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Towards an electronic orientation table: using features extracted from the image to register Digital Elevation Model

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Abstract: Looking at a countryside, human has no difficulty to identify salient information such as skyline in case of benign weather. At the same time, during the last decade, smartphones are more and more abundant in our daily life with always new efficient proposed services but augmented reality systems suffer from a lack of performance to offer a well adapted tool in this context. The aim of this paper is then to propose a new approach coupling image processing and Digital Elevation Model (DEM) exploitation to remedy that shortcoming. The proposed method first discriminates skyline and non-skyline pixels and then introduces a realtime matching between previously extracted map and DEM. In order to evaluate objectively each step and our finalized tool, a new tagged dataset with ground-truth is created and will benefit the entire scientific community.

1 INTRODUCTION

People hiking in the mountains or simply walking are always looking for information about what they are seeing : mountain names, elevations, village names, hiking trails, tourism information, *etc.* Even if hiking maps can provide such information, they require the hiker to match the 2D data he has on the sheet with the 3D landscape he can see and this is not that always easy for no experts. Orientation tables also help for such problems but they are located at some too rare points in the mountains. As nowadays everyone or almost has in his pocket a smartphone that integrates instruments such as compass, accelerometer, GPS, *etc.*, with more and more memory and computing power, the idea of this work is to create a smartphone application that provides as much information as possible to the people looking at a mountain landscape. The idea consists in visualizing the landscape with the smartphone camera and the desired information will be displayed on the screen thanks to augmented reality tools. Objectively, some smartphone applications already provide information about mountains peaks around a user, but the data are mostly displayed as maps on the screen (Peakfinder, 2016; pointdevue, 2015; swissmap, 2016) or, for few of them, they are superimposed on the screen image (Peaksanner, 2016; Peak.AR, 2010). Figure 1 shows two examples

of screenshots of such applications.

None of these applications is exploiting the image content in order to help the data registration. Indeed, the mountains peaks are reconstructed from the available digital elevation model (DEM.) and from the smartphone sensors (GPS and digital compasses). The poor accuracy of such sensors badly impact the augmented reality results, making these applications almost unusable. This is in fact the main comments done by the users on the stores. In recent years, many approaches have been proposed to compensate the lack of performance of such sensors, particularly in constrained environment, but none our way.

Thus, we propose a new approach in order to cope with this problem. Our solution consists in extracting a probability map of skyline in the image acquired by the smartphone camera and then, to match these data with the 3D data available from the DEM. To avoid Internet connection problems, it is directly stored in memory before its utilization. This matching step allows to display the data on the screen with high accuracy.

Our contributions are threefold:

- Unlike the classical skyline detection algorithms that are based on channel-wise edge detector, we fully exploit the 3D color information of the pixels by **learning a color metric** that helps in discriminating skyline edges from non-skyline edges.



Figure 1: Screenshots of two existing applications, namely "Peakfinder" and "Point de vue", that display local maps on the screen without registration.

- Because the time response and the accuracy of the application is crucial, we propose a **fast matching** between the probability map and the 3D data available from the DEM.
- Since other applications exist in order to provide information about peak mountains, we created a **new tagged dataset with ground-truth** so that the accuracy of the different approaches can be assessed and compared. This dataset as well as the ground-truth data will be publicly available.

2 RELATED WORKS

There is in the literature few articles dealing with the extraction of the skyline. The purpose of some of them is the extraction of this line from the image data only. However others exploit the smartphone sensors such as GPS and compasses in order to superimpose the data. But the accuracy of these sensors is small and do not have very satisfactory results from the users point of view.

This is the reason why we recommend to exploit the image data in order to improve the quality of the registration step. And the main image information that can be matched with the DEM is the skyline.

Some papers have already proposed approaches in this direction as we shall see below but in different contexts and with slightly different constraints.

2.1 Skyline detection

Lie *et al.* (Lie et al., 2005) and Kim *et al.* (Byung-Ju Kim and Kim, 2011) consider that the skyline is constituted by the strongest edges in the image. So, they propose first to extract the edges with the classical Canny detector. Lie *et al.* apply a threshold on the edge image to obtain a binary edge map, which is the input of a dynamic programming search. The idea is to connect the candidate edges that respect some criteria whose aim is to preserve local smoothness and to satisfy geometrical preferences (Lie et al., 2005). Kim *et al.* propose to select the best skyline candidate among the output of the Canny detector as the one that is mostly flat and symmetric (Byung-Ju Kim and Kim, 2011).

Hung *et al.* also apply the Canny detector as a first step and then learn a SVM classifier on these edge pixels to classify them into skyline edges and no-skyline edges (Hung et al., 2013). For this classification, they are using a 210-D feature vector for each edge pixel, that represents color and texture information extracted from the local neighborhood of this edge pixel. At test time, they create a map for each image in which each pixel is characterized by a value related to its probability not to be a skyline pixel. Then they propose a recursive algorithm that finds the shortest path in the image, from left to right, that minimizes the cumulative energy. This path is the detected skyline.

