Weather Analysis System Based on Sky Images Taken from the Earth

M. Labayen[1], N. Aginako[1], I. G. Olaizola[1]

[1] VICOMTech, Mikeletegi Pasealekua 57, 2009 Donostia, Spain. {mlabayen, naginako, iolaizola}@vicomtech.org

Keywords: Image Processing, Meteorology, Fog Detection, Cloud Segmentation and Pattern recognition.

Abstract

Meteorological analysis has been typically associated to objective measures (temperature, humidity, air pressure, etc.) and observer's visual subjective analysis of the sky as cloudiness. Cloud amount influences strongly the radiation equilibrium, while cloudiness and fog can be seen as indicators of the type and intensity of locally active thermal processes. Land-based cloud analysis shows different local details which are unavailable in operational satellite imagery [14]. In addition, according to the available state of the art, cloudiness and fog analysis from the earth has not yet been automatized. In this study, an image based method to obtain automatic cloudiness quantification and fog detection is explained.

1 Introduction

Different meteorological devices and systems provide an automatic information about the same phenomenon: weather and climate. However, some measurements like cloudiness are estimated still by trained observers from a meteorological station on the earth.

This work aims to obtain information applying image analysis algorithms to images of the sky taken from a camera located in a terrestrial meteorological station. This information will mainly provide additional data regarding the local weather conditions based on cloudiness or fog detection.

In chapters two and three, this paper makes a short analysis of the state of the art and the description of the global system and its specifications consecutively. Afterwards, in chapter four, automatic feature extraction and the image processing functionalities are explained. Finally, in chapters five and six, the document shows the results obtained from the system test and it ends with the conclusions and future work.

2 State of the Art

Current state of the art in meteorological analysis made from the images is divided in two types according to from where the images have been taken: based on satellite images and terrestrial images.

The analysis of images taken from satellites is an useful tool for meteorologist to weather prediction. It is the most developed automatic image analysis system for meteorological prediction purposes. The main researches in this field are made on cloud classification based on spatial textural and spectral measurements [9][2].

On the other hand, there are some experimental approaches regarding the analysis of sky images taken from the earth. They focus on cloud classification, using textural and spectral features (as edge sharpness, fibrousness and edge information) extraction techniques [14, 13, 5] or analyzing solar radiation measurements [7]. However, they do not offer any explicit solution for cloudiness quantification and fog detection which is the objective of this study.

3 System description

3.1 Overview

The goal of the system is to extract cloudiness and fog detection information from the whole sky image data. The system has to be able to capture images of the whole sky, as well as to extract useful information from the scene captured with the camera.

The general description of the system is shown in figure 1.

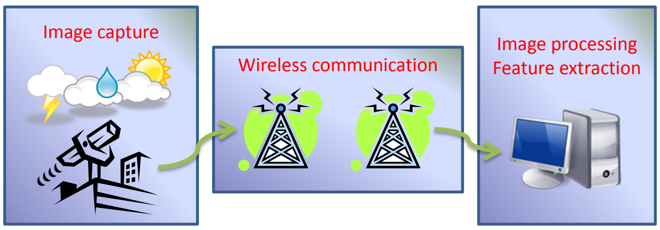


Figure 1: Block diagram.

3.2 Modules

The industrial project called *Skeye*, in which this research has been carried out, establishes the technical specifications that the system has to fulfil. In this section the functionality of each system module as well as their specifications are summarized:

Image capture This module works at the terrestrial meteorology station. It takes pictures of the sky covering all the angles (100° in a vertical plane, from $-10°$ to $90°$ and $360°$ panoramic view in a horizontal plane). The amount of necessary images to photograph the whole sky is inversely proportional to the equivalent focal length [8] of the lens.

The quality and properties of the images depend on how the camera parameters are set. The shutter speed and diaphragm aperture are configurable in order to provide following modules with images that improve the accuracy of the segmentation process. In addition, the white balance will be constant in order to achieve more homogeneity for the same colors in different images.

Wireless communication Terrestrial meteorological stations are usually placed at remote locations. Therefore, this project has been coordinated with a WIMAX network deployment that will allow the retrieval of the information provided by all these remote stations.

