

Computational Methodology to Filter Raster Images in GIS Applications

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Key words: Aeolian Potential, Energy, Filter, GIS, Raster Image, Vector.

SUMMARY

This paper describes a computational methodology to filter raster images concerning spatial geo-information modulation and analysis. Here, it is shown a practical example of application on the determination of the aeolian potential energy in Lousã Mountain, in Portugal.

This kind of energy is dependent on the available useful power for m^2 in the zone in study, that in turn is relative – among others parameters – to the speed of the wind in the place. This is a measurement largeness directly related to the morphology of the land, for that the use of Geographical Information Systems (GIS), in this context, becomes particularly adequate.

In this way, it is intended to present a methodology of determination of the aeolian potential, in accordance with *ENV 1991 Norm of Euro Code 1* [CEN, 1994], using a GIS tool (IDRISI) and a mathematics analysis program (MATLAB).

SOMMAIRE

Le sujet de cet article décrit une méthodologie informatique qui permet de filtrer des images *raster* pour exécuter la modulation et l'analyse spatiale de l'information géographique. Dans le travail ici présenté, il est démontré un exemple pratique de cette méthodologie sur la détermination de l'énergie potentielle éolienne dans la montagne de Lousã, au Portugal.

Ce genre d'énergie dépend de la puissance utile disponible par m^2 , dans la zone d'étude, et celle-ci est relative, entre autres paramètres, à la vitesse du vent dans l'endroit. Ce genre de mesure est directement lié au relief de la terre, pour cela l'utilisation des Systèmes d'Information Géographiques (SIG), dans ce contexte, devient particulièrement approprié.

De cette façon, le travail ici développé prétend à présenter une méthodologie pour la détermination du potentiel éolien, selon la norme *ENV 1991 Norm of Euro Code 1* [CEN, 1994], en utilisant un outil SIG (IDRISI) et un programme informatique d'analyse mathématique (MATLAB).

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1. INTRODUCTION

The aim of this project is to show not only how simple but also the usefulness of the application of mathematical filters on raster images can be whenever the available GIS utilities are not able to respond appropriately to some tasks considered somewhat complex.

Given this, a very simple computational methodology of easy application at a computing level is proposed, so that situations of the kind described above can be resolved using a GIS utility (IDRISI) and a mathematical analysis program (MATLAB), in which the filters related to the modelling of geographical phenomena involved can be applied.

In order to demonstrate the utility of the proposed method, and also as part of the Masters Degree in Geographical Information Systems, at the Instituto Superior Técnico (IST) in Lisbon, a project aiming to determine the aeolian potential of the Serra of Lousã was carried out, in agreement with *ENV 1991 Norm of Euro Code 1* [CEN, 1994].

In Portugal, there are some areas where the value of aeolian potential may validate its exploitation; therefore, the correct calculation of its value may be of great importance. The aeolian potential depends on the useful power per m² available on the area of study, which is directly related to, among other small parameters, the wind speed at that same area. This latter parameter is closely associated to the importance of the land, and hence, the application of the GIS utility, becomes increasingly appropriate.

The data used in this project was collected from the Instituto Geográfico do Exército (Geographic Institute of the Army) and the Instituto Nacional de Meteorologia (National Institute of Meteorology).

2. PRESENTATION OF THE COMPUTATIONAL METHODOLOGY

At the moment the available *software* on the market are not able to provide a compelling solution to the modulation and analysis of certain phenomena geographically separated, the use of other methods becomes necessary, namely the use of computing programming in which mathematical models are implemented in order to determine the correct solution to this variety of problems.

In this perspective, we propose a new method that may be applied to any given number of *raster* images, upon which filters can be applied in the following manner:

- Reading of the input images and storing of information in the format of vectors;
- Storing of data corresponding to every pixels represented within the image, in which the equations (filters) are applied cyclically, so that all boundary conditions are satisfied and the final image is constructed based on the output vector;

It is also worth mention that such operations may be repeated as many times as needed through other cycling results, until the required analysis may be performed.

