METHODS AND TECHNIQUES FOR THE CORRECTION OF NATURAL SHADES ON AERIAL-PHOTO OR SATELLITE MAPS

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ABSTRACT

This study examines possible ways first to restrain or even eliminate the "false" shades of the relief, created mainly by the direction of the natural sunlight presented on aerial-photo or satellite images, and then to replace them with the "correct" artificial hill-shading shades according to the cartographic principles of legibility and perceptibility, which allow the map user to easily and clearly interpret the relief's shapes and formations. The natural shades are eliminated from the aerial-photo or satellite images by applying special radiometric and statistical processing in order to create images free of shades. An analytical description of the earth's surface -stored as a digital elevation model- combined with computing tools of a variety of hill-shading methods are used to produce a cartographic "correct" image of shades of the study area. Finally, image-processing techniques are applied to create new images composed by the "correct" shades and the shaded free aerial-photo or satellite images. The outcomes indicate the potential of the incorporated methods and applied techniques in order to construct aerial-photo or satellite maps clearly and legibly perceived.

KEY-WORDS: *Aerial-photo/satellite maps, relief visualization, hill-shading, illumination models, correction of topographic effect.*

Introduction

The established map definitions are generally based on the graphical representation of the real world and the intrinsic phenomena or spatial relationships, where images and photographs are not conventionally parts of graphical symbolization. However, the various definitions introduced through the time, show that important changes have been accomplished in all mapping tasks and procedures, -mainly due to technological development- and lead to re-examination of the effectiveness of existing cartographic rules and principles [Nakos and Filippakopoulou 1993]. In some of the proposed definitions, the content and use of map are related to a wider range of activities, involving any graphic image that may include a spatial component, and subscribing to cartography's apparent interest for new products [Kraak 1989].

In most of the cases, images of the earth's surface have been used for cartographic purposes in an indirect way, as sources of collecting data through photogrammetric and remote sensing techniques. Late advances in the use of aerial-photo or satellite images have come to add new capabilities. These are:

- The continuous development of the earth observation systems and sensors used for data acquisition, by the means of increasing resolution.
- The increasing availability of the data produced by these systems even to the simple users.
- The consequent release of the appropriate software that supports the tools to take advantage of the new products.

The potential of these new capabilities enable users involved in geo-informatics to easily apply digital mapping procedures and produce graphical compositions combining aerial-photo or satellite images with existing vector cartographic data. This utilization of earth's images can offer a strong cue of familiarity to map users, stimulating their cognitive approach to support cartographic perception. Map design and production may be challenged by the exploration of the potential adjusting theoretical cartographic principles on the complex background of aerial-photo and satellite mapping.

One of the most critical components of these new cartographic applications is the representation of the topographic relief, which is already an inborn characteristic of the image, caused by the natural shades of the relief created from the incident sunlight. In several circumstances, the produced realistic shades make the earth's topography inversely perceived; whether the natural sunlight is directed east or even southeast. Cartographic methods of hill-shading use analytical techniques of computing relief shaded images characterized by a clear and legible perception of the earth's morphology. Such shadings could be added as a supplement to the original images [Yoeli 1965]. However the visual result will be improved if the share of relief's influence is isolated and removed from the existent tones, generated not only from the relief but also from various other factors as the vegetation, the earth texture, the weather, the conditions of sunlight, etc.

