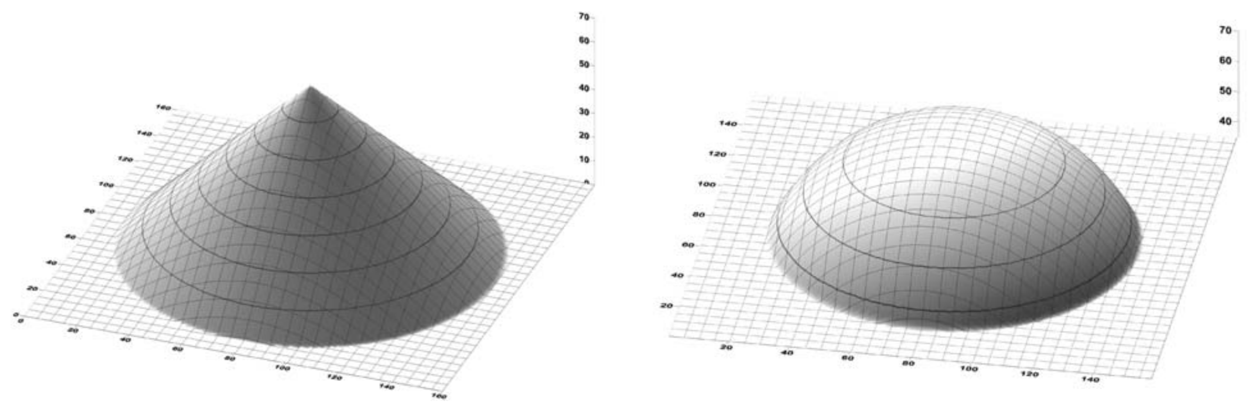

Figure 2. Digital models of simulated cone and hemisphere

While preparing the simulated solids for testing, it is important to restrict the slopes of the surfaces into a logical range of values. Experience from previous attempts to calculate corrections with Minnaert's method has shown that very steep slopes, which can be rarely found in the physical environment, need some special treatment [13]. At those locations of the surface under correction, where the steep slopes are combined with surface orientation turning away from the light source, the corresponding incident and reflected light is almost zero. In this case, Minnaert's formula computes extremely high values of corrections, which cannot have any impact on the absent recorded information, and on the other hand they increase maximum values too high, so no linear stretching can be practically applied for viewing the results of corrections. Thus, the simulated solids are created having slope values in normal ranges, that is, 45° for the cone and 60° for the hemisphere. The corresponding dimensions used are DX=DY=DZ=70 drawing units for the solid, and DX=DY=60.6 drawing units and DZ=35 drawing units. For their production, an in-house software module developed in *Visual Basic* programming language is used, with available options for output in several types of ASCII formats for easy transfer into other software packages for further processing.

The process of illumination is carried out in the platform of three-dimensional modeling software, *3D Studio* (© AutoDesk), where the surfaces of the solid models are built as mesh objects. The software is equipped with appropriate tools for establishing a desirable configuration of environment, consisting of illumination sources with a desirable orientation, materials for objects with specific reflectance properties and selective options for including more factors of lighting, like ray tracing for reflection from adjacent areas, attenuation of light, skylight and volumetric light for effects based on interaction with the atmosphere. Two light sources are set, one for the application of diffuse and specular reflection, with illumination coming from 60° up from the horizontal plane (30° zenith angle) and north-west direction, and the other one for ambient light. The selection of how high the light will be situated has been balanced between the natural sunlight inclination and the usual cartographic hill-shading illumination. The material applied on the surfaces, is assigned in the various examples with values of 10% and 20% of specular reflection, and also another 10% and 20% of additional ambient light. The final designed scenes are captured under the commonly-specified vertical viewing direction, and then stored in standard image formats. Additional image cropping and resampling are carried out in a simple image processing software package, like *Photoshop* (© Adobe Systems Incorporated).

The implementation of a computation algorithm for the Minnaert corrections has been programmed in *AML*, the macro language of GIS software package *ArcInfo* (© ESRI)*,* and executed in the *Grid* module, offering appropriate tools for raster analysis. In the developed code, it has been attempted to incorporate one more filtering condition for avoiding possible extreme values of corrections, by providing the option to define the maximum sun incidence angle i to be corrected , at a smaller value than the standard of 90°. It uses inputs for the existing digital model, the orientation of illumination applied and the value of k. The digital models of solids are transferred in the same environment, along with the artificially produced images of illumination, which are registered on the same area covered by the solids' surfaces. The relief-normalized image is the result of multiplication between the image of illuminated surface and the calculated corrections based on the digital model, and readjustment of the values of the product operation for fitting into a 256-tone range so it can be viewed as a grayscale image (Figures 3 and 4).

