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A METHOD FOR DIGITAL RELIEF VISUALIZATION BASED ON TERRESTRIAL PHOTOGRAMMETRY USING GIS TECHNOLOGY

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ABSTRACT

This paper presents a method that has been developed for creating perspective relief images capable of extracting measurement information as a feature of the distance from the observation post. This method produces a perspective image of the relief, as the latter would look if it was photographed from a known shooting point in relation to a target point, using a photo camera of known geometry, and based on the digital terrain model of the area and the shaded view of the same relief. The method is applied in the Lefka Ori mountain range in Crete, and the results are compared to actual photo shootings in the same area. The digital relief visualization can assist in better comprehending the three-dimensional space and in efficiently managing the visual environment.

Keywords: digital relief visualization, DTM, GIS, hillshading, terrestrial photogrammetry.

1 INTRODUCTION

Digital landscape visualization has a relatively short history. Arguably the first efforts were in the 1960s. The development of CAD and computer graphics in general also started at that time, but the majority of these early efforts focused on the representation and visualization of objects, such as gears, airplanes, teapots. It was during the early years of GIS development that the visualization of terrain became a subject of study and development, and grid meshes and triangulated irregular networks, among other useful techniques, were invented. However, the applicability of many such techniques was limited, for a variety of reasons [1, 2]:

(a) Natural phenomena are far more complex than any human construction and, consequently, it is hard to substitute them with a model. The physical relief, due to the irregularity of its shape, cannot be efficiently substituted by a model using basic geometrical shapes such as those utilized in automated design applications (CAD/CAM).
(b) The data that are necessary for creating digital terrain models (DTMs) are outnumbered by the data used in other visual representation applications.
(c) The need for geometrical accuracy is increased compared to other applications.
(d) Perspective relief representations lack spatial homogeneity in terms of detail. This entails the generalization of both the information and the details of the relief in relation to the distance from the viewing point.
(e) Perspective terrain models are more complex, due to the atmospheric refraction, the atmospheric conditions and the curvature of the earth's surface.

There is a wide spectrum of techniques for the perspective presentation and imaging of the physical relief, which differ in terms of both their symbolism and their reliability of results. The more factors and variables taken into account, the more reliable the result is.

Items that are indispensable and used by all these models for creating a perspective relief representation are:

1. a DTM,
2. the observer's location and the direction of observation, and
3. a relief shading model.

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Perspective imaging can be achieved even without the use of shades, as for example in relief representation models in grid form. This, however, reduces the quality of the result. In addition to the above items, data that can be used in the presentation process, e.g. the colour and roughness of land surface and the representation of landforms, contribute to a more comprehensive result.

Today, 40 years later, landscape visualization is used in mainstream professional work, such as architecture, landscape architecture, civil engineering, and is now enabled by many CAD and animation/rendering systems, as well as GIS and remote-sensing software. Recent developments in computer science and computer graphics have made breathtaking and eye-tricking effects possible; CAD and GIS and image processing and even digital video technologies and techniques have blurred together into a powerful combined system for creating digital landscape visualizations [3–5].

Landscape visualization models try to mimic the features of real landscapes and may be three-dimensional [6] and/or dynamic, showing change over time. Significant attention in landscape visualization has focussed on realism [7, 8] and effective human–computer interaction in a landscape-planning context [9]. Several studies have shown the value of landscape visualization in a range of areas including forestry [10], landscape ecology and urban planning [11, 12].

In terms of landforms and in spite of the above advances and impressive results, a number of challenging problems remain. Typically landform modelling and representation require large digital data sets. Thus terrain and site modelling have historically been associated with GIS, rather than CAD, and are assumed to require more powerful computers, more memory and faster processors than other modelling tasks. Various modern GIS packages, such as IDRISI, ArcGIS, MapInfo, allow the visualization of surface data. These modern GIS packages allow the development of three-dimensional perspective displays, analytical hillshading and the merging of hillshading with map layers. They also provide the view of a surface from multiple viewpoints, perform three-dimensional navigation and provide interactive flight over a digital elevation model.