Likewise, Ahmad *et al.* also propose to learn a classifier on the pixels in order to classify them into skyline pixels and no-skyline pixels (Ahmad et al., 2015). The input of the classifier is a 256-D feature vector characterizing the local neighborhood of the considered pixel. The difference with (Hung et al., 2013) is that they are classifying all the pixels, and not only the edge pixels, because they argue that true skyline pixels may be not detected by the Canny edge detector. Then each image is transformed into a classification score map which is informing about the probability of each pixel to be a skyline pixel. Finally, they also find the shortest path with highest cumulative energy in this map.

The approach of Saurer *et al.* is a bit different from the previous ones (Saurer et al., 2016) because they classify all the pixels of the image into sky and non-sky pixels. The feature vector characterizing each pixel is a concatenation of 4 bags of words (textons, local ternary patterns, self-similarities and SIFT), each one being quantized to 512 clusters and independently in 5 different color spaces. After running the classifier on all pixels of the image, they determine the skyline as the line that maximizes along

the columns the number of pixels being classified as sky above the line and as non-sky below the line, regularized by a smoothness term that helps the line to be smooth.

The output of all these works is a binary image in which each pixel is classified as skyline or non-skyline. In order to improve the accuracy of the matching between the DEM and our image, we will show in the experimental results that it is better to work with a classification score map, where each pixel is associated with its probability to be a skyline pixel, instead of a binary map (skyline vs non-skyline). Consequently, these approaches would not help to solve our problem as they are actually proposed. Nevertheless, the classification step of some of them could have been interesting for our work, but it is clear that the size of the proposed feature vectors and their extraction time are not adapted to our problem. Indeed, we are looking for features that do not require too much memory place and that are very fast extracted.

Some other works also propose solutions to match the detected 2D skyline with 3D data extracted from the available digital elevation model.

2.2 Matching the detected skyline with 3D DEM data

Baboud *et al.* propose a solution to automatically annotate mountain pictures (Baboud *et al.*, 2011). Their idea is to detect edges in the mountain pictures and to match these edges with *silhouettes* extracted from the 3D DEM. The originality of this work is to introduce a *vector field cross correlation* that accurately match 2 sets (from image and from DEM) of local edges. Unfortunately, this processing can not be adapted to our problem since it requires 2 minutes per image. Indeed, for image annotation problems, the processing time is not as crucial as for smartphone applications. So they rather concentrate on accuracy matching and do not use only the skyline in the image but all the edges that could help for the matching.

Fedorov *et al.* exploit the skyline detection algorithm from (Lie *et al.*, 2005) and match this skyline with 3D DEM data (Fedorov *et al.*, 2014). Their aim is also to annotate mountain pictures and so they do not try to improve the processing time. Thus, they apply a high number of successive steps in order to improve the matching. After extracting the skyline with (Lie *et al.*, 2005), they apply the vector field cross correlation from (Baboud *et al.*, 2011) in order to find 3D skyline candidates in the DEM. Then, for each candidate they evaluate a Hausdorff distance with the image skyline in order to find the best candidate. Finally,

they resort to a local alignment step by applying again vector field cross correlations locally at different positions of the skyline. It is clear that this multiple stage approach can not reach the processing time constraint required by our application.

The aim of the work of Saurer *et al.* is to geo-localize an image that has been acquired in the Alps (Saurer *et al.*, 2016). So, from an image, they first extract the skyline as described below and try to find the most similar skyline in the DEM data they have. So their work is more about skyline retrieval than skyline matching. Hence, they propose an invariant and a compact skyline descriptor and, try to retrieve the image skyline in a dataset of skylines, in order to deduce coarse GPS position of the considered image. Consequently, their work can not help our skyline matching step.

Finally, Zhu *et al.* propose an image/DEM registration system based on skyline (Zhu *et al.*, 2013). This work is interesting because of its real-time constraint but unfortunately, it is only adapted to urban environment and requires the presence of buildings in the image in order to detect the vanishing point. Consequently, this approach can not be used in our context.

3 FAST AND ACCURATE SKYLINE EXTRACTION AND MATCHING WITH DEM

For our electronic orientation table, we propose a two-steps solution. First, in a similar way as previous works, we resort to a classification step in order to extract the skyline from the image. But, unlike all the other previous approaches, we use very simple color features that are adapted to our problem thanks to a metric learning algorithm. Then, we propose to match the detected skyline with the extracted skyline from the DEM and project it in the image space.