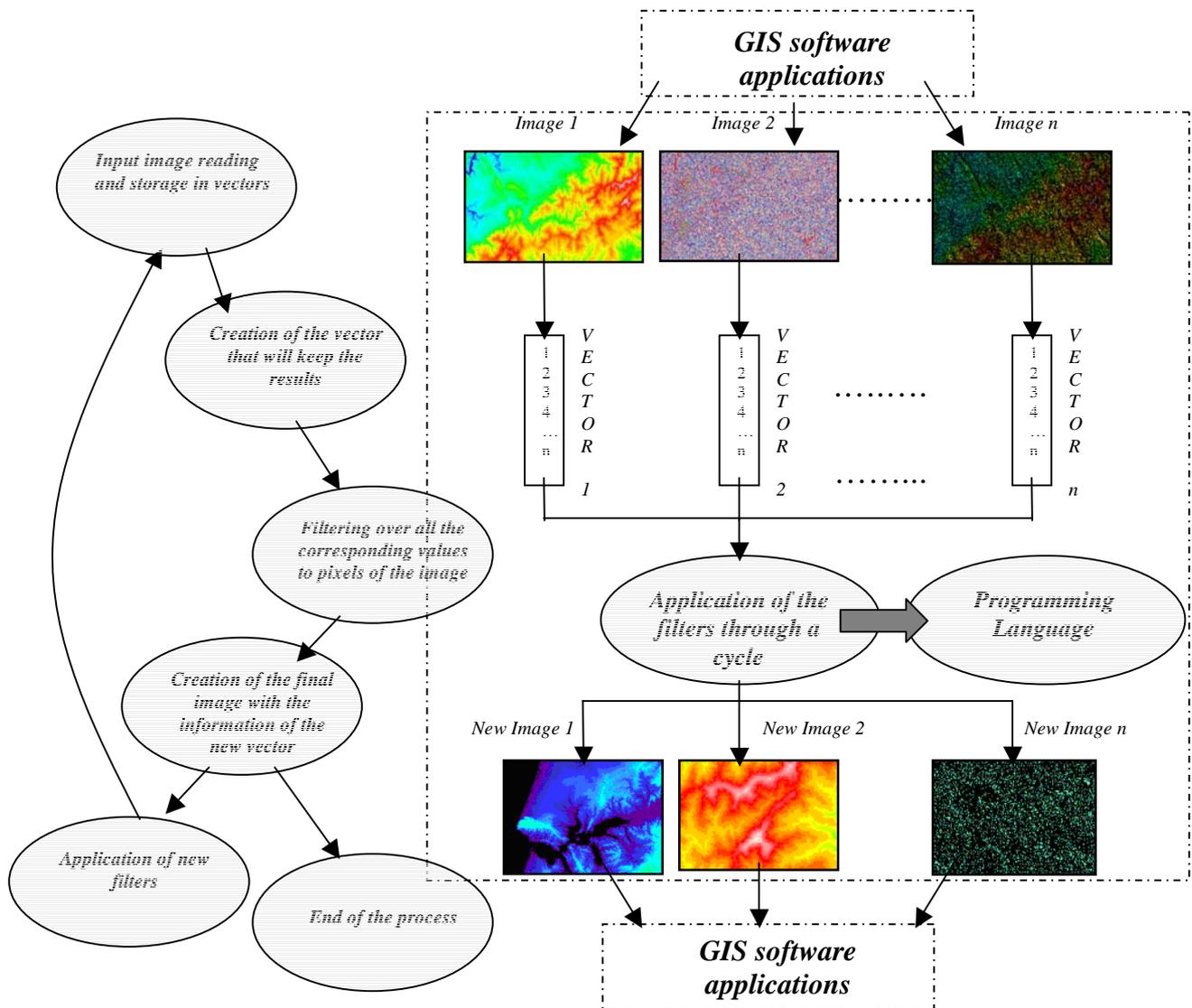


Figure 1 Data flow when raster images

Next, the input and output files – specified within the MATLAB code – that enable the analysis of raster images are presented. Also, the applied mathematical filters will be different depending on which objective the user intends to be. In this way, one good example of the utility of such filters will be shown below along with the process of the calculation of the aeolian potential of Lousã mountain (Portugal) using this computational method.

Input Image Reading, Storage in Vectors and Creation of the Vector that will keep the results (for 3 raster images):

```
fid1=fopen('IMAGE1','r');
[1, COUNT] = fread(fid1,inf,'float32'); %IMAGE1 reading and rank of its values on vector1
```

```
fid2=fopen('IMAGE2','r');
[2, COUNT] = fread(fid2,inf,'float32'); %IMAGE2 reading and rank of its values on vector2
```

```
fid3=fopen('IMAGE3','r');
[3, COUNT] = fread(fid3,inf,'float32'); %IMAGE3 reading and rank of its values on vector3
```

Creation of the Final Image with the Information of the New Vector Filtered (for 1 raster image):

```
fid1=fopen('IMAGE1','wb');
fwrite(fid1,CN,'float32'); %Creation of the final binary file (IMAGE1)
```

3. EXAMPLE OF APPLICATION ON THE DETERMINATION OF THE AEOLIAN POTENTIAL ENERGY

The aeolian potential is defined as the highest value of the useful wind power per m² within the considered area. The measurement of such unit together with other parameters, allows the study for the possibility for aeolian parks considering the exploitation of aeolian energy.

