Boundary extraction of sodar images

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Abstract

Sound radars provide valuable information on the characteristic patterns of atmospheric boundary layer (ABL). The ABLs are, however, often corrupted and broken due to various noises present in the sodar imageries. This often leads to wrong interpretation of the image. Standard image-processing techniques do not seem to remove these noises adequately. In our present work, we offer a preprocessing scheme that enables detection of continuous boundaries for the ABL and other regions of interest. The method adopted here is a two-step filtering approach specially designed to take into account the subtleties of sodar images and their characteristic patterns so that a continuous ABL contour can be obtained. Boundaries of other significant information regions are also demarcated. These contour lines can then be used in determining various features necessary for interpretation of the sodar imageries. © 1997 Elsevier Science B.V.

Zusammenfassung


Résumé

Les radars sonores fournissent des informations précieuses sur les structures caractéristiques de la couche limite de l'atmosphère (ABL). Les ABL sont, toutefois, souvent corrompus et partiellement détruits du fait de bruits divers présents dans les images sodar. Ceci conduit souvent à une interprétation fausse de l'image. Les techniques standards de traitement d'images ne semblent pas supprimer adéquatement ces bruits. Dans ce travail nous proposons une technique de pré-traitement permettant la détection des frontières continues pour les ABL et d'autres régions d'intérêt. La méthode adoptée ici est une approche de filtrage en deux temps spécifiquement conçue pour prendre en compte les subtilités des images sodar et leurs structures caractéristiques de sorte qu'un contour ABL continu peut être obtenu. Les contours des autres régions contenant

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1. Introduction

Acoustic sounding has assumed significant importance in diverse meteorological research since late 1960 [5,4]. One of its major applications is monitoring the atmospheric dynamics in the lower boundary layer [8]. The lowest part of the atmosphere extending from the ground level to about 1 km is called atmospheric boundary layer (ABL). Various atmospheric conditions (such as humidity, temperature, wind speed, wind shear, terrain condition, etc.) determine the height of the ABL. The ABL height and its pattern over certain time-period provide important information about prevalent weather conditions.

Sonic detection and ranging (SODAR) is one major technique in which an acoustic signal is transmitted vertically and their back-scattered signals are recorded in a three-dimensional recorder. Digitised versions of these records are then used in subsequent analysis to help meteorologists in interpreting weather conditions qualitatively. We shall call these digitised images ‘sodar imageries’ in our subsequent discussions.

Interpretation of sodar imageries requires consideration of three aspects:
1. Specifications of the nature of the ABL. By the nature of an ABL we mean the height at which the ABL is formed. If the sodar patterns are formed at a reasonable height (above 50 m, in the least), and has a reasonably long duration (at least half an hour) then the ABL is said to have an inversion. Other typical patterns of ABL includes plume, mixed structure, no structure, elevated structure, etc., and are characterised by various properties such as height, process of formation, duration. For more details one may refer to [1]. The nature of the ABL helps in forecasting the stability of the prevailing atmospheric conditions.
2. Identification of the ABL pattern. In situations where the ABL can be recognised as an inversion, one is interested in the shape of the ABL. There are four typical patterns of the ABL: flat-top (a relatively horizontal contour); inversion mixed with plume as is observed during the time of inversion break; gradual increment; and gradual decrement (the last two having usual sense). Often some subtle variations are found on the top of an inversion. Some of these typical variations are:
   - spike — a sharp increase in the echo height for a short period (a few seconds, say);
   - bulge — a long (more than 1 min, but less than 10 min) persistent increase in echo height;
   - depression — a long (more than 1 min, but less than 10 min) persistent decrease in echo height;
   - waves — a periodic variation in the echo height.

These pattern are useful in determining climatological outlook. For example, a spiky-top layer of height greater than 100 m indicates moderate to strong wind condition; low inversion height or overlapped diffuse plume structure indicates cloudy day. Many such climatological explanations can be found in [9]. These typical pattern types ought to be remembered and appropriate measures should be taken for their preservation while preprocessing a sodar image. A blind-folded noise cleaning scheme otherwise tends to remove sporadic occurrences of these patterns, and cause huge loss of information.
3. Characterisation of other features. Not only the ABL, but other particulars present in the image (above and/or within the ground inversion structure) are also important. Two major aspects in this regard include:
   - elevatedness — that provides information about formation of ‘multilayer’ (a contour of echo pixels is found at certain distance above the ABL);

   - vortex — a large patch of non-echo pixels found within the ground inversion. Such occurrences are termed as ‘hollowness’ of the image, or presence of ‘vortex’ in an image. Variation in temperature and
randomness of wind patterns may be the reasons behind formation of such hollowness.