The methods and techniques that have been developed aim at a comprehensive simulation of the relief. However, they do not allow the extraction of measurement information from the image created. This paper describes a method that has been developed for the perspective imaging of the landforms, based on terrestrial photogrammetry and using raster GIS technology. This method, apart from achieving the target of comprehensive perspective imaging, also allows the extraction of measurement information from the image. The method has been applied in the mountain range area of Lefka Ori in Crete, and the results are compared to actual shootings from the same area.

2 BASIC ELEMENTS FOR CREATING A DIGITAL RELIEF VISUALIZATION

2.1 Digital terrain models

The data used for creating DTMs are derived from ground measurements, from photogrammetric methods or from the digitization of maps. These methods offer varying data accuracy and their selection depends on the type and needs of the application pursued. The data is used to create DTMs using any of the interpolation algorithms of software packages.

Terrain modelling has depended upon a variety of representations and mathematical abstractions from spot elevations and contour lines to 2D grids and 3D meshes, ruled surfaces, triangulated irregular networks, regular and irregular solids, Boolean operations and non-uniform rational B-splines surfaces [3]. The grid representation, the basis of all raster GIS, enables a wide range of analytic calculations, including slope, aspect, visibility, drainage and others. As a visual representation, grids suffer from two basic flaws [3]: a requirement for constant spacing which is inefficient when surface variation details are few and inadequate when details are many, and the fact that the four points of a grid cell may not be planar, but more often form a complex curved surface, which poses problems for simple computer graphics rendering algorithms that depend upon flat planes for rapid calculation of surface normals and shading.

There are also other methods to simulate the earth's surface and create DTMs, either using geomorphologic models or utilizing fractal geometry, which is intended for an evocative landscape representation [1–3, 13]. Evocative landscape representations may be made to convey a sense of place, as artistic expressions, or as a fictional virtual landscape.

The fractal geometry-based models can prove to be useful in cases presenting low accuracy requirements, adding microrelief and detail to the already existing DTM [1–3]. This detail, even though it is hypothetical, adds realism, in particular to the nearby viewing zone (up to 1000 m), where the scale of the elements depicted is very large. Microrelief and detail can also be added using other means, either with models adding random 'noise' to the altitude or by creating a texture map, on the basis of standards adopted from photographs or other means [1–3]. Many amateurs are involved in the creation of imaginary, often evocative, landforms and landscapes. The early mathematical experiments with 'fractal terrain' were bolstered by the evocative qualities of some of those early renderings. Software such as Bryce 3D, Vue d'Esprit, Terragen and others—often designed for the purposes of video-gaming environments and special effects backgrounds—have put simple tools within the reach of millions of people, for creating such visualizations [3].

2.2 Creation of a shaded relief map

Hillshading provides a rendering of topographic surfaces by assigning brightness to surface elements based on the orientation of these elements and a selected direction of illumination. The detailed calculation of a relief's shading is a basic processing function of the DTM and is included in most GIS packages. There are many models for the production of shaded relief maps, differing from one another in terms of the theory and the techniques they rely on [14]. A parameter that is common in all models is the position of the light source, expressed by the azimuth and the zenith angle in relation to the horizontal level. The determination of shades takes place by calculating the intensity of the light reflected on each unitary surface of the DTM, depending on the relative inclinations of this surface in relation to the light source [14]. Some more developed techniques also account for other parameters affecting shade, such as aspect direction, the light falling upon the surface, which is examined through the multiple reflections of light on other surfaces including the sky or even the material composing this surface [1, 2, 14, 15].

2.3 The perception of depth

Representing the depth is a very important element that must be taken into account when creating a perspective representation of a relief, in order to correctly interpret the three-dimensional space depicted. Shades are the ideal way of presenting hypsometric variances of the relief and improve the rendition of the three-dimensional space; however, they do not suffice for the correct interpretation of the depth, given that colours in nature vary in proportion to the increase of the distance. This is attributed to the interference of the atmosphere. Owing to the vapour and to the minute particles of dust in the atmosphere, the tones of the landscape's colours tend to lighten and to gradually acquire a hazy tint similar to that of the sky. Beyond this point, visibility is substantially nil [16]. The dark tones of colours become brighter, the lighter tones are blurred, and the contrast between highlights and shadows reduces gradually as the distance increases [16]. This phenomenon has proved to be useful in the cartographic representation of the relief, because the third dimension can be represented through the variation of tones. Indeed, this is the reason why plains are usually depicted on topographic maps using a light tone of ochre, while mountains are depicted using dark tones of brown. In this case, the peak of a mountain is closer to the observation point (eyesight of the observer), and it is therefore depicted using a darker tone.