3.1 Skyline extraction

In order to fulfill our time constraints, we propose to use the *RGB* data available in the image instead of extracting some complex features. Instead of classical previous skyline detectors based on edges, we propose to exploit the simple color difference in order to detect the skyline. Of course the single color difference is not enough to classify all the edges, but the robustness of the approach mainly depends on the variability of the learning data. So, during the learning step, it is important to consider images under

a lot of different conditions (weather, illumination, , etc.). Evaluating accurate color differences from uncalibrated JPEG images is not an easy task (Perrot et al., 2014) but our aim here is rather to evaluate discriminative color differences, *i.e.* color differences that help to discriminate skyline edges from non-skyline edges. For this purpose, we resort to metric learning tools applied in the color RGB space.

3.1.1 Color metric

Most of the existing works in metric learning are focused on learning a Mahalanobis-like distance between 2 vectors \mathbf{C}_1 and \mathbf{C}_2 in the form:

$$d_M(\mathbf{C}_1, \mathbf{C}_2) = \sqrt{(\mathbf{C}_1 - \mathbf{C}_2)^T M (\mathbf{C}_1 - \mathbf{C}_2)}, \quad (1)$$

where M is a positive semi-definite (PSD) matrix to optimize (Bellet et al., 2013).

In our case, the vectors are the 3D colors denoted by $\mathbf{C}_1 = (R_1 \ G_1 \ B_1)^T$ and $\mathbf{C}_2 = (R_2 \ G_2 \ B_2)^T$ of the two compared pixels. Let denote $dk = k_1 - k_2$, $k \in \{R, G, B\}$, the difference between the components k of the two considered pixels. Thus the matrix M is a 3x3 symmetric matrix such that each coefficient $m_{kk'}$ represents the weight associated to each quantity $dk.dk'$:

$$M = \begin{pmatrix} m_{RR} & \frac{1}{2}m_{RG} & \frac{1}{2}m_{RB} \\ \frac{1}{2}m_{RG} & m_{GG} & \frac{1}{2}m_{GB} \\ \frac{1}{2}m_{RB} & \frac{1}{2}m_{GB} & m_{BB} \end{pmatrix}. \quad (2)$$

Indeed, from eq.(1) and eq.(2), we can evaluate $d_M^2(\mathbf{C}_1, \mathbf{C}_2)$ as:

$$d_M^2(\mathbf{C}_1, \mathbf{C}_2) = m_{RR}.dR^2 + m_{RG}.dR.dG + m_{RB}.dR.dB + m_{GG}.dG^2 + m_{GB}.dG.dB + m_{BB}.dB^2. \quad (3)$$

Note that if M is the identity matrix, the distance d_M is the simple color Euclidean distance. The aim of metric learning is to learn the matrix M that meets the problem constraints. In the case of skyline extraction, we evaluate the distance between each vertical pair of neighbor pixels and the constraint is that this distance $d_M(C_1, C_2)$ have to be higher between two pixels on both sides of the skyline than between two pixels that are both in the sky or both in the mountain. Thus, learning M from ground truth data (skyline vs non-skyline edges) allows us to find which components are important in the color differences to discriminate between skyline and non-skyline.

3.1.2 Learning phase

Practically, in order to learn the 6 coefficients of the matrix M , we re-formulate the problem as a max-

margin problem and solve it with a linear SVM. Indeed, $d_M^2(\mathbf{C}_1, \mathbf{C}_2)$ can be expressed as a dot product:

$$d_M^2(\mathbf{C}_1, \mathbf{C}_2) = \begin{pmatrix} dR^2 \\ dR.dG \\ dR.dB \\ dG^2 \\ dG.dB \\ dB^2 \end{pmatrix}^T \cdot \begin{pmatrix} m_{RR} \\ m_{RG} \\ m_{RB} \\ m_{GG} \\ m_{GB} \\ m_{BB} \end{pmatrix}, \quad (4)$$

$$d_M^2(\mathbf{C}_1, \mathbf{C}_2) = \mathbf{dC}^T . H_M$$

i.e. as a projection of the pair difference vector \mathbf{dC} on a 6D classifier H_M .

By looking at mountain landscapes it appears that the strongest edges, despite the skyline, are mostly in the mountains and not in the sky. So we propose to account the edge position when detecting the skyline so that the top edges in the image have more chance to be classified as skyline than the bottom edges. This is done thanks to a weighted step that is detailed in the next paragraph. Consequently, the main aim of our learning step is to remove the strong edges in the sky so that the skyline appears as the first strongest edge in each column when visiting the pixel from top to bottom. Thus, we create two sets of edges:

- the positive edges \mathcal{P}^+ that are constituted by the two neighbor colors that lie on both sides of the skyline,
- the negative edges \mathcal{P}^- that are constituted by two neighbor colors that lie above the positive edge of the same column in the same image and whose euclidean distance in the RGB color space is higher than the one between the positive pair of the same column. If in one column, no edge fulfills this condition, we randomly pick a non-skyline edge above the positive pair of this column, so that the positive and negative data are well balanced.