Interpretation of sodar images necessitates identification of these features as well.

Figs. 1, 5(a) and (b) show three sodar images of types plume multi-layer and depression (the last one with spikes), respectively.

Different approaches have already been suggested for automatic recognition and interpretation of ABL pattern from sodar imageries [1–3]. But application of these techniques, in general, requires determination of a continuous ABL and continuous boundaries of other regions of interest (such as multi-layer, vortex) on which the inference mechanisms ought to be applied. But the task is not straightforward because of the presence of noises of various kinds [10]:

- atmospheric disturbances — such as lightning, strong wind, rains, drizzles;
- man-made noise — such as loud horn of a vehicle, flying aircraft, loudspeakers;
- natural — such as bird’s chirping, flapping noise of tree leaves.

Such noises may have abrupt effects of varying durations on the facsimile records that may often be mistaken as true patterns, e.g. a sharp sound of short interval (e.g. a bird’s squeak, a car’s horn) may have a spike-like effect). Presence of these noises often complicates the sodar patterns. Standard image processing (IP) and/or pattern recognition (PR) techniques (such as ‘grey-value thresholding’ [11] or use of fuzzy c-means [6]) do not seem to clean the noises adequately so that continuous contours can be obtained. As a result, application of the various approaches mentioned earlier becomes highly questionable.

We, therefore, consider extracting continuous boundaries (for sodar images) to be the major goal of the preprocessing task. In this work we have addressed to this problem. We have developed an image processing scheme that considers subtleties of typical sodar patterns. While cleaning the noises in the image, this scheme retains prominent features of the ABL pattern: and also bridges the gap between portions of the ABL that may otherwise be missing during the noise cleaning operation. It also demarcates the boundaries of other relevant information present in a sodar image. Once these boundaries are determined, the information can be used in interpretation and modelling of the sodar patterns.

In the following section, we describe our approach in this regard, and show its effectiveness on different sodar images.

2. Development of the proposed scheme

Evidently, the primary aim of our approach is to remove noises from the image and to leave the information pixels in tact. Different available noise removal techniques (such as averaging median filtering [12]; smoothening of histogram [10]) have been found to have a tendency of smoothing out some true information, particularly when the information is thin (such as a ‘spike’). Hence, in our approach we take appropriate measures so that shapes of key patterns are maintained while removing the noise. At the same time, we try to join small, broken components (left after the noise cleaning operation) of the ABL and other regions. We do this in such a way that the overall shapes of the ABL and other contours are preserved. Although in our approach we have used some readily available ‘filtering’ and ‘boundary detection’ techniques, we have specially tuned them to address the needs of sodar pattern characteristics. We illustrate our approach using the image given in Fig. 1 (we call this image ‘example image’).

Our method comprises three stages – image thresholding, noise cleaning and boundary detection.

1. Image thresholding. Here we apply bi-level thresholding technique to divide the image pixels into two classes – the information (i.e. echoed pixels) and the background (non-echo pixels). The primary consideration here is to ascertain the threshold value. Different methods are already available for this purpose. We use an automatic threshold selection method proposed by Otsu [7] where statistical properties of the image pixels are used. For a given image this method computes the zeroth and the first-order cumulative moments of the grey-level histogram. The optimum threshold value is evaluated based on ‘within-class’ and ‘between-class’ variances (that are calculated from these moments) when thresholding divides the entire range of gray levels present in the image into...
two classes: ‘information’ and ‘background’. The goodness of the threshold at grey level value $k$ is determined based on the following discriminant criterion:

$$\lambda = \frac{\sigma_B^2}{\sigma_W^2}, \quad \kappa = \frac{\sigma_T^2}{\sigma_W^2} \quad \text{and} \quad \eta = \frac{\sigma_B^2}{\sigma_T^2},$$

where $\sigma_B^2$, $\sigma_W^2$, $\sigma_T^2$ are the between-class, within-class and the total variances of grey levels, respectively. The problem of searching the optimal threshold is reduced to an optimisation problem to find best $k$ which maximizes these discriminant functions. In fact, it has already been claimed [3] that $\eta$ is the simplest and appropriate measure to evaluate the goodness or separability of the threshold at level $k$.