There are many techniques for varying colours, which depend mainly on the variation of two of the colour's three components (hue, intensity and saturation) [17]. Therefore, a technique commonly used changes the hue depending on the distance, and the intensity depending on the shades, while the value of saturation is preserved [1]. However, despite the existence of all these techniques, selecting colours is not an easy task. On the contrary, it is a difficult process, critical for the reliability of the result. Its difficulty lies in the fact that the artificial colours must be selected in a way that they are close to the natural colours, and this is a task requiring much experimentation.

Another way for solving problems related to the distance from the observer is the use of multi-resolution terrain models, which visualizes the closer objects with a higher detail scale than the remote ones. Multi-resolution terrain models have been developed to provide a compact representation of a terrain at different resolutions. Terrain representations at any level of detail can be easily extracted from such a model. Thus, a high resolution near the viewpoint is necessary, while terrain portions lying far from the viewpoint can be represented with less detail. This is available in various modern GIS software packages such as the Multi-Tesselation Package [18, 19].

3 ALGORITHM

The algorithm explained here aims to produce a perspective image of the relief, as the latter would look if it was photographed from a known shooting point in relation to a target point, using a photo camera of known geometry, and based on the DTM of the area and the shaded view of the same relief. The flowchart of the algorithm is presented in Fig. 1.

The algorithm was programmed and uses as its data source the DTM and the corresponding shading image of an area in raster form. Such data can be derived by the use of any GIS. It must be noted that the algorithm does not use analytical tools embedded in a GIS, i.e. it is an executable programme run from within the operating system. When the DTM and the corresponding shading image are available, the algorithm takes over the further processing in order to create the perspective image.

The output of the algorithm is an image, the resolution of which is determined by the user in advance depending on the dimensions desired and the printing medium. In theory, the size of the image elements must not exceed 0.1 mm when printing [14]. If this rule is not observed, the elements become visible and the reliability of the representation is reduced. However, using a margin of 0.25 mm, the results are satisfactory enough.

When the data of the shooting camera (focal distance, negative size) and the desired resolution of the perspective image are specified, we are able to know in advance the number of lines, columns and the total pixels from which the perspective image will be composed. Thus a blank raster image of known dimensions is initially created by the algorithm. It should be mentioned at this point that shootings are always regarded as horizontal and therefore the projection of the shooting point in the perspective image is always in its centre.

Subsequently, the algorithm updates the initial blank image, following three basic stages:

1. data entry from the DTM and the shading image;
2. perspective projection of the data;
3. updating of the perspective image.

The entry of the hypsometric and shading values takes place on specific dense directions and at an exponentially increasing distance value around the shooting point (Fig. 2). Taking into account