From this definition of the learning data, the aim of our learning step is to learn the Mahalanobis matrix M (or the classifier H_M) so that, given two corresponding positive and negative pairs from the same column and same image \mathcal{P}_i^+ and \mathcal{P}_i^- , we have $d_M^2(\mathcal{P}_i^+) > d_M^2(\mathcal{P}_i^-)$. Thus, if the respective pair difference vectors are denoted \mathbf{dC}_i^+ and \mathbf{dC}_i^- , we are looking for H_M so that $(\mathbf{dC}_i^+)^T . H_M > (\mathbf{dC}_i^-)^T . H_M$. This can be done by finding the classifier H_M and the bias b so that $(\mathbf{dC}_i^+)^T . H_M + b > 0$ and $(\mathbf{dC}_i^-)^T . H_M + b < 0$. With a classical linear SVM, it corresponds to maximize the margin between the two sets of pairs. The bias is just translating all the distances, which are initially positive, around 0, where skyline scores are positive and non-skyline scores are negative.

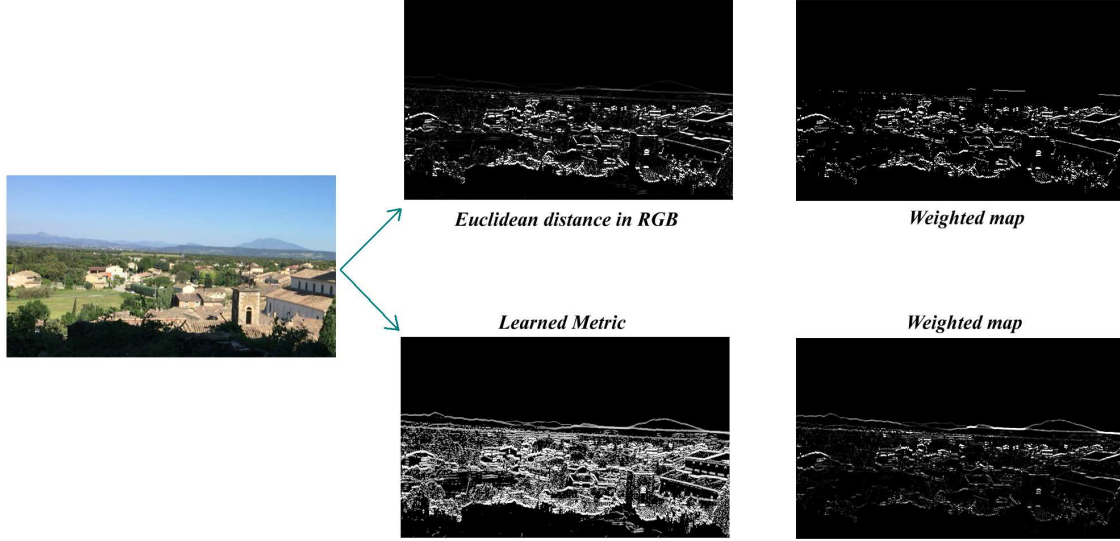


Figure 2: Comparison between the classical Euclidean distance in *RGB* and our color metric learning approach (see text for details).

3.1.3 Inference

After the learning step, we get the 6 parameters of H_M and use them to obtain the Mahalanobis matrix M (see eq. (2)). If this matrix is positive semi definite (PSD), it can be decomposed thanks to the Cholesky factorization as:

$$M = L^T . L, \quad (5)$$

where L is a 3x3 lower triangular matrix. In this case, eq.(1) can be expressed as:

$$\begin{aligned} d_M(\mathbf{C}_1, \mathbf{C}_2) &= \sqrt{(\mathbf{C}_1 - \mathbf{C}_2)^T L^T . L (\mathbf{C}_1 - \mathbf{C}_2)} \\ &= \sqrt{(L . \mathbf{C}_1 - L . \mathbf{C}_2)^T (L . \mathbf{C}_1 - L . \mathbf{C}_2)}, \end{aligned} \quad (6)$$

which is the Euclidean distance between the two colors $L . \mathbf{C}_1$ and $L . \mathbf{C}_2$. Thus, from a PSD Mahalanobis matrix M , we can deduce a matrix L that projects the *RGB* colors into a new color space in which the skyline edges can be easily detected thanks to a simple euclidean distance. Consequently, at test step, we just have to project the *RGB* color vectors of each pixel on the new learned discriminate color space thanks to a simple matrix multiplication $L . \mathbf{C}_1$ and $L . \mathbf{C}_2$ and, to evaluate a simple Euclidean distance between the new colors of neighbor pixels in order to detect the skyline. Hence, for each pixel pair, we get a distance that is related to the chance of each edge to be on the skyline. Note that, for all the tests we run, we always got a matrix M that was PSD. If the matrix M is not PSD, we have to project it on the PSD cone matrix

in order to get the nearest PSD matrix that fulfills our learning constraints.