Following, a new method for calculating the value of the aeolian potential will be presented, in agreement with *ENV 1991 Norm of Euro Code 1* [CEN, 1994].

3.1 Useful Power

The useful power (Pu), in terms of electrical energy, is given by:

$$Pu = Pd \times \mu \quad (\text{eq. 1})$$

where Pd is the available wind power and μ is the efficiency of the turbine;

But, the available power is also a function of the wind speed at the area of study. This relation is given by [SARAIVA,1985]:

$$Pd = k_e \times \frac{1}{2} \times \rho_{ar} \times \bar{u}^3 \times A \quad (\text{eq. 2})$$

where: $\left\{ \begin{array}{l} k_e - \text{factor of energy form (-)} \\ \rho_{ar} - \text{specific mass of air (kg/m}^3\text{)} \\ \bar{u} - \text{average speed of wind (m/s)} \\ A - \text{turbines influence area (m}^2\text{)} \end{array} \right.$

The constant factor k_e depends on the predominant direction of the wind within the area of study, which is related to the Weibull (k) distribution factor, that takes the values on

Table 1 Table 1 and ρ_{ar} is basically dependent on the atmospheric temperature at the area [SARAIVA, 1985].

Wind Characteristics	K	ke
Polar	1	6
Continental, irregular	1.5	2.70
Coastal, maritime	2.0	1.92
	2.5	2.57
Trade wind	3.0	1.36
	3.5	1.22

Table 1 Values for the parameter of form respecting to the distribution of Weibull (k and ke), in accordance with wind characteristics [SARAIWA, 1985]

The average wind speed is the result of the balance of the average speed ($v_m(z)$) in different directions (generally the 8 main ones), with a power indicator, comprising the corresponding frequency and reference speed ($f \times v_{ref}^3$). Following, the method for determining the value of the average speeds is presented.

3.2 Wind Average Speed

The wind speed within the atmosphere in a local perspective is essentially changed by two factors: the rugosity of the land and the topography.

The rugosity of the land, that depends on the type of presented vegetation and on the existence of rises of land, decreases the value of the wind speed when a transition from a surface of reduced rugosity to a surface of increased rugosity occurs. For the opposite case, the wind speed is increased.

The topography acts generally as an acceleration of the wind when the air rises over elevations of land or in the case of obstruction or narrowing of the air path. Due to the effect of topography, the windiest areas are generally mountain ridges, and hence, the study of aeolian potential should preferably be restricted to such areas.

According to *ENV 1991 Norm of Euro Code 1* [CEN, 1994], the average wind speed is given by: know

$$v_m(z) = c_r(z) \times c_t(z) \times v_{ref} \quad (\text{eq. 3})$$

$$\text{where: } \begin{cases} c_r(z) - \text{rugosity coefficient.} \\ c_t(z) - \text{topography coefficient.} \\ v_{ref} - \text{reference speed (m/s)} \\ z - \text{turbine height (m)} \end{cases}$$

3.2.1 Rugosity Coefficient

The Rugosity Coefficient accounts for the variation of the wind speed due to the height and the rugosity of the land along the direction of the wind, and is defined by the following expressions (eq. 4) and (eq. 5),

$$c_r = k_r \ln(z/z_o) \quad \text{if } z_{\min} \leq z \leq 200 \quad (\text{eq. 4})$$

$$c_r = c_r(z_{\min}) \quad \text{if } z < z_{\min} \quad (\text{eq. 5})$$

where: $\begin{cases} k_r - \text{land factor} \\ z_o - \text{rugosity length} \\ z_{\min} - \text{minimum height} \end{cases}$

where all of the parameters described above depend on the land category presented in Table 2.

Land category	k_r	z_o (m)	z_{\min} (m)
I – sea surface, lakes with at least 5 Km of surface in the direction of the wind and plain land without obstacles	0.17	0.01	2
II – agricultural land with fences, small structures of farm and occasional houses or trees	0.19	0.05	4
III – suburban or industrial areas and permanent forests	0.22	0.3	8
IV – urban areas with at least 15% of the surface covered with buildings, whose average height exceeds the 15 meters	0.24	1	16

Table 2 Category of the land and associated parameters [CEN, 1994]

3.2.2 Topography Coefficient

The *Topography Coefficient* accounts for the increase in average wind speed upon hillsides and scarps, and is related to the wind speed on the base of these “topographic elements”. The value of the *Topography Coefficient* may be obtained from the following expressions, which are related to the slope (Φ) [CEN, 1994].