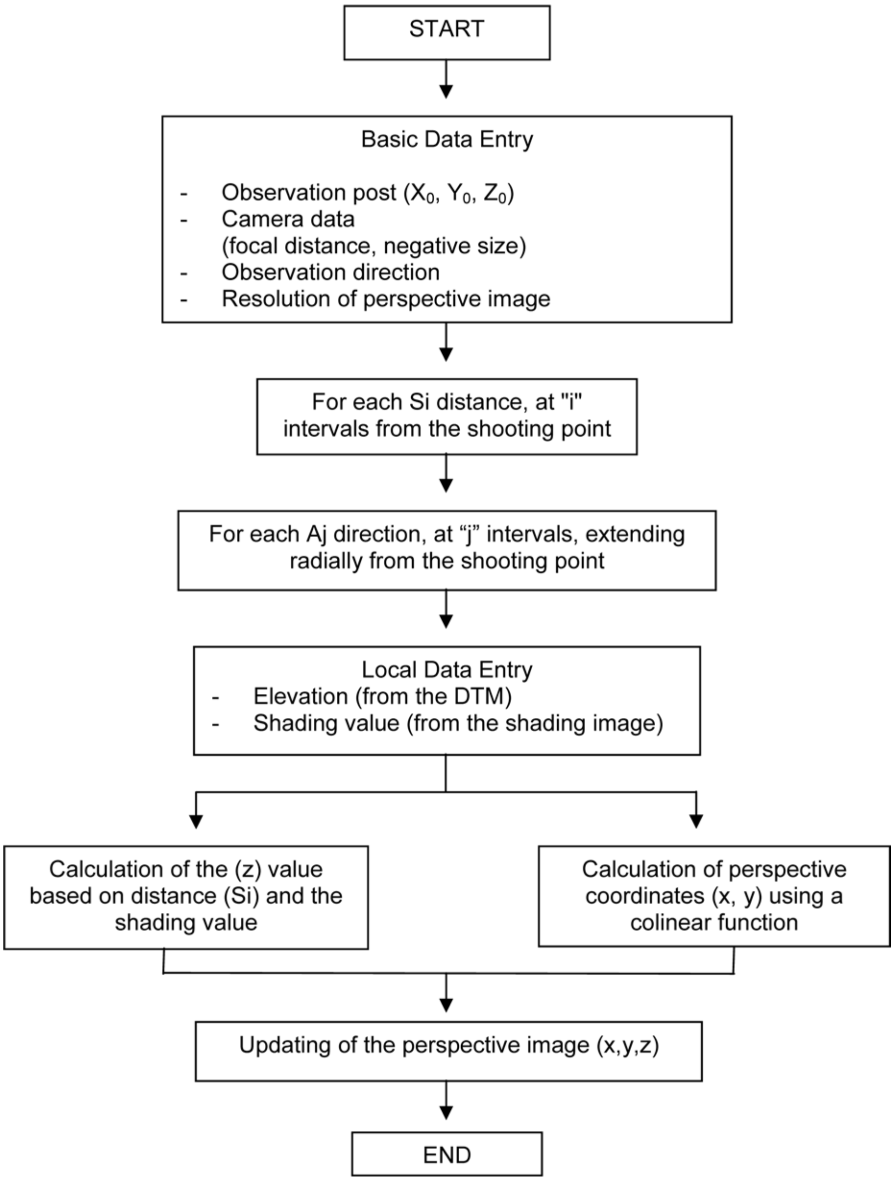


Figure 1: The flowchart of the algorithm to produce a perspective image of the relief.

that the photo shootings are regarded as horizontal, each column of the perspective image defines a direction, the azimuth of which can be calculated. All the pixels of the same column have the same direction (the pixel centre is taken into account for calculating the direction). Therefore, the directions in which the data is read from the DTM and the shading image depend on the number of columns of the perspective image. Therefore, for each direction and for every distance around the shooting point, certain points of the relief are defined with known horizontal tracing coordinates x, y (Fig. 2). Following this, and for these points, the elevation value (z) is read from the DTM and the value of the shading from the shading image, using bilinear interpolation (Fig. 3).

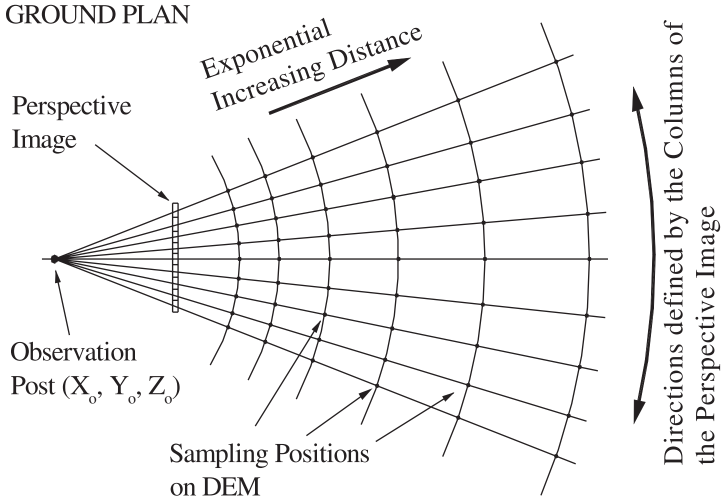


Figure 2: Data entry from the DTM and the shading image.