Image processing This module, explained in the next chapter, centralizes all the information coming from the different terrestrial meteorological stations. It is able to create a panoramic view of the whole sky keeping the physic areas relations using geometric transformations [10] and Gall-Peters projection mode [12]. This function allows to represent the local weather conditions in a unique image and centralize the visual information from the geographically separated places for the meteorologist.

Furthermore, it analyzes the images and extracts features using digital image processing techniques in order to segment the image and automatize the cloudiness calculation and fog detection.

4 Implementation of the Image Processing module

The most outstanding functionalities of the developed system are Equiareal panoramic representation, Cloudiness quantification and Fog detection.

4.1 Equiareal panoramic representation

The system has to be able to represent the environment around the terrestrial meteorology station on a two dimensional rectangular image. The state of the art presents some research [3, 4] on image stitching based on characteristic point extraction. Unfortunately, the texture properties of sky images are too homogenous to allow good results from these methods.

For this reason, a new "panorama maker" which is independent of the content of the image has been created. This new system is based on the predefined position of the taken pictures. The direction where each image was taken from is the basic information used to align the different images in the final panoramic representation.

Geometric transformations are needed to project the three dimensional surface into a two dimensional plane keeping the physical areas relations between the elements presents in the environment (clouds, sun, sky and earth). Basic geometric transformations allow to align the different images into a panoramic representation and Gall-Peters projection mode projects the panoramic picture into a equiareal representation as follows:

$$\begin{cases} x = (\lambda - 180°)\cos(\beta) \\ y = \sin(\varphi)\sec(\beta) \end{cases} \tag{1}$$

Where,
λ *is the position respect a horizontal center of the projection.*
φ *is the position respect a vertical center of the projection.*
$\beta = 44,138°$ *for Gall-Peters projection mode.*

Finally, multi-band Blending techniques [1, 11] are used in order to get a perfect fusion and a smooth transition between adjacent images.

As an output, the system provides a panoramic image which reflects a wider view than a single image taken by the narrow field of view lens. In addition, it has a higher resolution than images taken by wide field of view lens, as the fish-eye ones.

4.2 Cloudiness quantification

Cloudiness refers to the fraction of the sky covered by clouds. Traditionally, cloudiness is estimated by trained observers from a meteorological station on the earth and expressed in eighths. The aim of this section is to introduce a new computation method of cloudiness in numerical weather prediction models.

The mathematical definition of cloudiness is the cloud to sky ratio in the equiareal panoramic image. To be able to quantify the pixels of each region the application will segment the image in four clases: *earth, sky, clouds* and *sun*.

Firstly, the earth part of the image is segmented. According to experimental observations, if the image has been captured underexposing the scene, the histogram of the B channel in a RGB representation presents easily separable two pixel densities. They represent the group of pixels belonging to the earth and the rest of the image.

Since the background where the earth silhouette is allocated is variable because of cloudiness, the binarization process needs a dynamic threshold [6]. The analysis calculation is done image by image establishing the threshold as the equation 2 shows.

$$Threshold = H^{-1}\{\min(H(x))\} \qquad x_i \leq x \leq x_j \qquad (2)$$

Where,
H is the histogram function.
x_i and x_j are the experimental values which delimit the possible value of the threshold.

The second aim is to separate the non-covered sky for the sun and clouds. Pixels belonging to the non-covered sky are characterized by a chromatic (colors other than the neutral colors white, black, and the pure grays) component. On the other hand, the clouds and the sun are represented in the image with achromatic (white, black, and the pure grays) values.

The HSV color space [6] contents a representation which refers to the intensity of a specific color, the saturation. The binarization of a saturation with a suitable threshold makes posible the separation between the grey level and chromatic pixels.

Nevertheless the color degradation around the sun and the earth makes that non-covered sky tends to be achromatic. In addition, the transparency of some clouds reveals the blue hue of the background which is the sky.

In order to resolve this problem, a conservative threshold that classified the most transparent clouds as sky class is established. (figure 2 (b)). In a second step with a second analysis based on texture feature extraction the transparent clouds are separated for the sky (figure 2 (d)).