$$c_t = 0 \quad \text{if } \Phi = 0 \quad (\text{eq. 6})$$

$$c_t = 1 \quad \text{if } \Phi < 0.05 \quad (\text{eq. 7})$$

$$c_t = 1 + 2 \times s \times \Phi \quad \text{if } 0.05 \leq \Phi < 0.3 \quad (\text{eq. 8})$$

$$c_t = 1 + 0.6 \times s \quad \text{if } 0.3 \leq \Phi \quad (\text{eq. 9})$$

where: $\begin{cases} s - \text{scale factor} \\ \Phi - \text{declivity of the windward hillside in the direction of the wind} \end{cases}$

The slope Φ may be obtained from the ratio H/L , where L is the actual length of the windward hillside along the direction of the wind and H is the height of the rise of land, obtained by the difference between the height of the crest of the rise and the height of its base. L may be found by the value of L_u and H , where L_u is the horizontal distance from the crest of the mountain ridge to the base. In order to calculate the value of s , the morphology of the rise of land and the location of the area in study, namely the horizontal distance to the top of the mountain ridge (x) and the vertical distance from the ground, in this case located at the height of the turbine (z). *Figure 2* shows an example of a rise of land so that the nomenclature employed throughout the paper becomes clearer.

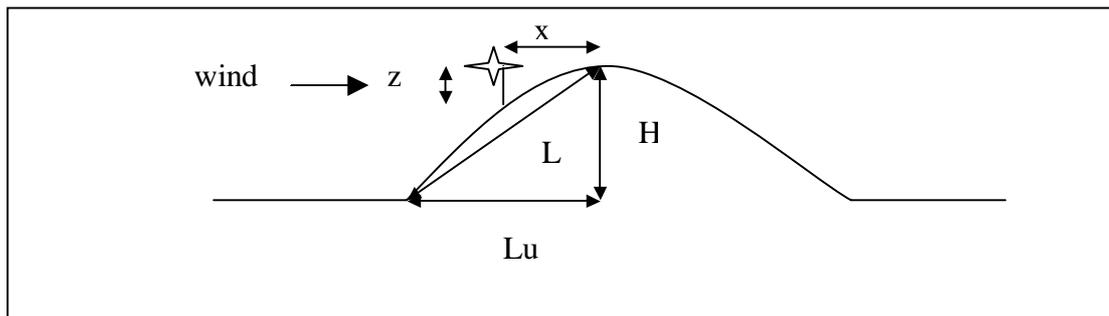


Figure 2 Used nomenclature in a rise of the land

3.2.3 Reference Speed

In order to determine the reference speed at a certain height, different parameters related to the wind speed at the area of study must be obtained. These parameters can be obtained from the database from the local Meteorological Station. Therefore, the reference speed is given by the following expression:

$$v_{ref} = \frac{v_m(z_m)}{c_r(z_m) \times c_t(z_m)} \quad (\text{eq.10})$$

where: $\left\{ \begin{array}{l} v_m(z_m) - \text{annual average speed} \\ c_r(z_m) - \text{rugosity coeffic.} \\ c_t(z_m) - \text{topography coeffic.} \\ z_m - \text{height of measurem. of the station} \end{array} \right.$

Since the meteorological information describing the wind parameters comprises generally eight different directions, this project will employ the same nomenclature: North (N), South (S), East (E), West (W), Northeast (NE), Northwest (NW), Southeast (SE) and Southwest (SW).

4. CASE IN STUDY – LOUSÃ REGION

In the following section, the method described above is applied on the Lousã region, using a GIS utility (IDRISI) and a computing program (MATLAB).

This area was chosen as the case of study for two main reasons: it shows a significant relief, causing high values for the wind speed and the corresponding aeolian potentials, and also, has a low population density value which causes a diminishing impact the may arise from creating an Aeolian Park relatively close to the populations.

4.1 Departure Data

The source of necessary information for this project may be inserted into three different groups: the conditions of area of study, adopted turbines and simplifications.

At the present work the base chosen is taken to be at the height at which the reference speed is found, 600 m high. Over such height, at the outer layer, the wind speed is solely dependent on the gradient of the pressure instead of the conformation of the windward land. In this manner, every calculation takes the base to be at a height of 600 m and the mountain ridges to be 800 m high.

Similarly, is also essential to determine the height at which the wind speed shall be calculated (z). Throughout the present work, the application of turbines is considered to be 50 m high, a diameter of 40 m and an efficiency of 42%, which gives a parameter value of 50.

Now, it is possible to follow the proposed method, showing the database concerning for the calculations of the different parameters:

In order to calculate the reference speed a few measurements need to be taken from the area of study. Next to the Lousã region, there are some meteorological stations with measurements of the speed and direction of the wind. Note that, in agreement with the restriction in height explained above, the measures taken must be presented in relation a reference height of 600 m. The following stations may be used to collect such data: Lagoa Comprida (40°23'N / 7°38'W) [INMG, 1991], Penhas da Saúde (40°19'N / 7°33'W) [INMG, 1991], Penhas Douradas (40°25'N / 7°33'W) [INMG, 1991] and Caramulo (40°34'N / 8°10'N) [INMG, 1990].