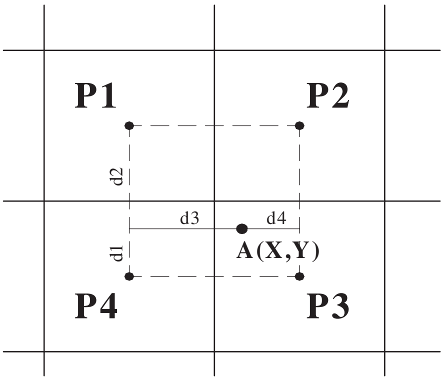


Figure 3: Bilinear interpolation.

In bilinear interpolation, the value of point A, under question, is calculated from the values of the four neighbouring pixels (P1, P2, P3, P4), in proportion to the distances (d1, d2, d3, d4) of point A from the centres of the neighbouring pixels (Fig. 3).

The above sampling technique, which was developed in the context of this work, addresses the problem of the large amount of data and increases the processing rate. As already mentioned, the perspective representations of a relief are not spatially homogenous in terms of detail. The longer the distance from the shooting point, the smaller the scale of elements and, therefore, the lesser the detail that can be perceived by the human eye. The technique used achieves a gradual visual generalization of the information and prevents the reading of redundant data, thus reducing processing time.

Further to this, the algorithm calculates the perspective coordinates (x, y) for any reading point (X, Y, Z), using equations of colinearity [20, 21].

Finally, the initial blank perspective image is updated at the relevant position (x, y) using a value (z) that represents the combination of the shading and distance categories from the shooting point. Sixteen distance categories were used (with a maximum distance of 15 km), together with 15 shading

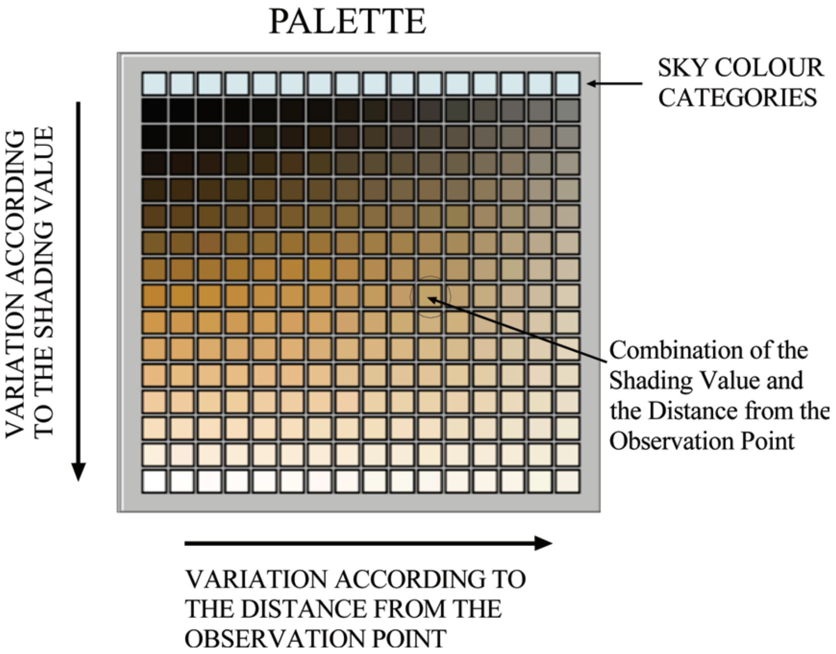


Figure 4: The colour palette.

categories, creating a matrix of 240 (16 × 15) different categories (z-values) in the perspective image. This categorization was made in order for a 256-colour palette to suffice in the final presentation. The remaining 16 categories ($256 - 240 = 16$) can be used for presenting the sky. In this way, the z-value corresponding to each of the image pixels corresponds to a given distance from the observation point (Fig. 4). Therefore, knowing the z-value, we can also extract measurement information.