Elimination of the natural shades in aerial-photo and satellite images

The natural shades of the relief present in aerial-photo and satellite images are not always created with proper illumination geometry such as the basic rules of cartographic hill-shading suggest, in order to achieve a correct interpretation of the topography. In fact, the technical schedule of satellites' capturing procedure is usually made to ensure that a clear image of the natural surface of the earth will be acquired, and this means that it occurs early in the morning when the sun comes from the east. Aerial-photos' capturing is easier to be programmed, and it usually occurs closer to the noon to avoid heavy cast shadows that conceal surface information. However, in the above illuminating conditions still some shading does occur, and in addition there are exceptions from the time schedule which cause intense shading. So, if the sun is low enough, then the "fault" shading and shadows are respectively heavy and they must first be omitted before applying the computed "correct" ones. Shading is a part of the entire physical process of illumination and radiance recording, on which remote-sensed data capturing is based. More specifically, the recorded radiance values of earth's surface could ideally correspond to the objective quantities of light reflected by the ground, depending only on the energy characteristics of the land-cover. In practice, there are two main reasons affecting the final recorded values: the atmospheric attenuation caused by scattering and absorption, and the geometric effect of topography on ground reflectance process [Krauss 1991, Jensen 1996]. The change in radiance due to atmospheric attenuation is a very complex phenomenon, that several alternative estimations have been suggested for its description. Although its influence on the whole process differs from the case of satellite to air-born capturing, in both cases its visual impact works in a global way. In the context of the present study, attention is focused on the topographic effect, which is the main reason for the formation of the locally dependent visual impressions of shading and shadows.

Topographic normalization is a basic radiometric correction, occurring in the preprocessing of remotely sensed images, and its calculation is carried out by extensive studies. The proposed correction methods refer to either an integrated model for atmospheric corrections, definitely requiring ground control measurements and knowledge of observing conditions' details, or to more practical mathematical and/or empirical models based exclusively on the topography of the surface [Karathanassi et al. 2000]. Below are presented two commonly used mathematical methods, the rather simple *cosine correction* and a more effective one called the *Minnaert correction*:

COSINE CORRECTION

$$L_H = L_T \frac{\cos(sz)}{\cos(i)}$$

MINNAERT CORRECTION

$$L_H = L_T \left[\frac{\cos(sz)}{\cos(i)} \right]^k$$

where
L_H = corrected radiance, corresponding to a horizontal surface
L_T = recorded radiance, corresponding to sloped terrain
sz = sun zenith angle
i = incidence angle between sunlight and surface normal
k = Minnaert constant, varying between 0 and 1

As it is obvious from the latter equation for k=1 the *Minnaert correction* degenerates to *cosine correction*. Evaluations of the known mathematical or empirical methods provide important information for their effectiveness [Meyer et al. 1993]. The *cosine correction*, which is exclusively based on the assumption of a Lambertian reflection of an isotropic distributed light by the illuminated surface, tends to overestimate shading in rugged terrain with weakly illuminated areas, thus it is mainly applied in flat terrain. On the other hand, the *Minnaert correction* takes also into account the component of light caused from diffusion and surrounding reflection, by applying a constant that implies the extent to which a surface is Lambertian. Furthermore, only small difference in results is observed between the *Minnaert correction* and other complex statistical methods present in literature. Thus, in the present study the above two methods were used for practical reasons.

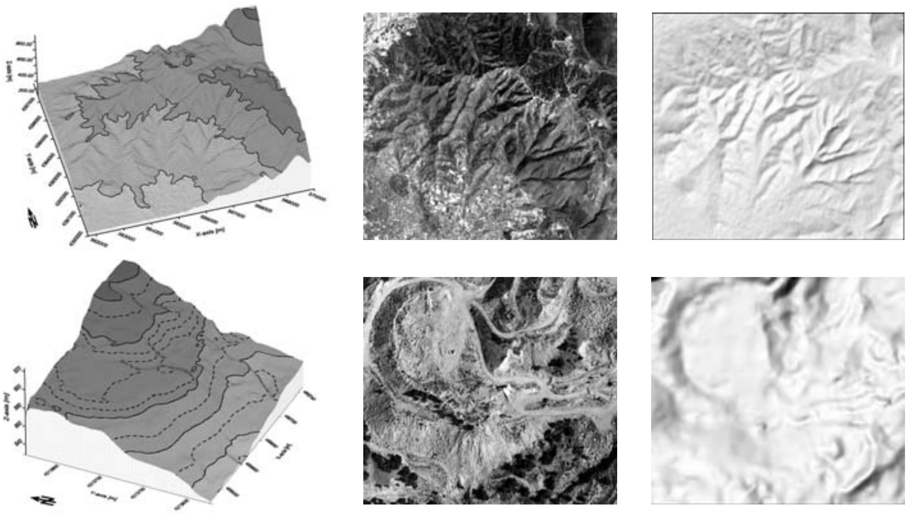
In this work, two samples of earth's surface images, one aerial-orthophoto and one satellite image, are used for an experimental procedure of shading correction as large-scale or small-scale representations respectively (Figure 1). The angles of sunlight for the satellite sample were found by the metadata information of older scenes of the same date, since the scene used came without this information. For the aerial-photo sample, the time and date of the shot were used as input data to calculate the polar coordinates of the sun position. The respective digital elevation models were interpolated using collected height information, by means of either digitized hypsometric contours and breaklines from maps of scale 1:50,000 (case of satellite data), or individual spot heights captured from stereo-pair images (case of the aerial-photograph). At this point a critical issue arises referring to the matching between the digital elevation model and the image to be corrected.