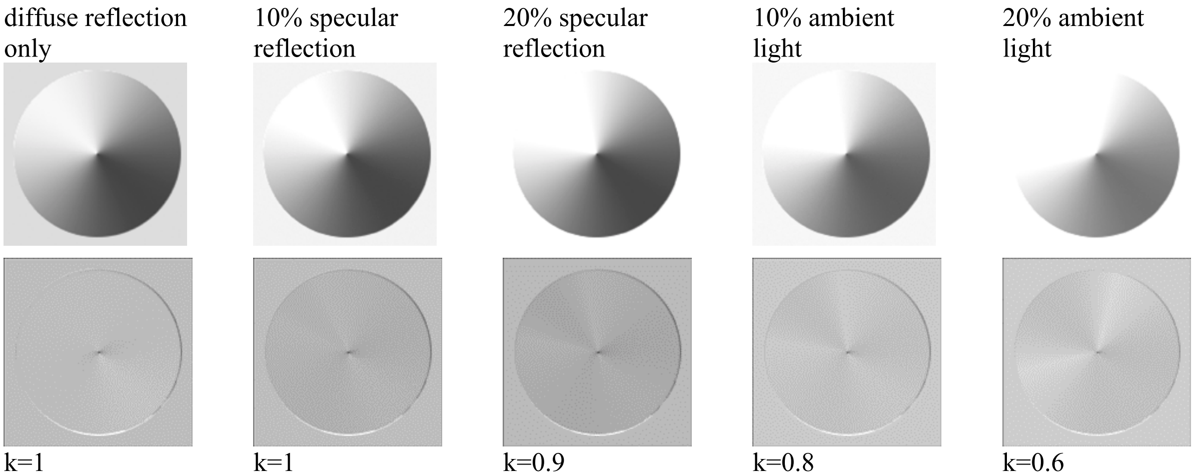

Figure 3. Shadings with different lighting conditions (above) and respective Minnaert-corrected images (below) for simulated conic surfaces

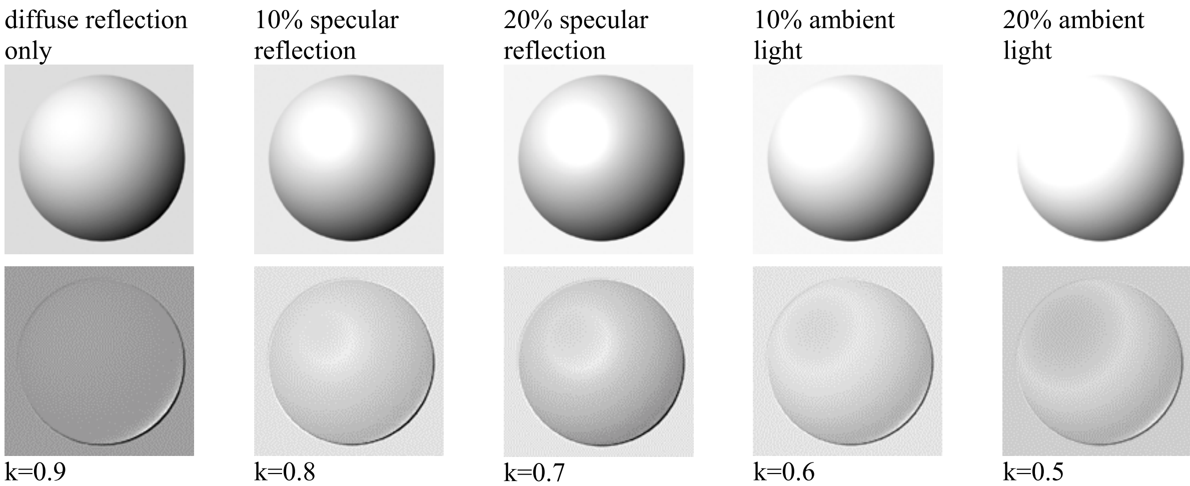

Figure 4. Shadings with different lighting conditions (above) and respective Minnaert-corrected images (below) for simulated hemispheric surfaces