The location of these stations was studied so that the existence of possible obstructions of the wind path could be taken into account in the data used. From this analysis it can be concluded that the only station that does not show significant obstructions of the wind path is the Lagoa Comprida Station, which, however, is located upon a hillside as a part of a rise of land in the South/Southwest direction. Nonetheless, since the hillsides along such directions are generally relatively smooth, the data from this station are taken as valid for the calculations of the reference speed.

The Meteorological data from the Lagoa Comprida Station [INMG, 1991] is accessible as average monthly data from 1951 to 1980, for every direction of the wind. The values of wind speed and frequency are averaged so that the representativeness of the measurements may be assured.

Hence, determining the coefficients of rugosity and topography ($c_r(z_m)$ and $c_t(z_m)$) for this station, taking the height of the measurements to be 4.5 m over the ground level, it is possible to apply (eq. 10) and to determine the reference speed at the area of study (v_{ref}). Table 3

Table 3 shows part of the meteorological data from this station, and the calculated coefficients and the corresponding reference speeds. Now, it is also possible to calculate the power indicator introduced in section 3.1 ($f \times v_{ref}^3$).

Direction	V (km/h)	f (%)	$C_r(Z_m)$	$C_t(Z_m)$	V_{ref} (km/h)	$f \times V_{ref}^3$	
						(km/h)	(%)
North	15.1	6.4	0.85	1	17.8	36097.4	2.6
Northeast	17.8	7.6	0.85	1	20.9	69382.9	4.9
East	18.3	15.9	0.85	1.11	19.4	116092	8.3
Southeast	26	13.9	0.85	1	30.6	398271.4	28.3
South	26.3	12.7	0.85	1	30.9	374696.1	26.7
Southwest	26.5	12.3	0.85	1.18	26.4	226316.9	16.1
West	22.1	15.2	0.85	1.25	20.8	136783.5	9.7
Northwest	16.5	9.1	0.85	1	19.4	47939	3.4

Table 3 Meteorological data, reference speed and power pointer for each direction (Lagoa Comprida Station)

In order to calculate the topography coefficient, it is only compulsory to identify the value of the scale factor s , from the *ENV 1991 Norm of Euro Code 1* [CEN, 1994]. Since this project is in principle restricted to the mountain ridges, the value of x is considered to be 0 (see *Figure 2*), and the constant s factor to be 0.8.

In order to calculate the rugosity coefficient ($c_r(z_m)$) it is required to be roughly identified with the morphology of the study area, which is revealed by the analysis of the ground occupation shown in the following image (*Figure 3*):

Hence, it is considered that the region in question is predominantly part of Land Category *III* (see Table 2), and therefore (eq. 4) may be applied for the calculation of the rugosity coefficient, which is constant throughout the entire study area.

In order to determine the useful aeolian potential (Pu) it is also necessary to verify four different factors: the energy factor (k_e), the specific air mass (ρ_{ar}), the area scanned by the turbines (A) and their corresponding efficiency (μ).

In terms of k_e , in the Lousã region, the regime of the wind is considered to be partially Continental regime, irregular, and the Costal regime, maritime (see Table 1), which assigns a

value for the Weibull constant (k) of approximately 1.8. From Table 1, by interpolation, the value of k_e is concluded to be 2.2, which is the value chosen for this project.