After evaluating the Euclidean distance in the new learned color space, we get a map of "scores" (chance to be on the skyline), that we call the score map. Note that, with the bias of the SVM added, the score $s(i, j)$ should be positive if the edge at position (i, j) is on the skyline and negative if it is not on the skyline. Since during the learning step, we have not considered strong edges below the skyline on each column (we have just removed edges in the sky, not in the mountain), we have to remove these strong edges. Our simple but efficient solution consists in weighting the scores $s(i, j)$ in the column j as follow:

$$sw(i, j) = \frac{s(i, j)}{1 + \sum_{row=0}^i s(row, j)(s(row, j) > 0)}, \quad (7)$$

where the $row=0$ is the top row, and $(s(row, j) > 0)$ is a test that returns 1 if $s(row, j) > 0$, 1 otherwise. By this way, we consider that, by visiting each column from top to bottom, the first strong positive edge has a high chance to be on the skyline. This is due to our learning process whose aim was to remove the strong edges that were above the skyline.

After this step, we get a weighted-score map illustrated in Figure 2. In this figure, we compare the results obtained by our metric learning approach with the ones obtained with the classical Euclidean distance in the *RGB* color space. We can see that since the edges along the skyline are not strong in the *RGB* space, they are not detected with the Euclidean distance. Fortunately, the metric we have learned clearly

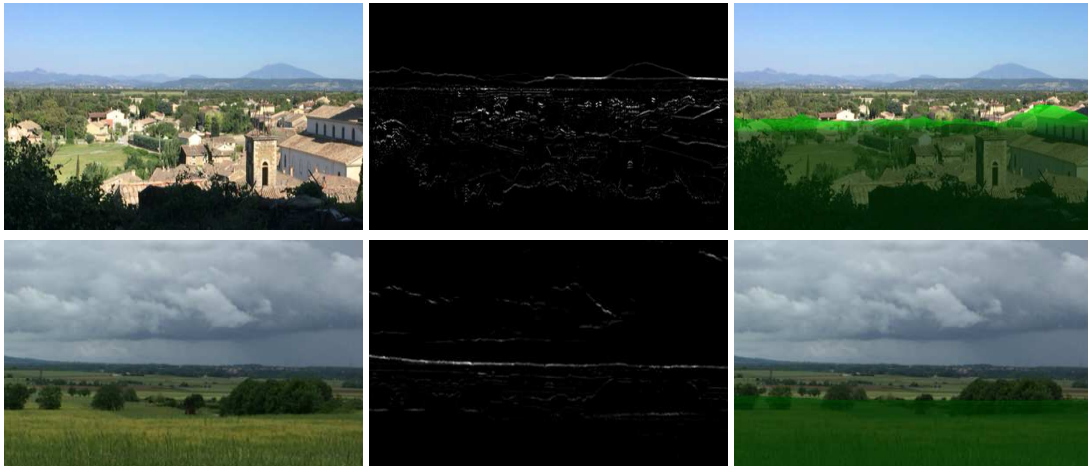


Figure 3: Two color images from our dataset along with their respective weighted color map and their relief map extracted from DEM.

identifies these edges as strong ones. The images on the right show the weighted maps obtained from either the Euclidean distance map or from the learned color metric. We can see that this step helps in removing most of strong edges that are below the skyline in the color metric map.

Nevertheless, it is clear that the information provided by an image can not be sufficient to get a perfect match between the detected pixels and the true skyline. Consequently, after this fast color detection, we propose to exploit the available DEM in order to refine the results. Our aim consists in registering the DEM with the obtained weighted-score map.

3.2 Skyline matching

Using the score map previously obtained that indicates the chance for each pixel to be on the skyline, our goal is now to register correctly the DEM on this map. Figure 3 shows, for two images, the weighted score maps as well as the information we have extracted from the available DEM and projected in the 2D image space from the data provided by the smartphone (GPS. and digital compasses) without using the image features. In these images, the brightness of the green is related to the altitude of the points. It is worth mentioning that the DEM we used is free, so its resolution is coarse ¹. This figure clearly illustrates the interest of combining the both data to detect the skyline: color edges and DEM.

More precisely, using the GPS coordinates and the intrinsic camera parameters, the DEM can be visualized from the camera point of view. The figure 4

shows an example of such a visualization. But as we can see on this figure, the projection is not perfect due to smartphone’s measure instruments error. So let explain now how we can exploit the previous score map to obtain a more reliable user’s orientation estimation.



Figure 4: Example of DEM projection, before registration with the skyline.

