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Enhancement of sand dune texture from Landsat imagery using difference of Gaussian filter

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Abstract. Satellite imagery provides a useful means of mapping various sand dune types in the sand fields. However, the texture and composition of dunes is usually not clear on the images. In order to enhance textural and spatial features of the dunes, difference of Gaussian (DOG) filters were applied to the Landsat Thematic Mapper digital imagery. The results indicate that this technique is effective in enhancing a broad range of textural features in the sand dunes. By varying the band width of the DOG filter it was possible to select a specific range and size of textural features to be enhanced.

1. Introduction

Sand seas in the Arabian Peninsula form the largest body of sand in the world with probably the greatest variety and complexity of sand dunes to be found. The major dune types encountered in these sand fields are transverse dunes (barchan, barchanoid ridges, and parabolic), linear dunes, star dunes, and dome dunes. Some of these dune types have been mapped using Landsat MSS imagery (McKee 1979).

The Landsat images provide a useful means of delineating and mapping large scale sand features on a regional scale. However, small textural features and the composition within the dune structure is not clearly identifiable on the images. In order to enhance the textural and structural features of dunes, spatial band pass filtering can be employed (Al-Hinai 1988).

A test site was selected to observe the effects of the DOG filtering in enhancing sand dune textural features. The site is located in the Nafud Al Thuwayrat in northern Saudi Arabia, east of Buraydah, at about longitude 44°30′ E, latitude 26°45′ N. It consists of large dome shaped dunes which have rounded crests and are covered by rows of crescentic dune ridges as shown in figure 1. The dome dunes have diameters in the range of 0·8–1·8 km and heights in the range of 100–150 m (Breed and Grow 1979).

Figure 1. Aerial photograph showing dome-shaped dunes in the study area. Crescentic ridges appear as fine texture on top of the dome dunes [McKee 1979].

2. Methodology

2.1. *Data selection*

The image used for this study is a subsection (256 × 256 pixels) of Landsat TM scene Path 167 Row 42 acquired on 17 April 1985. After careful visual examination of all the bands, it was observed that the near infra-red band (TM band 4, 0·76–0·90 μm) showed a good contrast between sand dunes and other surficial deposits. In accordance with our observation, it was decided to use TM band 4 in this study.

2.2. *Image processing*

The image processing technique investigated in this study for the enhancement of small textural features is basically an extension of the general filtering procedures. Image filtering using predefined operators such as compass gradient, line finding, or Laplacian masks is useful for enhancement of general spatial or directional features (Pratt 1978). However, if feature sizes are to be taken into consideration, then special convolution operators are required. Frequency domain filtering techniques allow special filtering functions to be more conveniently specified. The frequency domain filtering functions can then be approximated by spatial masks for the speed and simplicity of implementation (Gonzalez and Wintz 1987).

The sharpest possible frequency cut-off that does not induce ringing is produced by a Gaussian filter (Gonzalez and Wintz 1987). Ringing is the production of spurious edges surrounding a real edge. The mask elements of the Gaussian filter can be calculated from the following formula in which the central mask element has coordinates (x_0, y_0):

$$G(x, y) = \frac{1}{\sigma} \exp\{-[(x-x_0)^2 + (y-y_0)^2]/2\sigma^2\} \tag{1}$$

where σ is the standard deviation and controls the width of the function in the mask. A sketch of this function is given in figures 2 (*a*), (*b*) and its intensity plot appears in figure 2 (*c*). If σ is varied in units of pixels and two Gaussian functions corresponding to two different values of σ are subtracted, the features whose scale lies between the two σ values are enhanced.

In this study, to cover the range of small textural features (60–180 m), standard deviation values were varied from 1 to 3 pixels and DOG filter responses were coded in 7×7 masks. These masks were then convolved with the test image and the resultant output images were stretched to show maximum contrast. The DOG filters were designed to pass some of the low spatial frequency components in order to facilitate interpretation of the filtered images.