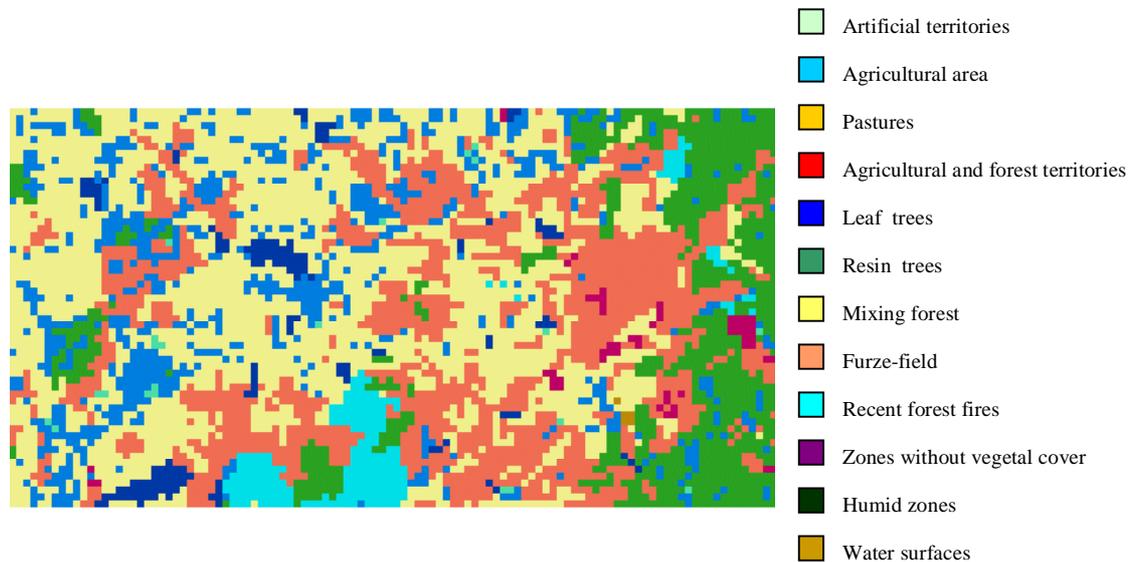


Figure 3 Ground occupation in the region of Lousã

The specific air mass depends implicitly on the air temperature, which then is associated to the height of the area of study. In order to estimate that value, the temperatures from the Meteorological Stations of Caramulo and Lagoa Comprida are taken into consideration, since height of both stations (approximately 800 m and 1600 m, respectively) are in better agreement with the height of the area study. Based on the temperatures taken from the station of Caramulo [INMG, 1990] and Lagoa Comprida [INMG, 1991], respectively 12°C and 7.4 °C, and taking the average temperature of the air to be 10°C, the specific air mass is found to be of 1.246 kg/m³ [MONTEITH and UNSWORTH, 1995].

Since the present work suggests the proposed modelling to be performed by the GIS raster tool, the considered area relates to the resolution of the associated *pixel*, in this case, 25 m along X and 25 m along Y, which gives a total area 625 m². Finally, as mentioned above, the useful power of the turbines used (Vestas turbines) is 42%.

4.2 Application of the Computational Methodology

Considering the aim of this project mentioned above, the IDRISI tool is applied, version IDRISI32, due to its multiple resources for the resolution of problems associated with the spatial modelling in GIS, and the MATLAB software that enable the introduction of the proposed filters.

Concerning the resolution of this project, the work plan is divided into three different, though related, subgroups, as illustrated below (*Figure 4*):