SAMPLE OF SATELLITE IMAGERY
(SEMI-MOUNTAINOUS AREA AT TRIKALA, CENTRAL GREECE)

AREA: 8.1X7.3 KM^2
ELEV: 141-880 M
CELL SIZE = 20M
SUN AZIM = 152°SE
SUN HEIGHT = 60°

SAMPLE OF AERIAL-PHOTO IMAGERY
(AREA WITH QUARRIES AT PENTELIKON MOUNTAIN, NORTHWEST OF ATHENS)

AREA: 240X220 M^2
ELEV: 828-923 M
CELL SIZE = 0.4M
SUN AZIM = 140°SE
SUN HEIGHT = 68°



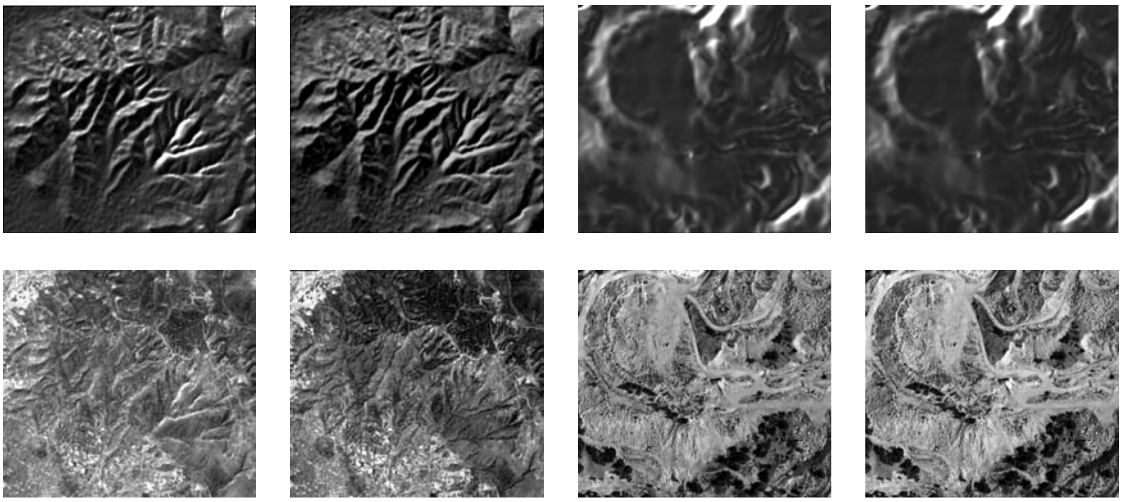
(a) **(b)** **(c)**

Figure 1: Sample imagery and relative available information for the corrections

(a) 3D visualizations of the samples' areas with draping of hypsometric tints over the interpolated DEM
(b) The respective samples of satellite and aerial-photo imagery
(c) Computed shading images corresponding to the position of the sun at the date and time of data capturing

Both methods of correcting topographic effects are applied on the two samples, where the Minnaert constant (k) is approached by successive approximations of values between from 0 and 1. The adopted value of k was empirically estimated by selecting visually the most effective result. The final image values (L_H) calculated by multiplying the corrections with the existent values (L_T), are normalized to the range of grayscale visualization. Evaluating visually the results of the computations applied on the satellite image sample (Figures 2a,b), it appears that the *cosine correction* indeed causes overestimations. Contrary, the Minnaert formula applied with a constant valued equal to 0.6, gives satisfactory removal of shades with the consequent loss of three-dimensional impression.

