2.2 For each entry (i, j) in the list of insignificant sets do:
2.2.1 If the entry is the set of all descendants of (i, j), $D()$, then output $S_0(D(i, j))$ as before; if $S_0(D(i, j)) = 1$, then
– Proceed as before by testing each coefficient of direct descendants indexed as (k, l). However, should $S_0(k, l) = 1$, then if $c_{k,l} \geq T_0$ then output 1, otherwise output 0; proceed as before.
– Otherwise proceed as before.
2.2.2 Remains unchanged.
3. Refinement: Remains unchanged.
4. Quantisation update: Remains unchanged.

Results and conclusion: In Table 1, for those 512 × 512 standard grey-scale test images that satisfied the simple test, the SPIHT and modified SPIHT bits/pel (bpp) are compared. Clearly, the percentage improvement increases with reduction of PSNR. We also reduced the dynamic range of the pixels in each image by subtracting 128 from the each pixel, in the manner of the IW44 algorithm [5], to achieve a low-complexity approximation to zero meaning. The result was a reduction from eight to six of the images ('bridge', 'barbara', and 'man' are now unmodified, with 'crowd' becoming modified) that passed the initial simple test, but gains in bit rate for the six that are similar to the results of Table 1.

This Letter has recommended a simple modification to the SPIHT quantiser, which can be effected in hardware, and leads in many cases to an improved bit rate, without any distortion penalty. The improvement is the result of removing one round of embedded bit-map transmission. It is thought that the technique may be applicable to similar algorithms such as EBCOT [6].

Note: Images available from http://www.sys.uea.ac.uk/Research/researchareas/imagevision/images_ftp/ (last accessed 3.3.03).

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Wavelet-watershed automatic infrared image segmentation method

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A novel approach for infrared image segmentation with applications to ship surveillance and classification is presented. It employs a watershed transformation using a marker that combines wavelet transform modulus maxima with morphological techniques. This approach is totally automatic and has many advantages compared with the traditional methods, such as its ability to extract objects beyond or below the environment temperature, robustness to noise inherent to infrared images, as well as a solution of the horizon problem.

Introduction: To extract semantic objects from a scene, an *a priori* knowledge of the image type and object characteristics is necessary. An infrared image is the result of the acquisition from the thermal radiation of the scene producing a two-dimensional map representing the temperature, emissivity and reflexivity variation of the scene. The *a priori* knowledge for infrared image segmentation is based on the fact that the object that has to be extracted has either a larger or smaller temperature than the environment, being characterised by transient elements such as edges and peaks.

A popular approach to object extraction in infrared images is the thresholding technique [1]. Although this technique can be easily implemented, it is very dependent on the threshold selection. In addition, techniques to calculate the threshold based on an image grey-level histogram [2] frequently yield problems when the object pixel values change across the object or the background. The model-based approach [3], another popular technique for infrared image segmentation, requires an *a priori* knowledge about the object shape.

Mathematical morphology [4] is a powerful tool for image processing, due to its ability to deal with the object image directly in the spatial domain. For segmentation, the main morphological tool is the watershed transformation [5]. To avoid the over-segmentation that occurs when the watershed is applied directly on the image, Beucher and Meyer [5] proposed a paradigm that consists basically of two steps: the first is considered the 'intelligent' step, choosing the objects that will be extracted and its markers; based on these markers, in the second step the watershed transformation is executed on a simplified original image.

Here we propose to use the wavelet transform modulus maxima [6] combined with morphological operators as a pre-segmentation step in order to find the markers that are then used by the watershed transformation.

Wavelet-watershed segmentation process: The block diagram of Fig. 1 describes the proposed segmentation process. It can be considered as having three main steps: one where the semantic objects are extracted and the marker is determined, another that simplifies the original image, and one that executes the watershed transformation as well as the final filtering.

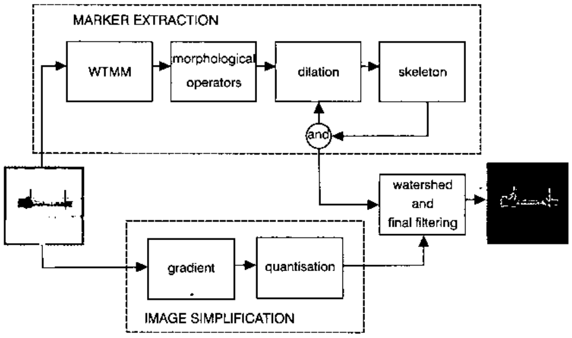

Fig. 1 *Block diagram of proposed segmentation approach*

First step: The *a priori* knowledge available for extracting semantic objects from an infrared image is that they are positioned at transient regions such as edges. Unfortunately, in most infrared segmentation applications the noise level is high, which leads to undesirable false target detection. The edge detector chosen here is the wavelet transform modulus maximum [6] which presents two main advantages: the lowpass filtering due to the dyadic wavelet transform process and the possibility of choosing relevant line using multiresolution information. These help reduce the influence of unwanted noise on the segmentation process.