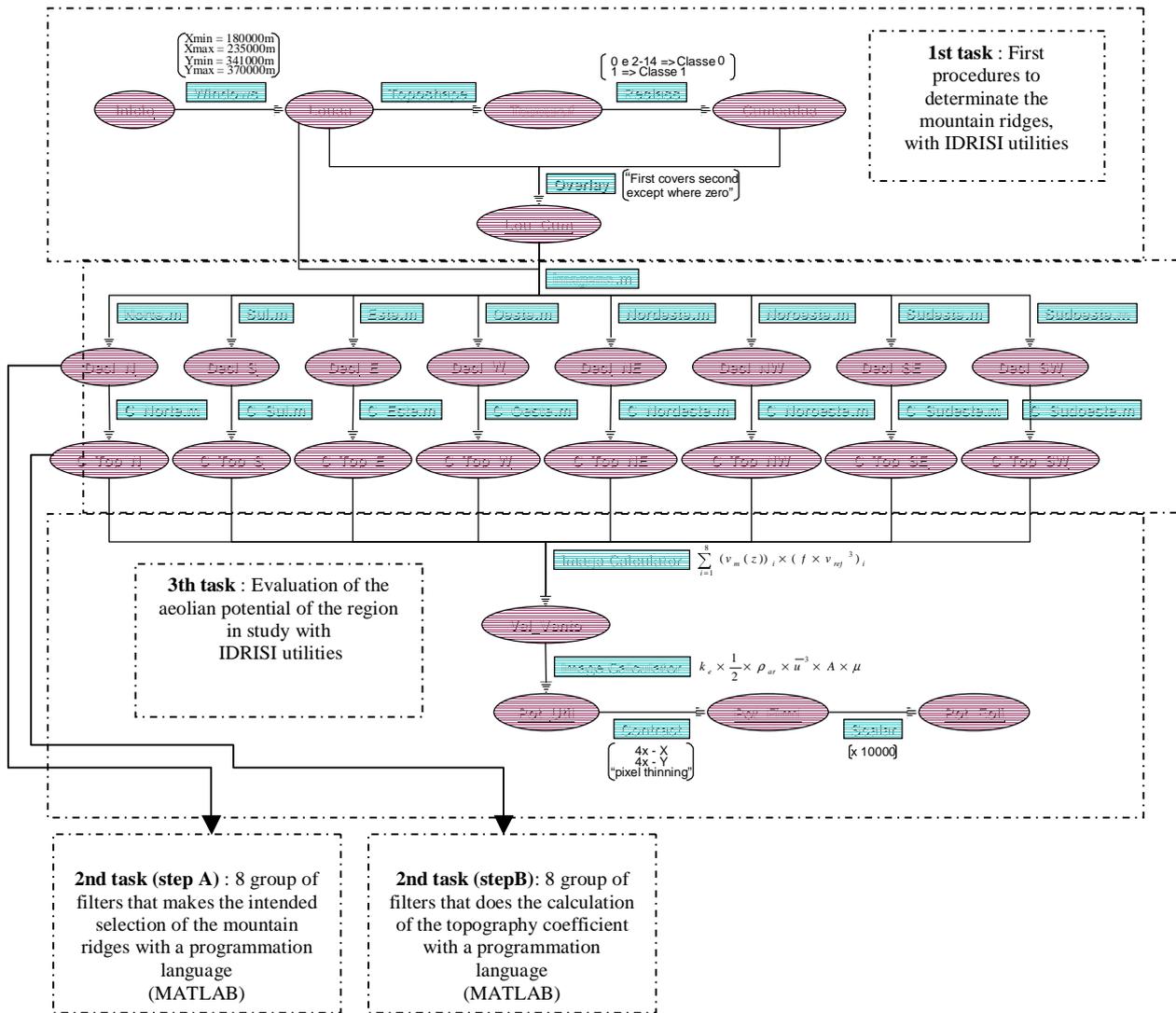


Figure 4 – Diagram showing the application of the computational methodology (using IDRISI and MATLAB) to calculate the aeolian potential in Lousã mountain (Portugal)

4.2.1 Determination of the Mountain Ridge

Initially, the area of study is limited – see maps 20-I, 20-III and 20-IV, scaled by 1:50000 from Instituto Geográfico do Exército – to area confined by the Datum73 co-ordinated

$$\text{military, respectively } \begin{cases} X_{\min} = 180000 \text{ m} \\ X_{\max} = 235000 \text{ m} \\ Y_{\min} = 341000 \text{ m} \\ Y_{\max} = 370000 \text{ m} \end{cases}$$

Using a model of analysis from the IDRISI program that classifies the land into 11 different topographic categories, the mountain ridges that are part of the present of study are determined, restricted to areas over 800 m high.

After determining such mountain ridges and acknowledging the data described above concerning the calculation of the average wind speed, it becomes essential to find the topography coefficient (c_t) associated with these areas.

4.2.2 Calculation of the Topography Coefficient

Taking the eight main directions of the wind into account, a specific programming routine analysis is performed so that the methodology proposed in section 3.2.2 may be applied in order to determine the value of the slope (Φ).

For every routine or direction of the wind, the algorithm used must guarantee the following conditions:

- Specific analysis of the mountain ridges (over 800 m).
- Further analysis solely along required direction.
- No further analysis upon at the reference height (600 m), the limit of the image or at a height over the height of the mountain ridge of study. For the latter case, the mountain ridge is considered as part of a higher mountain ridge, which causes no acceleration of the wind due to the topography – topography coefficient takes the value of 0.
- Due to incomplete information, for the mountain ridges located at the border of the area of study, the coefficient size was also considered to be 0.

The filters applied are set in a sequence of steps that include the following operations:

- Reading of the *input* images and storing of that data in the format of vectors:

Imagens.m:

```
fid=fopen('lou_cum.rst','r');
[A, COUNT] = fread(fid,inf,'float32'); %lou_cum.rst reading and rank of its values on
vectorA
```

```
fid2=fopen('lousa.rst','r');
[B, COUNT] = fread(fid2,inf,'float32'); %lousa.rst reading and rank of its values on vectorB
```

Creation of the vector that will go to keep the results, scanning for all the corresponding values to pixels of the images through a cycle, where the described conditions are guaranteed all previously, and finally creation of the final image with the information of the exit vector (showing an example on the North Direction):

1st Filter (Step A / Norte.m Filter) that makes the selection of the intended mountain ridges :

```
rmax=1160; % Number of rows in the image
cmax=2200; % Number of columns in the image
CN=zeros(size(A)); % creation of the exit matrix CN
for r=1:rmax
    for c=1:cmax %Scanning all pixels
```

```

p=(r-1)*cmax+c;

if A(p)<800
    CN(p)=0;
else
    cota=B(p);
    r1=r;
    c1=c;
    p1=p;
    while r1>1 & B(p1)<=cota & B(p1)>600
        r1=r1-1;
        p1=(r1-1)*cmax+c1;
    end
    if r1<=1
        if r-r1>0
            CN(p)=(cota-600)/sqrt((cota-600)^2+(25*(r-r1))^2);
        else
            CN(p)=0;
        end
    end
    if B(p1)>cota
        CN(p)=0;
    end
    if B(p1)<=600
        CN(p)=(cota-600)/sqrt((cota-600)^2+(25*(r-r1))^2);
    end
end
end
end
end
fid3=fopen('decl_N.rst','wb');
fwrite(fid3,CN,'float32');
fclose(fid3);