In order to select the colours that will be used in the final presentation of the image, we use all three colour components (hue, intensity, saturation). Following experimentation, the variation of each component was determined in order to present the relief in as much a perceivable relief presentation as possible. The 240 different categories were processed simultaneously for each colour component, in order to prevent discontinuities and intense contrast. In this way, every component was varied simultaneously in relation to the distance and shading (Fig. 4). This technique, which was developed in the context of this work, provided the best output compared to all the above-mentioned techniques, which correspond the variation of the distance to one colour component and the shading to another in a distinct manner.

In practice, the selection of the palette colours was carried out based on the following process:

1. After experimenting and studying the colours of real pictures, the first (the most shaded) and the last (the brightest) colours of the first and the last column of the palette (excluding the first line that concerns the sky) were selected (Fig. 4). The first column of the palette corresponds to the close distance zone from the observation post and the last column corresponds to the long distance zone.
2. Using linear interpolation in the three colour components (hue, intensity, saturation) the intermediate colours of the first and the last column of the palette were determined.
3. From the two previous steps the first and the last colour of each line of the palette were determined, and further to this, also by using linear interpolation the intermediate colours in each line were determined.

In this way each colour is unique and corresponds to a distance and shading category, allowing the user to extract information about the distance of each pixel from the shooting post. The Photostyler application program was used for processing the colour palette.

For the time being, the 16 categories of the first line of the palette, which were left for the sky, have the same colour that was defined arbitrarily. The development of the algorithm will be improved in the future, in order to be enriched with techniques that increase the reliability of the presentation, such as the addition of microrelief items and the improvement in the presentation of the sky.

4 APPLICATION

4.1 Application details

The algorithm was applied in an area of the Lefka Ori mountain range in Crete, presenting a variety of relief forms.

The contour lines were digitized in order to create the DTM, using the Cartalinx digitizing software. The contours were derived from topographic maps, which were supplied by the Hellenic Military Geographical Service, using a 1:50,000 scale. The contour interval in these maps is 20 m, but there are also supplementary contours at 10 m intervals which were also digitized. This scale is the one most commonly used in analysing and managing medium-scale landscapes [22]. For creating the DTM and the corresponding shading images, we used the GIS IDRISI 3.2 software package. Utilizing the data, we created a DTM with a resolution of 15 m. As for the shadings, the orientation of the light source was the one commonly used in cartography, northwest of the shooting axis of the perspective image and at a 45° inclination angle above the horizon. This orientation serves human perception capabilities, even though it is not representative of astronomical reality [23].

The photographic shootings (Fig. 5) were effected using a wide-angle camera lens ($f = 34$ mm), on a 24 × 36 mm negative. In landscape analysis, normal lenses ($f = 50$ mm) are commonly used because they closely match human vision [24]. However, in this case, the aim was to somehow compare the images with actual shootings and not to use these shootings for landscape analysis. Shootings were taken at crossroad points or at other characteristic points (monuments, churches, etc.) that could also be identified on the topographic maps of the scale used. The shooting axis was practically horizontal, while its direction was determined using a simple magnetic compass.

In order to create the perspective images, we used the geometrical elements of the camera, and, with the assumption of strictly horizontal shootings, the observation height was 1.5 m [25]. The data was projected up to a distance of 15 km from the point of each shooting.

As already mentioned, the colour palette was processed using the Photostyler software package, and a 720 dpi resolution printer was used for printing the images.