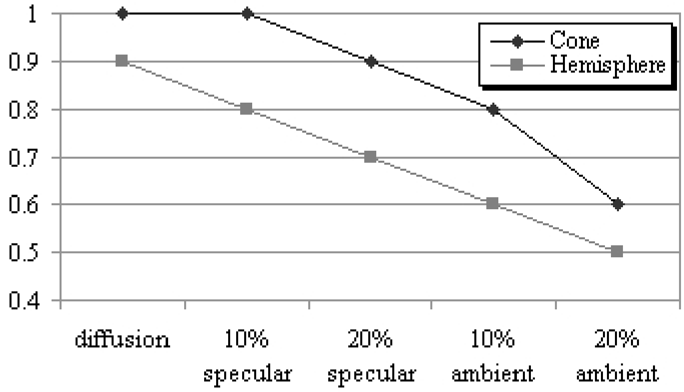

Figure 5. Minnaert constant *k* for different lighting conditions

4. RESULTS OF THE TESTS

The cases of lighting conditions tested, are: 1) total diffuse reflection, 2) diffuse reflection with 10% of specular reflection, 3) diffuse reflection with 20% of specular reflection, 4) diffuse reflection with 10% additional ambient light and 5) diffuse reflection with 20% of specular reflection. These five cases applied for each of the two solids selected differ in either the selection of the additional factor to join diffusion in the procedure of lighting, or the variable contribution specified for the same factor. More specifically, these two factors tested for their influence on relief shadings, are related to the illumination procedure, included in the first step of lighting, as described above. For each case and for each solid tested, the proper value for the Minnaert constant is selected on the basis of a visual evaluation, by selecting those relative corrected images in which the surface is presented most “flat”. One first comment on the behavior of parameter *k*, is that it decreases as lighting conditions decline from the absolute diffuse reflection model. This can be explained by the operational meaning of *k*, which “gentles” the computed corrections when illumination becomes brighter, something that is actually happening in the above tests. The values of *k* adopted for the different lighting conditions tested, are presented on an empirical diagram (see Figure 5).

The visual results of the tests on the conic surface, which is characterized by the combination of standard slopes for certain aspects of the surface, show that corrections are applied in an easy way, and the normalized images lack of any relief effect, resembling the image of a planar disc. Of course, it must be kept in mind that the light source is placed high enough so as not to let back-facing sides to form dark shades. Hemispheric surface appears to be a more difficult case, and the reason is probably that slope changes continuously, even when running on a certain aspect of the surface. Even when the optimum corrections are applied, some over-correcting has to be accepted at the higher slopes of 60° facing backwards. Effects of highlights are observed not only for the specular reflection contributing tests, but for tests with ambient light added too, and they are due to the spherical shape of the object’s surface. These effects are not eliminated completely, but they are greatly decreased so that relief impression is absent.

Both of these two last mentioned shortcomings on the corrected images might be avoided, if care is taken for a registration as accurate as possible between the shaded image to be corrected and the digital model used for computing the corresponding corrections. For the tests carried out in this work, shadings are implemented in a different environment and then are transferred and registered with the corresponding digital models, based on the fact that they are covering the same area. Procedures of image processing like resampling or cropping, which are used in order to adjust the scenes of shaded objects taken from the rendering software with screen-dumping, to the dimensions and sampling cell size specified by the digital model, might cause some small shifts and distortions. At those locations close to the basis of the shaded sides of the hemispheric surfaces, where slopes suddenly change from the maximum to the minimum, these conditions can cause dark tones like the ones presented in the images of Figure 4, which stretch the corrected image values more than expected.

5. DISCUSSION AND CONCLUSIONS

In this paper, an attempt is made to examine the physical procedure of natural lighting in its full extent. The theoretical concepts presented, are used as analytical background for the implementation of light and its effects, in all the state-of-the-art technologies of nowadays which include relief presentation: digital cartography, imagery of earth and realistic 3D rendering and animation of topography. A general knowledge of this background is helpful for the users of these technologies, because the same physical phenomena and meanings can be found in the literature and related research of each field, being described with different terms and emphasized in a variable scale of importance.

Reflectance is the only lighting factor having a direct relation and strong interaction with characteristics of relief, like orientation and elevation. For this reason, cartographical hill-shading techniques are based primarily on this factor in order to represent relief. But until the emitted quantities of light reach the ground surface, they are influenced by intervening factors of extremely high complexity, like the sky irradiance and atmospheric attenuation. And then, until the reflected light is captured by a viewer or by a satellite sensor, more factors interfere again and alter the transmitted light, like the path radiance. These factors change by the terrain distribution of a rather wide neighboring area, or by the atmospheric conditions, which in turn are different for areas of higher or lower elevations. They add important visual effects, like haze, skylight, atmospheric depth, which are very much appreciated in realistic three-dimensional visualizations of topographic surfaces.

In remote sensing applications, the whole theoretical background of lighting is taken into account, even for the factors related to the existence of atmosphere, since these ones have a stronger influence on the visible spectral range. Here, the primary goal is to eliminate the contribution of all the other physical procedures from the recorded values of tones, except the actual quantity concerning the surface material. But the increasing availability of earth's imagery during the last years, along with the tools and software packages for processing, has introduced their use also in the cartographic context. Similar meeting points between these apparently discrete technologies become easier to occur, so that fundamental principles from both topics will have to be applied in a conventional way. This is what happens in the case of captured images of earth's surface which are intended to be used for cartographic purposes, and so they first have to be corrected from the in-born relief shading before applying a new one which will be designed according to cartographic standards.