The case of the aerial-photo (Figures 2c,d) has certain difficulties. First, the relief corresponding to images of large scale is very detailed and complex. The slopes at locations with rough terrain are larger that the expected physical ones, resulting in extremely high values of corrections at the adequate locations. Assuming that the maximum logical slope on the ground is up to 50%, the maximum correction is computed for the relief of this area, and values larger than this are ignored. The aerial-photo's corrections then, become similar to the ones computed for the satellite sample. In this way, the problem of overestimation using *cosine correction* is not apparent and this method produces more satisfactory results than Minnaert's. An even more inconvenient problem is that the shading tones interfere with tones of different reflection due to land-cover, whose variation is certainly higher. This lack of three-dimensional impression of natural shading in aerial-photos, due to the covering and flecked texture of earth's surface had been identified long ago, while browsing ways to model the early efforts on manual skillful hill-shading [Imhof 1982]. Still, it is clear to be seen that shades of relief have been omitted, if the corrected image is closely examined together with the simulated image of the relief shading according to the date and time of capturing.



(a) **(b)** **(c)** **(d)**

Figure 2: Grayscale visualizations of corrections ("the larger the lighter") and respective results
(a) *Cosine corrections* on the satellite sample **(b)** *Minnaert corrections* (*k*=0.6) on the satellite sample
(c) *Cosine corrections* on the aerial-photo sample **(d)** *Minnaert corrections* (*k*=0.5) on the aerial-photo sample

Relief-shading for combined visualization with other surficial representations

The role of relief representation as a map component, varies from being a supplementary background that enhances the depiction of the main portrayed phenomena [Wheate 1996] to "the foundation for all the remaining contents of the map" [Imhof 1982, p. v], depending on the purpose and type of the map. In any case, the continuous three-dimensional nature of relief makes the choice of its symbolization a particularly complicated and special-treated map procedure [Robinson et al. 1995]. One of the earliest developed methods for relief representation is the method of hill-shading, which gives a realistic and easily perceived depiction of the relief even for casual users. However, cartographers had to wait for contemporary technological achievements in order to overcome the difficulties in production, and efficiently practice and experiment with hill-shading images.

The cartographic method of relief-shading or hill-shading is the visual differentiation of tone under specific light conditions and due to the variable local orientation on each point of earth's surface, counted with the percentages of the reflected light. In reality the interplay of illumination with a surface is expressed using many parameters which denote more complicated physical models and position-dependent effects of illumination, like cast shadows, illumination from neighbor surface points or atmospheric perspective. But as cartographic hill-shading is used for representing and not simulating reality, effects like these are not implemented because they do not necessarily serve the perception of the surface shapes [Imhof 1982, Horn 1982]. Instead of that, convenient assumptions that ensure legible shading images are considered; Lambertian, perfectly diffusing surfaces that demand relatively simple calculations, and hypothetical sunlight that psychological reasons enforce its placement to west directions are applied. Further guidelines are the fitting of main light direction to the dominant aspects and slopes of relief, and adjustment of light source according to local surface orientation. Among the several methods of representing terrain information, hill-shading applies for its ability to present a quick, comprehensive, non-skilled and familiar image of topography. The aforementioned characteristics make it the most proper method to visualize terrain information in combination with other phenomena that are also portrayed by using surficial symbolization, eg. polygonal thematic data, discrete-zoned or continuous realistic hypsometric tints, conventional analogue maps which have been scanned and geo-referenced, or images of earth's surface.