```

%All pixels that are not mountain ridges

%Pixels that are mountain ridges

%Beginning of the positioning increments

% Positioning increments

% Positioning that is out of image

% Positioning on the border of the image

% Superior quota when comparing to the departure quota pixel

%Stops in the altitude of reference of 600m

% Creation of the final binary file (decl_N.rst) with the information of matrix CN

Knowing the slope of the area of study, it is then possible to determine the topography coefficient (c_r) of the area, applying the equations **Error! Reference source not found.** to **Error! Reference source not found..** To do so, a second group of filters was developed and later applied for every one of the 8 possible directions of the wind. Each of these filters works in a very similar way, in terms of the steps operated, to the filters used before:

Reading of the *input* images and storing of that data in the format of a single vector which will store the results, the values corresponding to every *pixel* within the image, by means of a cyclic application of the suitable equation. Also, the final image is constructed based on the data stored in this output vector (showing an example on the North Direction):

any direction. Next, the weighed average of the results above is found considering the power indicator ($f \times v_{ref}^3$) so that the average wind speed may be determined (\bar{u}).

Finally, the equations (eq. 2) and (eq. 1) are applied so that the useful aeolian power (Pu) may be determined considering the results presented in section 4.1. In order to perform such calculations, the function of calculus *Image Calculator* from the IDRISI program was used.

For the present work, the aeolian potential of the region of study, is presented in areas of 100 m x 100 m, so that the *pixel* resolution within the image of the useful aeolian potential is decreased 4x, along X and Y, using the model *Contract* of the program IDRISI. Each *pixel*, as part of the final image, is the average of the *pixels* corresponding to the image of the useful aeolian power that in this case takes the value of 16.

For a deeper understanding of the nature of the study, the aeolian potential was divided by the area corresponding to every *pixel* (10000 m²), obtaining the following image (see *Figure 5*) for the aeolian potential of the Lousã region.

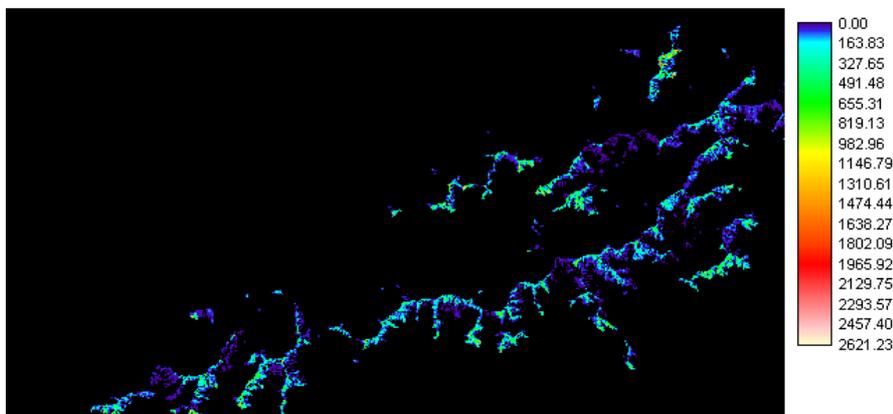


Figure 5 Aeolian potential (W/m²) for the region of Lousã mountain

5. CONCLUSIONS

The development of the proposed methodology, which involves the use of a GIS tool and a computational programming language – for the region of study – allows the attainment of a rather satisfactory set of final results that is essential upon the process of decision-making.

The application of such methodology may be implemented on any other areas, as long as there is available data that guarantees the requirements presented.

Note that, as for any experimental study, the proposed model is solely an approximation to the real phenomena in question, and therefore, the determined parameter (aeolian potential), an indicatory measure for the possible energy that may be obtained from the wind.

Also, the proposed project verifies that the modelling of geographic phenomena using GIS tools is still somewhat limited, namely in terms of the analysis of space-oriented data. Hence, the introduction of filters as part of the program proposed, this means in *software* independent of the GIS tool, that allows the achievement of the proposed aim of this project.

Finally, it is clear from the discussion section above, that the GIS tools proposed are still in need of development of adaptability in terms of new applications. However, such limitations may play a vital role in view of the knowledge broadening that may arise, since the development of computational applications for GIS Raster images is considered, in fact, very positive.

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