Unlike the method in [6] where the modulus maxima are searched only along the horizontal direction, here we perform an improved search in both directions. We have used the second and third levels of the wavelet decomposition. The two corresponding edge maps obtained are combined with a logical OR operation.

Generally, the boundaries of the important coherent structures generate the larger edge lines. To eliminate edge lines smaller than a given length while maintaining the others intact, the morphological area open operator [4] is executed. The area open compares the objects in an image with a structuring element, and, if the object has a smaller area than it, it is removed. The structuring element is a line the length of which was experimentally determined. Simulation results have shown that this line length is suitable for all tested cases.

Since the main application of this method is to detect ships in infrared images, one can be faced with an undesirable effect: the horizon line is usually large enough to remain even after the area open execution. Thus, it can compose a set with the image margins, leading to its detection by the watershed process. To eliminate such horizon lines, a process based on mathematical morphology was developed.

The horizon is simply an almost horizontal line that touches the two image vertical margins (see Figs. 2 and 3). Then, testing if the image has elements that touch the two margins is the first step of the process to solve the horizon problem. To do this, we use a logical AND of two morphological reconstructions by dilation [4] with the pre-segmented image as a marker. The structuring elements are the right and left vertical image margins, respectively. This way, all lines that touch the two image side margins simultaneously are removed. Unfortunately, this procedure has the drawback of removing any object that touches the horizon or the two margins. We have circumvented this problem by performing a directional gradient [4] having as a structuring element a horizontal line. This preserves elements that touch the horizon line or the two margins but are not horizontal. The desired result is obtained by the logical OR of the results of the morphological reconstruction by dilation and the directional gradient.

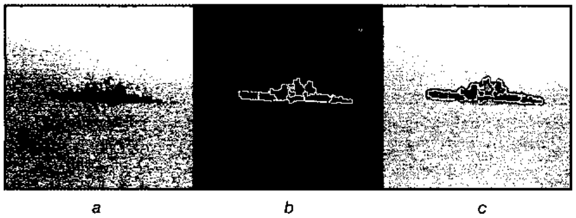

Fig. 2 *Original image, segmented image and original image plus segmented image*
a Original
b Segmented
c Original plus segmented

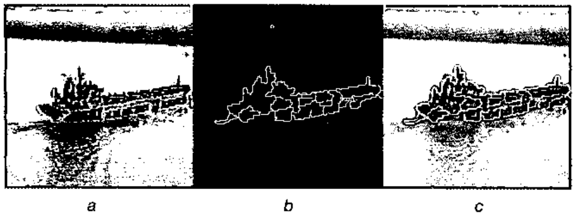

Fig. 3 *Original image, segmented image and original image plus segmented image*
a Original
b Segmented
c Original plus segmented

At this point, the binary image obtained, which can be considered as a pre-segmented input image, is dilated using a 6×6 box as a structuring element. The watershed process considers as a valid marker a binary image that has, at least, one white pixel enclosed by a black region. To guarantee that even small object markers have a white pixel inside a black region, a skeletonisation followed by an area open [4] is executed on the dilated image. The dilated image and its skeleton are combined with a logical AND. Note that this area open is then performed in order to avoid, as much as possible, false markers derived from very small noise structures.

Second step: Before performing the watershed transformation it is necessary to simplify the original image. This is performed by computing its morphological gradient followed by its quantisation to 100 grey levels. Such quantisation filters out some undesirable low amplitude texture elements.

Last step: Once the marker and the simplified original image are available, the watershed transformation can be executed. After the watershed transformation another area open is performed in order to eliminate any small false target that might have remained after the entire segmentation process.

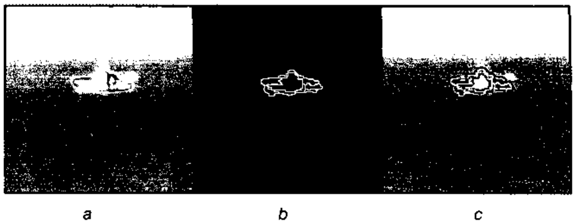

Fig. 4 *Original image, segmented image and original image plus segmented image*
a Original
b Segmented
c Original plus segmented

Results: To assess the efficiency of the proposed method a set of 35 infrared ship images were segmented using it. These images were obtained from an AN/AAS-44V 'forward-looking infrared' (FLIR) camera mounted on a SH-60B helicopter noose, and from a FLIR Prism DS camera fixed in a laboratory. As can be seen in Figs. 2–4 the segmentation process is quite sharp. The horizon problem was eliminated, as can be seen in Figs. 2 and 3. Hot ships, as in Fig. 3, are extracted in the same way as cool ones (Figs. 2 and 4). This indicates that the method works regardless of whether the semantic object temperature is above or below the ambient temperature. Observe that despite some ship images having very thin structures as in Fig. 4, due to the skeletonisation these structures are successfully extracted. Note that, in Fig. 2, although there is a reflection of the ship on the surface of the water, our method was successful in not detecting it. The good results shown in Figs. 2 to 4 are consistent all over the test set, pointing to the robustness of the proposed process.

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