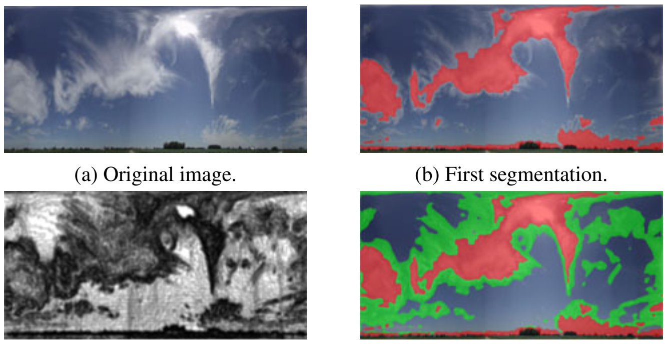
The texture [15][6] represents the relation of each pixel with its neighbors. If the variance between the pixel analyzed and its neighbors into a defined window is high, the texture will be rough. In other cases the texture value is classified as homogeneous. The thin clouds over the sky generate a more rougher texture than the homogeneity of non-covered sky. This characteristic is used to segment the transparent clouds from the sky.

Measurements of texture computed using only histograms suffer from the limitation that carry no information regarding the relative position of pixels with respect to each other. The second analysis uses the co-occurrence matrix [15][6], which takes into account the positions of pixels with equal or nearly equal intensity values.

In order to characterize the content of co-occurrence matrix the entropy descriptor [16] is used. As the equation 3 shows, this descriptor is a measurement of randomness, reaching its highest value when all elements of co-occurrence matrix are maximally random (figure 2 (c)).

$$Entropy = \sum -P_{i,j}\, ln(P_{i,j}) \qquad (3)$$

Where,
P is the normalized co-occurrence matrix.
*It is assumed that 0*ln(0)=0.*



(a) Original image. (b) First segmentation. (c) Entropy values. (d) Second segmentation.

Figure 2: Non-covered sky segmentation.

Finally, the region belonging to the sun is segmented to label this region as sky. Its intensity values are represented with the maximum value of the grey level histogram. However, some clouds near to the sun can contain regions with the same property. To separate it definitively from the clouds the constant area, characteristic circle shape and orientation properties of the sun region are used.

In the case of the earth segmentation, the sky background is subject to a different illumination because of the unpredictable cloudiness. In addition, the interpolations made in different geometric transformations to create the panoramic representation miss the texture features needed to segment the transparent clouds. For these reasons, the segmentation of the earth and the non-covered sky are made image by image before applying the transformations.

On the other hand, the sun segmentation is made in the panoramic image because the system takes into account the characteristic shape and the area of the sun region, so the sun has to be fully stitched in case it has been captured in the union of various images.

4.3 Fog detection

The fog usually appears during the morning reducing visibility to less than 1000 m. It is detected because it covers parts of the earth which are usually visible without fog.

The earth class has a constant shape when it has been captured without fog. The automatic detection is based on a variances in this constant shape. The applied techniques are two: detection based on pattern recognition [6] and detection based on earth silhouette shape analysis.

For the first analysis, it is supposed that any area of the segmented earth can be considered as a constant pattern (in scale and rotation) form which will be easily detected in all of images without fog. The mountain hills are selected as pattern (figure 3(a)) because they are the first areas of the earth part of the images covered by the fog. The statistic value used to quantify the similarity of the specific area of the image under analysis with the chosen pattern is a correlation.

The pattern and the image under analysis may have been captured under different camera exposition mode because of the light presented in the scene. The luminance of each image is referenced to the same white in order to make equal as much as possible the area which will be detected.

The equation 4 shows the mathematical operation of correlation between both images ($f(x, y) \circ g(x, y)$, the pattern (g) and the image which is being analyzed (f)), and the decision threshold used to detect the fog. Figures 3(b) and 3(c) support this equation graphically.

$$thr \geq f(x,y) \circ g(x,y) = \sum_{m=1}^{M-1} \sum_{n=1}^{N-1} f^*(m,n) g(x+m, y+n) \tag{4}$$

Where,
$*$ is the complex conjugate.
thr is the established decision threshold.