The two-toned image obtained in this way is then subjected to the noise cleaning operation. In this image the echo pixels are represented as black, and the non-echo ones as white. Fig. 2 presents the two-tone image obtained after thresholding the example image (Fig. 1).

2. Noise cleaning. Evidently, the thresholding method is associated with two types of errors:

Type a – where an echo pixel is misclassified as a background pixel. This may happen when due to local atmospheric variation a certain pixel receives an intensity value that is high enough to be considered as an echo.

Type b – where a non-echo pixel is misclassified as an echo pixel. This may happen due to the presence of noise.

Because of the presence of these errors the ABL contour appears broken – as patches of echo pixels are found to be interspersed with non-echo pixels. The purpose of the noise cleaning stage is to remove the effects of these errors. Here, cleaning of noise is performed in three passes:

First pass. In this pass we try to remove the effect of ‘type a’ error by joining small gaps between two patches of echo pixels. This is done by shifting a $5 \times 5$ mask over the image. If the number of information (echo) pixels covered by the mask at any certain position is greater than or equal to 13 (i.e. median) then we replace the central $3 \times 3$ pixels covered by the mask by information value.

Second pass. The purpose of this pass is to make thin features (such as a ‘spike’) more prominent. Usual noise removing filters tend to remove these thin features. Hence, we take special care to retain them. This is done by shifting a $21 \times 1$ vertical mask over the image. If at any instance the number of information pixels covered by the mask exceeds 10 (i.e. at least the median value) then we
replace the pixel at the centre of the mask with an information pixel. Thus, discontinuous vertical patterns of significant length are joined.

The justification of using this mask is that a spike-like feature is rather transient in nature. Hence, in our setup a spike’s width cannot be more than one pixel. Some noises of very short duration too may have a single-pixel width, but their height will be less. On the contrary, the height of a spike is rather tall. We have experimented with masks of different lengths. For the images that we are currently using, a mask of length 21 has been found to be optimal. While masks of larger length fail to capture many true spikes, masks of smaller lengths have been found to recognize non-spike vertical patterns to be as spikes. Using this mask we have been able not only to join the spikes, but also to clean some spurious short-duration noises.

**Third pass.** In this pass we repeat the same operation as done in the first pass to fill in any gaps that may still be present.

The final processed image for our example image is given in Fig. 3. The image thus obtained is subjected to the boundary detection phase.

**Boundary detection.** In this phase, we extract the boundaries of all components present in the image. A boundary pixel is defined as an information pixel that has at least one background pixel as neighbour in horizontal or vertical direction. The image is scanned both columnwise and rowwise for this purpose. If two consecutive pixels differ in their values then the information pixel is marked as boundary. Once the boundary information about the pixels is obtained, the boundaries are traced and extracted in a continuous manner in the following way:

The tracing starts from a seed point obtained by a topdown scanning of the processed image. If a boundary point is detected it is marked and a new boundary point is scanned in its 8-neighbourhood. At each point the neighbouring pixels are scanned clockwise from the top-left corner of a 3 x 3 mask. If a new boundary point is not available within the neighbourhood, a boundary point that has already been marked once is considered for continuation of the boundary tracing.

In Fig. 4 we see the boundaries obtained from the example image. It gives the ABL contour and boundaries of other information.

In Figs. 5(a) and (b) we provide two other sodar images. Figs. 6(a) and (b) provide the boundaries obtained from these images, respectively, using our technique.
Fig. 5. Sodar images: (a) multilayer structure, (b) inversion.

Fig. 6. Boundaries of (a) Fig. 5(a), (b) Fig. 5(b) using the proposed scheme.
The co-ordinates of the ABL contour can now be easily identified and the pattern of this ABL can be recognised using appropriate pattern recognition techniques.

3. Concluding remarks

Interpretation of sodar imageries depends largely on obtaining a continuous ABL contour. We have developed an image processing scheme that cleans the noises that are normally present in a sodar image. It also provides a means to join fragments of the ABL contour obtained through image thresholding by pattern specific region growing. The effectiveness of the method has been tested on a variety of sodar images. The output image can be used in identifying the ABL pattern, and/or describing other related information present in the image.

The mask size that we have used, in boundary detection, is specific to the resolution of our images. For images of significantly different resolutions appropriate masks ought to be designed.

One major disadvantage of this approach is that it is inherently slow as the entire image is filtered thrice. Use of parallelisation is therefore recommended for any real-time use of this method.

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