Actually, such a problem is a 6-dimensional problem (considering we know camera’s intrinsic parameters) as explained in (Zhu et al., 2013) because the parameters that have to be adjusted are the position (three parameters) and the orientation (three parameters too) of the camera. Trusting the GPS position and considering the projection of the DEM onto a 2D image, we reduce the problem into one that consists in finding the best 2D transformation to match our score-map with the DEM projection. This transformation is composed of one 2D translation and one rotation only. We do not have to seek for the right scale to apply to our DEM, this information is contained into camera’s intrinsic parameters.

¹<http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1>

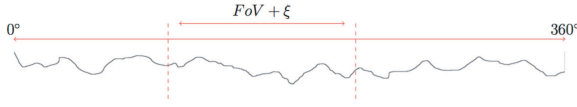


Figure 5: From the field of view provided by the smartphone, we can reduce the search space.

In practice, we consider an angle a bit larger than the real field of view to deal with the lack of precision of the compass.

Let us denote by S_{DEM} the skyline extracted from the projection of the DEM in the image. Notice that to quickly perform translations and rotations, this skyline is stored as a set of 2D vectors, corresponding to the relative positions of the points in the image, with respect to the left-most point:

$$\hat{S}_{DEM} = \{v_k \mid v_k = S_{DEM}(k) - S_{DEM}(0)\}$$

where v_k is the k^{th} vector of the vectorized skyline \hat{S}_{DEM} , and $S_{DEM}(i)$ is the 2D position of the theoretical skyline at the column i .

To find the best registration between the DEM skyline and the weighted-score map sw , we define the energy function $E(\hat{S}_{DEM}, T)$ as follow:

$$E(\hat{S}_{DEM}, T) = \sum_{k=0}^n sw(v_k * M)$$

where T is a 3x3 matrix consisting in a translation and a rotation and $sw(p)$ the value of the weighted score map at point p . The matrix M satisfying $argmax_T(E(\hat{S}_{DEM}, T))$ is the best transformation to apply to the DEM skyline to match with weighted-score map sw (see Fig. 6).

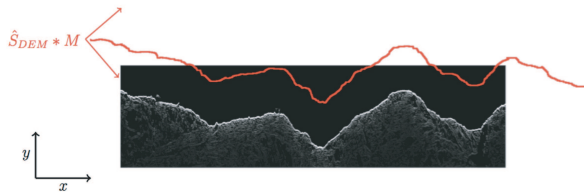


Figure 6: Illustration of the registration between the detected skyline (grey-level image) and the DEM (red curve).

In order to find the best transform matrix T , the brute force approach would have consist in testing all the possible T and keeping the one that maximizes the previous energy function $E(\hat{S}_{DEM}, T)$. The parameters of T are the translation t_x along the horizontal axis, the translation t_y along the vertical axis and the rotation angle α around the left-most point. We call P

the set of possible solutions defined as:

$$P = \left\{ p = (t_x, t_y, \alpha) \right. \\ \left. \begin{array}{l} t_x \in [t_{x_{min}} ; t_{x_{max}}] \\ t_y \in [t_{y_{min}} ; t_{y_{max}}] \\ \alpha \in [\alpha_{min} ; \alpha_{max}] \end{array} \right\}$$

So, we have a 3D search space, and given our discretization choice, we have $card(P) = 3.6$ millions of possible solutions to test.

In order to reduce the complexity of the algorithm, we resort to an original multi-resolution approach. The idea consists in:

- testing all the solutions in the search space for few points of the skyline,
- among these solutions, keeping only the ones that provide the top values for the energy function (the other solutions are definitively removed from the search space),
- adding few points to the skyline and testing the selected solutions of previous step for these points,
- iterating the two previous steps until the full-resolution skyline is tested.

Practically, we propose an algorithm in $\log_2(n)$ steps, where n is the number of points in the DEM (close to image width), *i.e.* 10 steps for our 1024x768 images. At each step i , we consider only 2^i points uniformly picked in the DEM and evaluate the energy function only for these DEM points. Let denote u , a geometric series such that $u_0 = card(P)$ and $u_{\log_2(n)} = 1$. So, at each step i , we keep only the u_i best transforms T that will be tested in the next step. Thus, at each step, we reduce exponentially the number of solutions to test while we increase the precision of the DEM. Our matching algorithm takes 0.5 second for a 1024x768 image on a computer Intel Core i5 1.3GHz.

4 EXPERIMENTAL RESULTS

Since there is no dataset with the information required by our system (pictures with GPS coordinates and camera orientations), we created one which will be publicly available. Below, we will first present this dataset and the necessary meta data. Then, we will present the results on this database evaluating in particular the distance between the skyline in the ground-truth images and the one extracted from projected DEM in image without and with registration step.