The topographic normalization of existing relief shading is selected as an example of a task which can be influenced by the variation of the implemented lighting conditions. The experiments on correcting the shaded images of artificially illuminated simulated solids show that different combinations of the factors for diffuse reflection, specular reflection and ambient light, create shadings that require different parameters of correction for the same surface. This indicates that the task of designing correction algorithms should incorporate analytical back-processing for the influence of these factors. Similar tests can be applied for exact computation of shadings including accurate ray-tracing for the inter-reflections of terrain, or the contribution of atmospheric conditions which is increasing in the visible range of solar spectrum [12].

On a technical basis, the procedures carried out for the experiments of this study, provoke for dynamic implementation of all the stages of computations and the ability to directly visualize the results, in order to make more accurate and quicker decisions. The use of a common integrated software platform instead of several ones for single specific processing tasks, can help to avoid problems because of the transfer of data from one software to the other, but of course something like that might require the utilization of custom programming for additional routines, or available add-on modules, which are very often too costly.

6. REFERENCES

[1] A.H. Robinson, J.L. Morrison, P.C. Muehrcke, A.J. Kimerling, and S.C. Guptill, "Elements of Cartography" (6th Ed.), pub John Wiley & Sons, New York p.9 (1995)

[2] M.J. Kraak, "Computer-assisted cartographical three-dimensional imaging techniques", pub Delft University Press, Delft p.44 (1988)

[3] P.M. Mather, "Computer Procesing of Remotely-Sensed Images, An Introduction" (2nd Ed.), pub John Wiley & Sons, New York p.87 (1999)

[4] J.R. Jensen, "Introductory Digital Image Processing (2nd Ed.), pub Prentice Hall, Englewood Cliffs p.107 (1996)

[5] R. Richter, *"Correction of atmospheric and topographic effects for high spatial resolution satellite imagery"*, International Journal of Remote Sensing, 18 p.1099 (1997)

[6] T.M. Lillesand, and R.W. Kiefer, "Remote Sensing and Image Interpretation (4th Ed.)", pub John Wiley & Sons, New York p.477 (1999)

[7] J.A. Richards, and X. Jia, "Remote Sensing Digital Image Analysis, An Introduction (3rd Ed.)", pub Springer-Verlag, Berlin p.39 (1999)

[8] C. Proy, D. Tanre, and P.Y. Deschamps, *"Evaluation of Topographic effects in Remotely sensed data"*, Remote Sensing of the environment, 30 p.21 (1989)

[9] E. Vermote. D. Tanre, J.L. Deuze, M. Herman, and J.J. Moncrette, *"Second simulation of the satellite signal in the solar spectrum, 6S: an overview"*, IEEE Transactions of Geoscience and Remote Sensing, 35 p.675 (1997)

[10] B.K.P. Horn, *"Hill-shading and the reflectance map"*, Geo-Processing, 2 p.65 (1982)

[11] P.T. Giles, *"Remote sensing and cast shadows in mountainous terrain",* Photogrammetric Engineering and Remote Sensing, 67 p.833 (2001)

[12] P. Meyer, K.I. Itten, K.J. Kellenberger, S. Sandmeier, and R. Sandmeier, "*Radiometric corrections of topographically induced effects on Landsat TM data in alpine terrain",* Photogrammetric Engineering and Remote Sensing, 48 p.17 (1993)

[13] N. Tzelepis, and B. Nakos, *"Methods and techniques for the correction of natural shades on aerial-photo or satellite maps",* Proceedings of 20th International Cartographic Conference, p.672 (2001)

A STUDY ON THE LIGHTING FACTORS AFFECTING RELIEF PRESENTATION

Tzelepis, N. and Nakos, B.

Cartography Laboratory, School of Rural and Surveying Engineering,
National Technical University of Athens. 9, Heroon Polytechniou Str., Zographos,
GR-157 80, Greece. E-mail: niktzel@central.ntua.gr and bnakos@central.ntua.gr

Biographies

Nikolaos Tzelepis was born in Athens in 1969. In 1994 he graduated from the School of Rural & Surveying Engineering, National Technical University of Athens. He is graduate student of the School of Rural & Surveying Engineering, National Technical University of Athens. Currently, he serves as Research Associate in the same University. His research interests are related to Cartographic Visualization and Hill-Shading. He is author of more than 5 papers related to Cartography and Geo-Informatics.

Byron Nakos was born in Constantinople in 1955. In 1979 he graduated from the School of Rural & Surveying Engineering, National Technical University of Athens. Since 1990 he holds the degree of Doctor Engineer from the School of Rural & Surveying Engineering, National Technical University of Athens. Currently, he serves as Associate Professor in the same University. His research interests are: map generalisation, maps and atlases for children, 3-D cartographic modelling and visualisation. He is author of more than 50 papers related to Cartography and Geo-Informatics and 3 Lecture Notes related to Cartography. He is member of ICA Commission: Map Generalisation