(a) Pattern defifiniton.

(b) Pattern detected. Fog existence discarded.

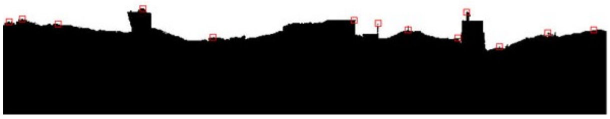
(c) Pattern undetected. Fog detected.

Figure 3: Pattern recognition.

The second analysis takes only into account the shape of the earth silhouette. The earth class segmentation mask is different if the fog is present in the scene. For each image under analysis the system takes the earth segmentation mask and interprets the boundary of the mask [6] as a function. It calculates the relative maximums which are the mountains hills of the image.

For a scene without fog (figure 4(a)) this characteristics point are stored (figure 4(b)) as point coordinates of the image matrix. The extracted points from each analyzed image are compared with the stored characteristic points. The fog presence is detected when there are not characteristic points in the image that is being analyzed.

(a) Original image.



(b) Characteristic points detected over the earth segmentation mask.

Figure 4: Characteristic points detection.

5 Setting up and results

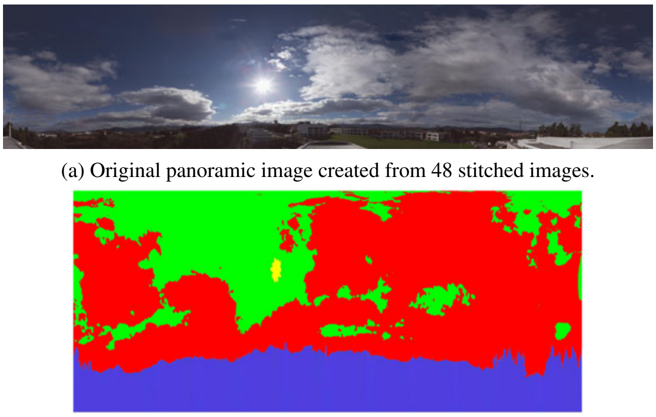
The initial assessment has enabled to specify more in depth which parameters of the camera will make easier the further segmentation process. In addition, the parameters of geometric transformations and segmentation thresholds of all the used techniques have been established.

According to this first assessment, in the images which have been captured underexposing the scene and using light polarizer the segmentation is more accurate because these techniques reduce the sun color degradation effect in the sky and get darker the earth part of the image.

The system has been tested with a database provided by Esukalmet meteorological agency. The images that conform the database have been taken at different time during the daytime and under diverse meteorology conditions.

The database has 10 panoramic images (48 single images/panoramic image) which have been taken during the daytime (from 09:00 to 17:00, 2 images/2 hours) in autumn season. The results which have been contrasted with the profesional staff of Euskalmet meteorological agency, have been aceptable for the images taken between 11:00 and 15:00. Actually, the precision in cloudiness measurement is higher than the obtained from the meteorologist visual analysis. Nevertheless, at dawn (09:00) and at nightfall (17:00) the obtained result have not been aceptable because the intensity and colorimetric properties of the sky and clouds are different because of the sun illumination, making also more difficult the visual segmentation.

An example of the successful segmentation is shown in figure 5.



(a) Original panoramic image created from 48 stitched images.

(b) Equiareal representation of segmented image.

Figure 5: Segmentation result.

Since the available information comes from the visual spectrum, the analysis during the night is discarded.

Fog detection techniques depend on the correct segmentation of the earth class from the image. For this reason, in above described cases where the segmentation works properly, the fog detector has retrieved all the foggy areas, without generating any false positive (figures 3(b)3(c)4(b)).

24 images of 480 images which conform the database, contain fog. Part of these images have been taken in the morning (09:00) and the others during the rest of the daytime period. Independently of the time when the images have been taken, the results are aceptable because when the fog is present in the image the earth class segmentation is not subject to the sun undesirable effects at dawn and at nightfall.