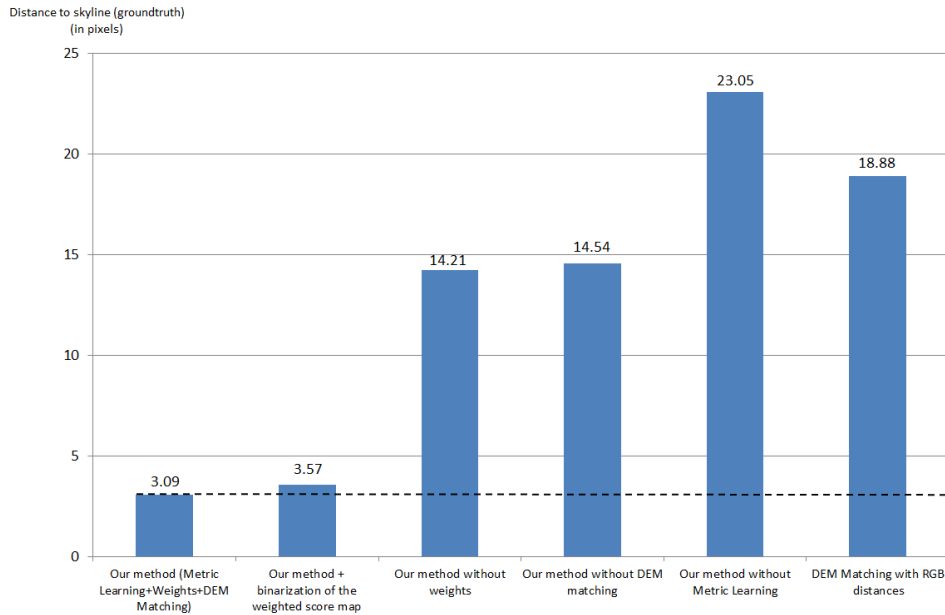


Figure 7: Average distances for the tested methods between detected and ground-truth skylines (lower is better).

4.1 Our dataset

To create the dataset, we developed a smartphone application which allows to take a picture of a landscape and meanwhile to record the geographic position of the user and the value of the various instruments that are available in the smartphone. More precisely, the data stored are the following:

- latitude, longitude, altitude,
- angle with north and magnetic north,
- tilts X, Y and Z.

Some of these parameters are already provided by some datasets, but the ones concerning the orientation of the camera are not available. All these elements are stored in a JSON file.

Furthermore, for each acquired image, we created a ground truth and so we manually segmented the skyline. Hence, JSON file is accompanied by a binary file in which the pixels of the skyline are marked.

For the tests, about twenty images are taken into account. We will enrich the dataset over time.

4.2 Results

In order to assess the quality of our algorithm, we propose to test it on our dataset and to evaluate the average distance (in pixels) over all the images between the skyline we obtain and the ground-truth skyline. Of course this distance is relative to the image size 1024x768. The results are shown in figure 7.

In order to check the relevance of each contribution of our algorithm, we have run several tests by removing each single step from the whole process and check the results for each. We recall that the main contributions of our algorithm are : color metric learning, score weighting and matching with DEM. In figure 7, we clearly see the relevance of each individual step, since the average distance dramatically increases (from 3 pixels to 14 or even 23) when we remove one of them. It is worth mentioning that our learning step has been run on the CH1 dataset described in (Saurer et al., 2016) and not on our dataset. The CH1 dataset consists of images of mountains in which the skyline has been manually segmented (unfortunately, no geographic information are provided with this dataset, so that we can not extract the correct DEM to run our algorithm on these images). This shows that our new color metric has been learned once on one dataset and can be used on any other dataset without fine-tuning it to the new considered images.

Furthermore, in figure 7, we show the results obtained by our algorithm when the score map is binarized before the DEM matching. The binarization consists in only keeping the highest score in each column. We can see that this binarization does not help the matching step (and even slightly increases the distance). This is interesting to see that our matching algorithm is performing better with a dense score map (where each pixel is characterized by a score) than with a binary skyline detection. Finally, we also show the results provided by a baseline method which con-

sists in evaluating column-wise the *RGB* distances in the image and to match the DEM with this score map (without weights and without ad-hoc color metric). Figure 7 shows that this approach provides poor results since the average distance between the detected and the ground-truth skylines is around 18 pixels.

We can see that by combining all our contributions, we obtain an average distance equals to 3 pixels, which is negligible with respect to the size of the images (0.4 %). This shows that the proposed skyline detection is the perfect candidate to be integrated in an electronic orientation table.

In figure 8, there are some visual results. We have zoomed on some examples of mountains to show in detail the obtained registration. The two original registrations using only the DEM and the smartphone localization objectively completely fail but the result is better by coupling DEM and image processing.