The production of a relief-shading layer for combined surficial representation has two main phases of processing, where certain choices can define the final result. First and foremost, is the main production of the hill-shading tones, requiring a digital elevation model of the area, and the selection of the most convenient available shading model and the appropriate parameters. The common parameters for any model are the azimuth and zenith angle of the hypothetical sunlight direction –usually placed to north-east and 50% from the ground- while special other parameters for a certain model might also exist. It is very important to note here that, despite of the significant progress of research about hill-shading, only a restricted range of certain models can be found in the computational environments of the commercial and staple software products used for cartography. If a wider choice of selection is needed, either use of other type of software must be developed (eg. based on 3D computer graphics) or programming of routines should be implemented along with the necessary tools for data-exchange. According to the type of combined spatial representation, some general –even mostly empirical so far– aspects of choosing the appropriate kind of model may be applied, but still it is only the visualization of shading that can affirm if the choice of parameters of shading is adequate or not.

Secondarily, the produced grayscale image of shading is further adjusted towards its tonal characteristics and texture, according to the combined spatial representation. The basic concept of this fine-tuning is to confine the shading values to a subset of the full range covering from black to white. The adjustments that can be made consist of the improvement of brightness and contrast, and the smoothing of imperfections or unnecessary details using appropriate filters. At large scales shading aims to emphasize the dominant forms of the topography while at smaller scales more detailed information is needed, and the maximum intensity is limited by the relationship between the shading and the legibility of map [Keates 1989]. Successful combination of the component representations is achieved when their features as they are presented in the resulted image are supported by the balanced interplay of each component's contribution.

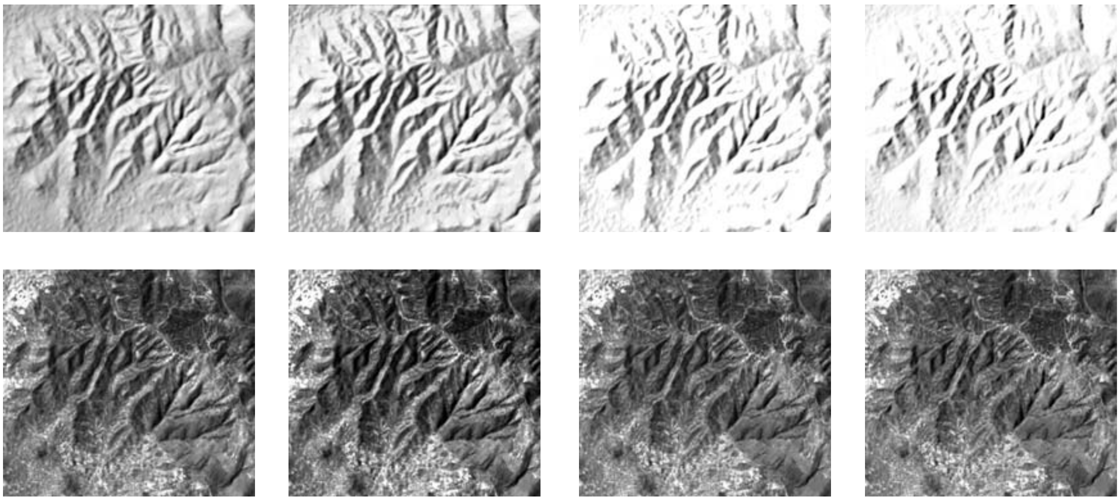
As these modifications of hill-shading tones depend totally on the combined surficial representation, they should be accomplished together with the final implementation of two respective images. During the procedure of combination, there is one more way to optimize the visual result. By using a regulatory factor *a*, there can be a balance between the fully mixed image and the initial one [Tzelepis 2000] as described by the following equation:

$$V_{fin} = a \cdot V_{comb} + (a-1) \cdot V_{init}$$

This is a characteristic way of image combination, available in most of the image-processing software. This feature together with the ability of direct previewing, are very helpful tools for the successive implementation of a hill-shading method.