3. Discussion and results

Two sets of DOG filters were designed to enhance textural details of sand dune and interdune areas. In the first set of filters, the band width was gradually increased from 1·0–1·5 to 1·0–3·0 pixels. The DOG masks for this set were created using standard deviation values in the ranges of 1·0–1·5 pixels, 1·0–2·0 pixels, 1·0–2·5 pixels, and 1·0–3·0 pixels which correspond to feature sizes between 60–90 m, 60–120 m,

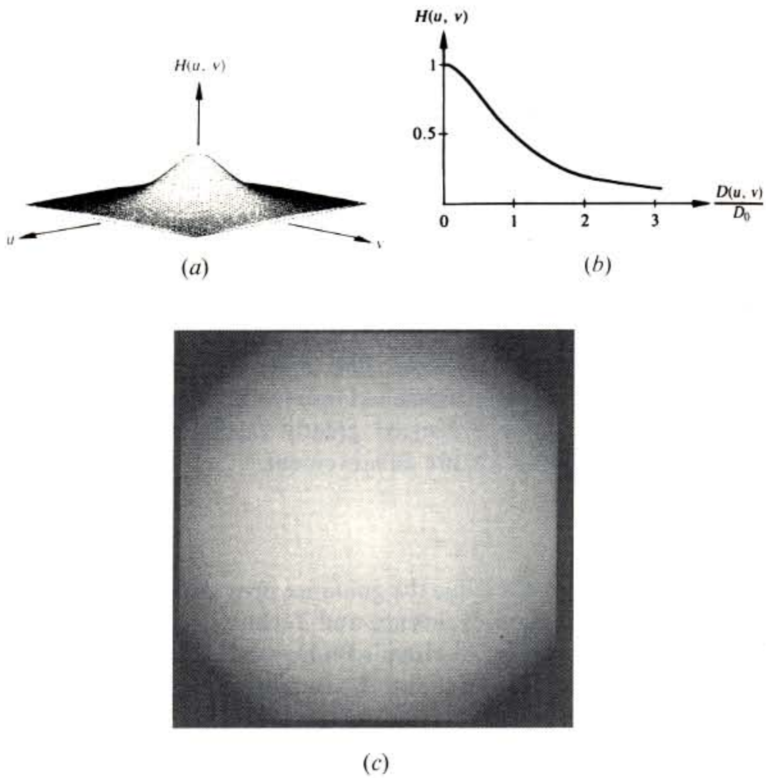

Figure 2. (*a*, *b*) Sketch of the Gaussian function. (*c*) Intensity plot of the Gaussian 7×7 mask $\sigma = 1 \cdot 0$.

60–150 m and 60–180 m respectively. As an example, the frequency response of the DOG filter with standard deviation of 1·0–1·5 pixels, is shown in figure 3 (*a*). In this plot spatial frequency is coded as radial distance from the origin. The filter response is coded in different colours. The yellow colour represents areas of maximum filter response while symmetric concentric rings surrounding it represent successively decreasing response. The white colour represents zero filter response. Figure 3 (*b*) shows the frequency spectrum of the test image used in this study. A close examination of the two figures reveals how the filter will modify the spectrum of the image and which features will be enhanced. The images resulting from applying the first set of convolution masks to the original test image (figure 4 (*a*)) are shown in figures 4 (*b*), (*c*), (*d*), (*e*). A comparison of the original image with the filtered image clearly shows enhanced small sand dune ridges on top of the large dome dunes. Also, the narrow sand dune arms in the inter-dune area are more pronounced in the filtered images than in the original image. Thus it can be seen from these images that a variation in the band width of the DOG filter can be employed to select the scale range of the textural features to be enhanced.

In the second set of filters, the band width was shifted gradually from higher to lower frequencies (1·0–1·5 pixels to 2·5–3·0 pixels). The DOG masks used here were created by using standard deviation values of 1·0–1·5 pixels, 1·5–2·0 pixels, 2·0–2·5 pixels, and 2·5–3·0 pixels which correspond to feature sizes of widths 60–90 m, 90–120 m, 120–150 m, and 150–180 m respectively. The images resulting from applying the convolution masks of the original test image (figure 4 (*a*)) are shown in figures 5 (*a*), (*b*), (*c*), (*d*). These figures show only sand dune ridges and other textural features which matched specific sizes of 60–90 m, 90–120 m, 120–150 m and 150–180 m of the corresponding filters. All the textural features outside the allowed size by the filter have been suppressed. Hence, by an appropriate choice of standard deviation values it is possible to construct DOG masks for the enhancement of textural features of specific sizes.