4.2 Output comparison—comments

The selection of pictures in the given presentation was effected in order to present different forms of relief from different observation posts. The comparison of the actual pictures (Fig. 5) with the artificial images (Fig. 6) shows some morphological and hypsometric deviations, which are due to: (a) the accuracy of the data, owing to the scale of the maps used; (b) the various errors arising during the creation of a DTM (digitization errors, errors of the interpolation algorithm, etc.); (c) the assumption of the strictly horizontal shootings; (d) human intervention (roads, etc.); (e) the algorithm that was developed and used for the creation of perspective images. In any case, all the algorithms present a certain degree of malfunction during their implementation. Improving the accuracy of the results

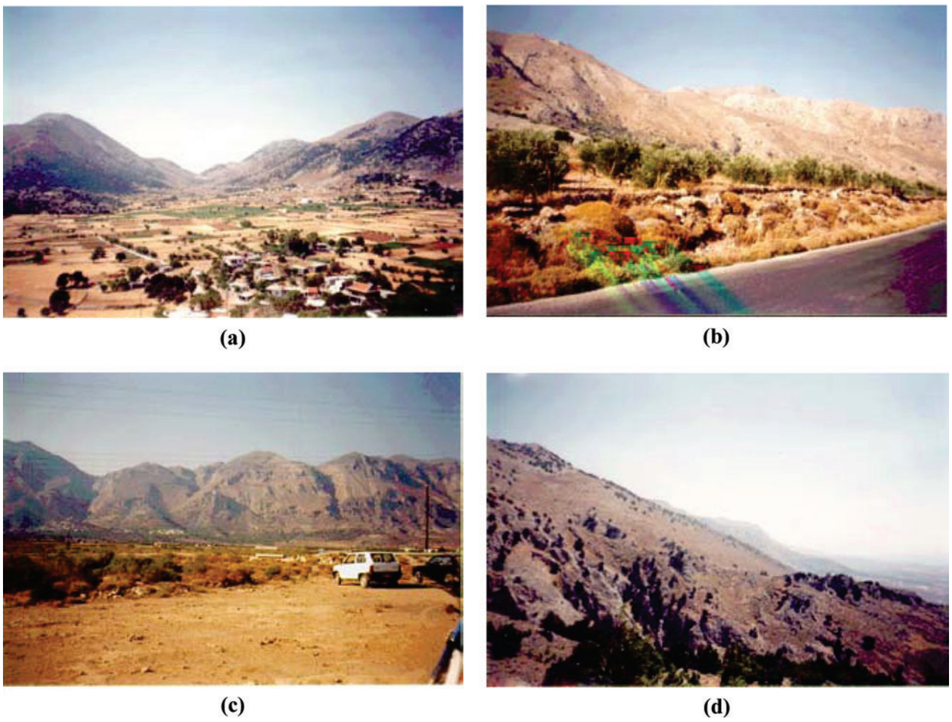

(a) (b) (c) (d)

Figure 5: Photo shootings in the Lefka Ori area.

will be one of the basic issues for research in the future development of the algorithm. However, these deviations do not reduce significantly the characterization of the relief depicted (e.g. flat or mountainous, presenting intense slopes, etc.) and also do not alter visibility to a perceivable extent.

The problems that are present in the very close viewing zone (up to 500 m and particularly in the first 100 m zone), in which the reliability of the output is reduced, are due to the lack of microrelief elements (a problem attributed to the map scale and also to the level of detail of the digitized data) (Fig. 6d).