Combination of computed hill-shading and a non-shaded image of earth's surface

A successful incorporation of relief-shading representation in a satellite or an aerial-photo image free of shades is achieved when the critical features of the two components are preserved, or even further enhanced. A primal approach to this effort is an understanding of the particularities, carried out by the close examination of types and functioning of the visual elements for each component. As indicated by a conceptual framework of image analysis, tone or color is a fundamental property of imagery, while other visual elements like shape, pattern or texture are expressed by means of spatial arrangements of it, sequentially perceived in an intermediate or higher level [Estes et al. 1983]. All elements are functioning in the context of several image analysis tasks (detection, identification, measurement, knowledge-assisted labeling and significance), for aiming at the interpretation and perception of the spatial objects and at relationships among them. In hill-shading images a similar situation is evolved; tone is the fundamental property, shapes and patterns are formed by arrangements of tone, revealing the forms of relief in the presented area. The visual element of size is also apparent in both components, but it functions with more detail in the context of the imagery. Generally, these two visualizations seem to be perceived in a similar way, subscribing to their combination for producing harmonic visual result –here carried out by multiplication of the respective images' values at corresponding points.



(a) **(b)** **(c)** **(d)**

Figure 3: Computed hill-shading images and combinations with the satellite imagery sample.

(a) Standard model of Lambertian surface based on the perfect diffusion assumption. The sunlight azimuth selected for better shading is 156° NE.

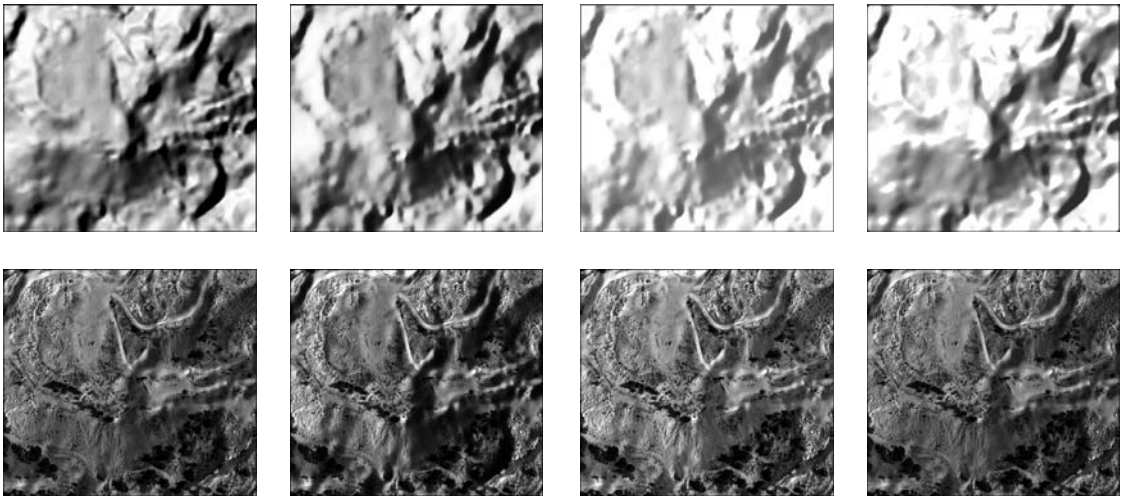
(b) Local adjustment of azimuth and elevation of light direction for better lightning of the area, relatively to the result of 3a (here equal to 25% for each angle).

(c) Fine-tuning of shading on example 3b, by tonal modifications (increased brightness 50% and contrast 25%).

(d) An alternative choice with similarly balanced results, produced by a simple mathematical model (parameters to be defined are the gray tone for horizontal surfaces and the rate of change for the gray tone to slope ratio, here equal to 50% each, brightness and contrast of shading image have been improved).