6 Conclusions and Future work

The project concludes with a weather automatic analysis system based on images taken from the earth which carries out the specifications required for the daytime period.

Creating panoramic representations of the environment of each terrestrial meteorological station and being able to centralize them, the system enables meteorologist to cover more area to make their visual analysis. The new "panorama maker" (adjustable to any camera and lens) has been developed entirely because according to our knowledge, the state of art did not offer any solution to the union of images with homogeneous content such as an image of a clear sky.

Current state of the art offers other solutions for weather analysis using image data coming from satellites. However, the innovative aspect of the project makes possible the consolidation of image processing techniques combinations to analyze and extract useful meteorological information from the images taken from the earth, providing meteorological sciences with an automatic application.

The study of different techniques, and their combination and customization for the specific purpose for meteorological analysis from the images taken from earth, have enabled to contribute to emergent research field using traditional image processing techniques.

Research on High Dynamic Range images will be constitute the future work in order to improve the efficiency of the system during the daytime, making more homogeneous the texture and colorimetric characteristics around the whole panoramic and reducing the undesirable sun degradation effect over the sky.

On the other hand, the analysis has to be expanded to IR in order to extend the functionalities described in this document and be able to get more information from the night period.

Acknowledgements

The authors gratefully acknowledge the collaboration offered by SPRI[1] (Society for Industrial Promotion and Restructuring), Dominion[2] (Services, Applications and Infrastructure for ITC'S), and Euskalmet[3] (Basque Meteorology Agency).

References

[1] E. H. Adelson, C. H. Anderson, J. R. Bergen, P. J. Burt, and J. M. Ogden. Pyramid methods in image processing. *RCA Engineer*, (29-6), Nov/Dec 1984.

[2] M.R. Azimi-Sadjadi, M.A. Shaikh, B. Tian, K.E. Eis, and D. Reinke. Neural network-based cloud detection/classification using textural and spectral features. 2:1105 – 1107, 27-31 May 1996.

[3] M. Brown and D.G. Lowe. Recognizing panoramas. *Proceedings of the 9th International Conference on Computer Vision*, pages 1218–1225, October 2003.

[1] http://www.spri.es
[2] http://www.dominion.es
[3] http://www.euskalmet.euskadi.net

[4] M. Brown, R. Szeliski, and S. Winder. Multi-image matching using multi-scale oriented patches. *Proceedings of the International Conference on Computer Vision and Pattern Recognition*, june 2005.

[5] K. A. Buch, C.H. Sun, and L. R. Thorne. Cloud classification using whole-sky imager data.

[6] Rafael C. Gonzalez and Richard E. Woods. *Digital Image Processing*. Pretice Hall Upper Saddle River, New Jersey, second edition.

[7] J. A. González and D. Pagès. A method for sky-condition classification from ground-based solar radiation measurements. June 20 2001.

[8] S. Kelby. *The Digital Photography Book*. Peachpit Press, 2006.

[9] N. Khazenie and K.A. Richardson. Classification of cloud types based on spatial textural measures using noaa-avhrr data. 3:1701 – 1705, 3-6 Jun 1991.

[10] M. Labayen. Análisis metereológico basado en imágenes. Master's thesis, Escuela Superior de Ingenieros Industriales y de Telecomunicación, Universidad Pública de Navarra, March 2008.

[11] J.M. Ogden, E.H. Adelson, J. R. Bergen, and P. J. Burt. Pyramid-based computer graphics. *RCA Engineer*, (30-5), Sept./Oct 1985.

[12] A. Peters. Die neue kartographie/the new cartography. *Friendship Press*, 1983.

[13] M. Peura and A. Visa. Land-based cloud classification.

[14] M. Peura, A. Visa, and I. Kostamo. A new approach to land-based cloud classification. *Proceedings of the 13th International Conference on Pattern Recognition*, 4:143 – 147, 25-29 Aug 1996.

[15] R. Sapina. Computing textural features based on co-occurrence matrix forinfrared images. pages 373 – 376, 2001.

[16] Claude E. Shannon. *A Mathematical Theory of Communication*, volume 27. July, October 1948.