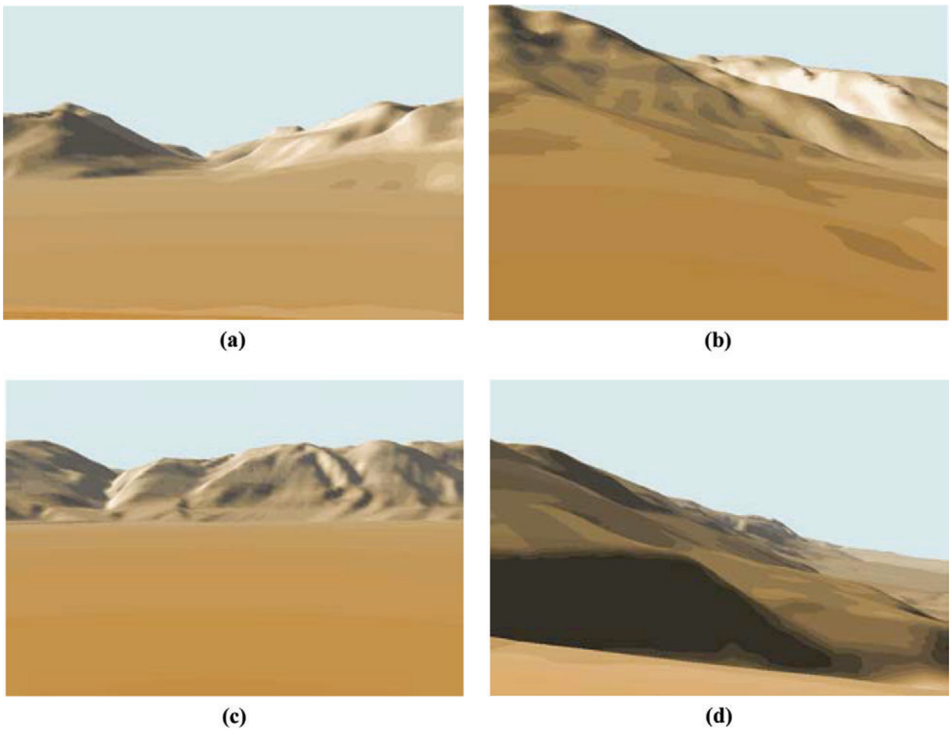
The very close viewing zone, which some experts place at 100 m and some others at 400 m, is not examined during landscape analysis or evaluation, because it is considered to be a general threshold for the convenient stereoscopic observation of objects [26]. A simple workaround that can be used to mitigate the problem of the very close viewing zone, in the case that this is really intense, is to increase the observer's elevation. Based on experimentation, an observation height of 5–10 m significantly enhances the final output without altering the visibility range of the observation post in the zones of interest. This workaround was applied in Fig. 6b, where, owing to the ascent of the relief, the first 100 m covered almost half of the picture.

It is believed that the above-mentioned problems can be mitigated or even eliminated with the use of larger-scaled maps and the increase of the information.

The final selection of the data scale and analysis depends on the researcher, on the needs of the application and, naturally, on factors such as the time and means available.

5 DISCUSSION

As an important facet of society and environment, the landscape's visual quality is attracting people's attention. To satisfy people's appreciation for high quality landscapes, planners improve the visual



(a) **(b)**

(c) **(d)**

Figure 6: Artificial relief images.

sustainability in urban and natural landscapes and maintain valuable natural landscape resources with high visual quality. Visual landscape evaluation includes three major problems: the technical problem of how to visualize possible changes in the landscape, the theoretical problem of how to evaluate scenic beauty and the administrative problem of how to integrate visual aspects in the planning process [27, 28].

Visual impacts relate to changes in views of the landscape and the effects of those changes to people. They arise from the changes in land use. In addition, in the life of a project many different sources of impact occur at various stages, i.e. during construction, operation, decommissioning and restoration. Visual impact assessment is an important component of landscape planning, and 3D simulations of the relief play an important role in the assessment of visual impact.

The technique of digital relief visualization can assist in better comprehending the three-dimensional space and in efficiently managing the visual environment. Both the prediction and the assessment of visual impact can be facilitated and better documented, while new possibilities and prospects are opened for the development of new methods of quantitative visual impact assessment. A perspective visualization, capable of presenting both the form and the individual characteristics of the relief that can be seen from a given location, can be a very useful tool in managing the visual environment and in predicting the visual impact, particularly in the case of activities that significantly alter the relief of an area (e.g. a lignite mine, a quarry, a sanitary landfill site, etc.).

A preliminary aim of this study was to create a digital perspective depiction capable of rendering the form and the individual characteristics of the relief, so that the final output could be used in lieu of a photo and to allow the extraction of measurement information on distance. The application output was quite satisfactory and encouraging in terms of the preliminary aim. The equipment and the means used for producing the images are nowadays widely used, ensuring easy application for both scientific and research purposes.

Further work in this direction can lead to a more dynamic presentation of the physical relief. The techniques that increase the reliability of the presentation, such as adding microrelief elements and improving the presentation of the sky, should be improved. It is also interesting to investigate the algorithm in terms of the ability to use other information, in addition to the shading information, such as an orthophotomap or a land uses map.

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