The presence of hill-shading adds to the image the essential cue for depth perception, which is required in order to operate as a non-perspective simulation of three-dimensions [MacEachren 1995]. In contrary to the original captured images, the relief forms perceived using proper shading rules correspond to the actual ones. Moreover, for those spatial objects that are shaped along with underlying relief formations, it can be seen that perception is impressively enhanced. In large-scale images (aerial-photos or high resolution satellite imagery) objects like these can be artificial features like road network or modulations around buildings. In this case of course these objects must be also included in the utilized digital terrain model. The beneficial influence of representing the relief with correct hill-shading can be seen in all stages of image analysis; from the early stage of detection where mental images are recalled to help the observer to label the object, to more time-consuming consideration needed for more complex arrangements, where special related knowledge might be required. In the contrary, there are cases where the perception of relief is helped by locative information derived from the image, recalling existent special knowledge related to the site. In fact, the interpretation of objects and spatial relationships presented in the images of earth's surface, and the perception of forms of relief accentuated under conditions of correct shading, are mutually enhanced.

The corrected samples utilized for this work, are combined with hill-shading images computed from the staple model of Lambertian reflection (Figures 3a, 4a) or other alternative methods. More specifically two methods are tested for the satellite image; the adjustment of light source for better local reflection and brighter shades (Figure 3b) and a simple mathematical method based on balancing the result around a defined gray tone for horizontal surfaces (Figure 3d). For the aerial-photo the same model was applied, assigning the horizontal surfaces with a darker tone (Figure 4b). An example is given also using a method of specular reflection designed for use on computer graphics, which gives an image of "plastic" shading that fits the realistic impression caused by observing in a close distance (Figure 4d). The dominant aspects of relief are found, indicating convenient directions for hypothetical light sources. Further modifications of brightness and contrast are made to optimize the shading towards to incorporate it into the imagery (Figures 3c, 4c). The tuning of the shading image in order to reveal the relief forms consists of delicate and critical graphical decisions taken under serious constraints. The fact, that slight changes of shading are impossible to be seen in the continuous presented information of the images, suggests that enforcement of contrast should be high enough to permit the detection of relief shapes. On the other hand special care is needed to avoid the presence of dark tones disturbing the legibility and readability of imagery's information, which is still the first priority of this combination.



(a) **(b)** **(c)** **(d)**

Figure 4: Computed hill-shading images and combinations with the aerial-photo imagery sample.

(a) Standard model of Lambertian surface based on the perfect diffusion assumption

(b) Utilization of a mathematical model for more balanced results, because of the dark tones caused by existence of steep slopes (same parameters to be defined as in [Figure 3d], with the gray tone for horizontal surfaces here equal to 12.5% and the rate of change for the gray tone to slope ratio, equal to 50%)

(c) Fine-tuning of previous shading by tonal modifications (with increased brightness % and contrast 25%)

(d) A different choice produced here by a mix of 50% Lambertian and 50% specular reflection for computer graphics (brightness and contrast of shading image have been improved)

Concluding Remarks

At the context of this work, an attempt has been made to experiment with optimal visualizations of the relief-shading in the new fast-spreading satellite and aerial-photo mapping products. For practical reasons of simplifying the procedure at this first approach, only grayscale images were used. The several tasks of the procedure were carried out using commercial software for GIS and conventional image processing (ARC/Info, Adobe PhotoShop) and custom programming routines. First, existent natural shades that mystify the perception of users were removed using techniques of radiometric pre-processing. The calculation of corrections from direct reflection by these techniques, based on the Lambertian reflection law, is only a part of an integrated procedure for environmental noise. The inclusion of more parameters like reflection from neighbor areas or scattering can be further examined for more reliable computation of correction.

The complexity of the imagery's information itself requires that the production of the hill-shading representation needs to be implemented along with the final task of its incorporation in the image, in order to avoid disturbances on image reading and final product legibility. Strong visual tools like direct previewing are essential for getting out the most of this delicate graphical procedure. This need becomes even more important if color images are to be used, introducing another critical point of the selection among alternative combining procedures based on different color models or graphical techniques. The efforts described herein constitute some general experimentation based on the characteristics of the single component visualizations. For an objective documentation on the perceptibility of the combinations of hill-shading methods and the images, it is suggested that related questionnaire including visual examples like the above, should be planned and applied on users, so that data for statistical processing to be provided. In addition, it is a strong challenge to elaborate these first results in order to develop the entire project to three-dimensional visualization.

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