5 CONCLUSION

This paper presented a robust two-steps method able to create a smartphone application identifying instantaneously the skyline in an image. The proposed method starts by image simplification based on efficient color difference between aligned pixels giving rise to a score map between sky and non-sky pixels. Then, based on available data directly from the smartphone offering a coarse localization, a second step matches extracted skylines from the digital elevation model with this map to identify precisely the real skyline. The interest of this couple between image processing and digital elevation model is twofold: it gives an efficient tool in this context of electronic orientation table, and it allows to improve augmented reality tools based on smartphones using image processing techniques. Moreover, the tagged dataset built in this paper will benefit the entire community in this field. Future works will first consist in analyzing robustness to meteorologic conditions and then in detecting other notable elements in the image using image analysis but also the DEM. Let us remember that our final goal is to present to the user information concerning points of interest in the image using augmented reality. For this, we also intend to use databases containing monuments, roads, *etc.*

There is still an immense potential in this field because of its utility in many areas like in tourism of course but also, for example, for hikers who want to visualize hiking trails, for persons interested in geology because it would be possible to show them the structure of the ground also and so on. Smartphones are today abundant in our daily life

and augmented reality systems could be developed by mixing their instruments with image processing algorithms.

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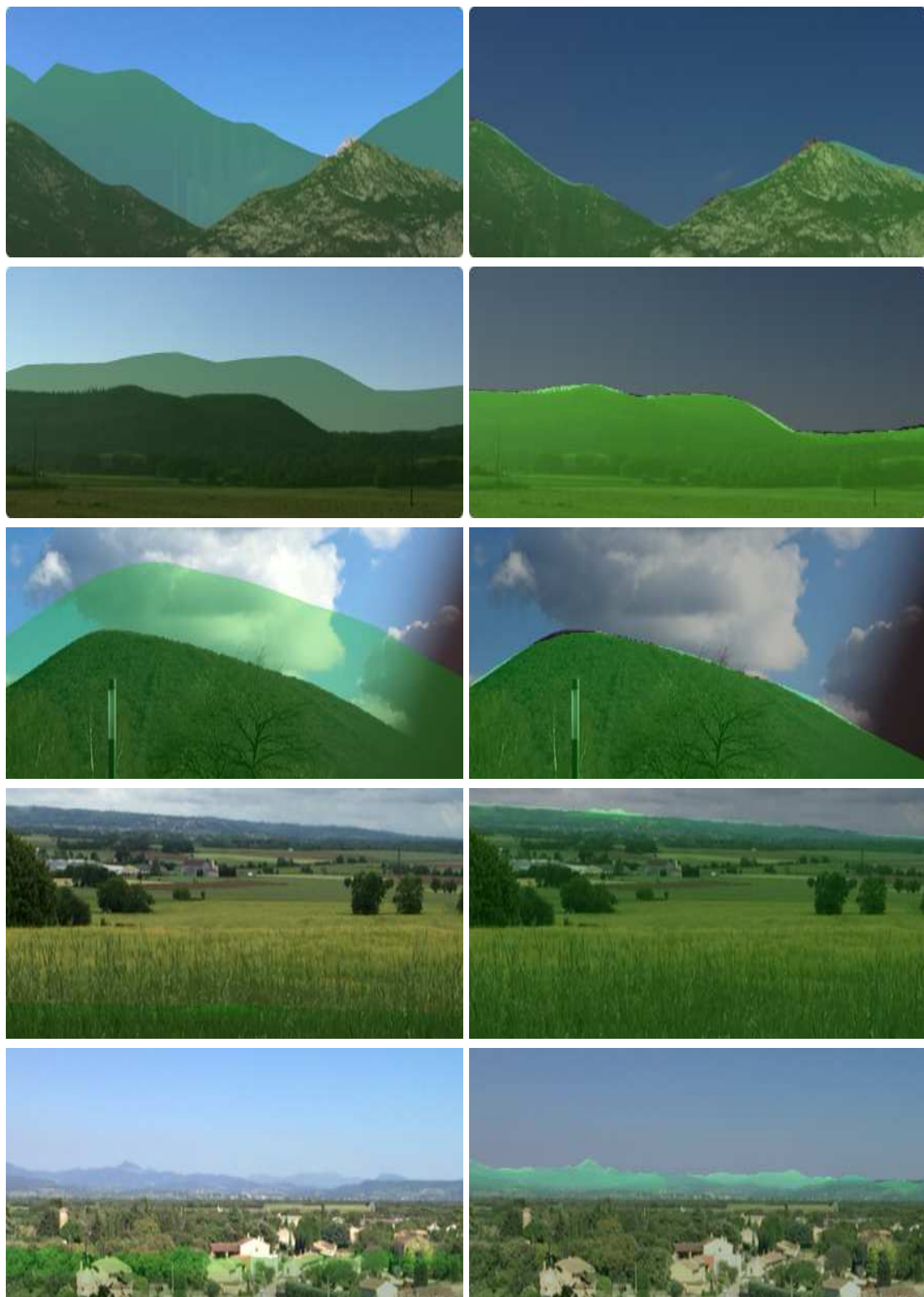


Figure 8: Some results provided by our method. Left : DEM, projection from the smartphone sensors. Right : DEM, projection after registration with our weighed score map.

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