4. Conclusion

The textural enhancement provided by the DOG filters in the sand fields reveals fine details of composition and structure of dunes and inter-dune areas which are not normally visible on the Landsat images. The filters allow the flexibility of size and range of textural features to be incorporated into the filter design. A prior knowledge of the texture features to be enhanced greatly facilitates selection of standard deviation values for optimum texture enhancement.

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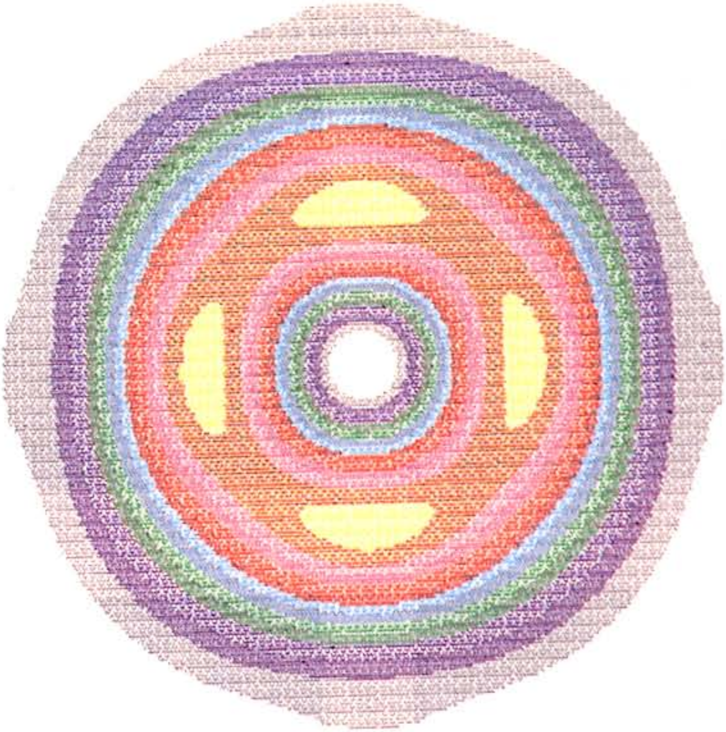
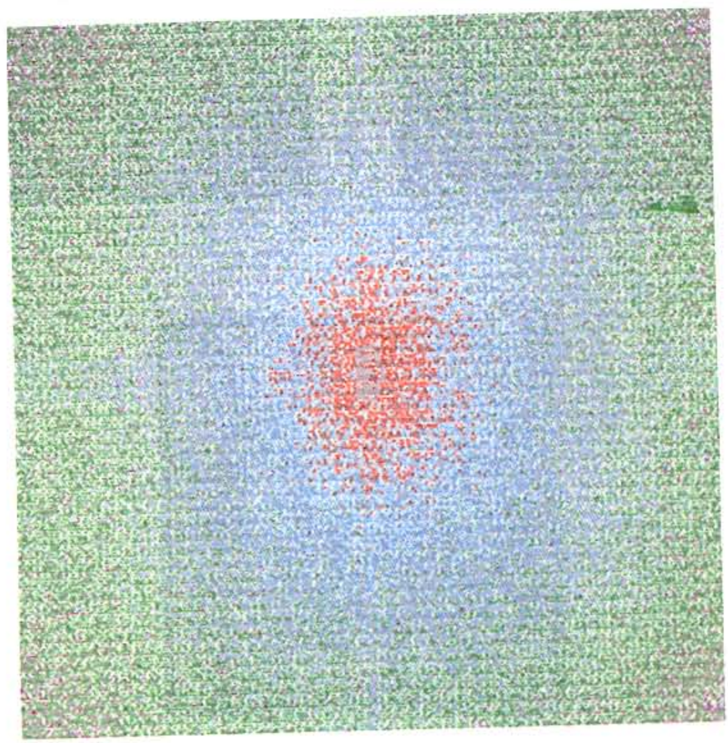


(a)



(b)

Figure 3. (a) DOG 7 × 7 frequency response ($\sigma = 1{\cdot}0$–$1{\cdot}5$ pixels). (b) Frequency spectrum of the test image.

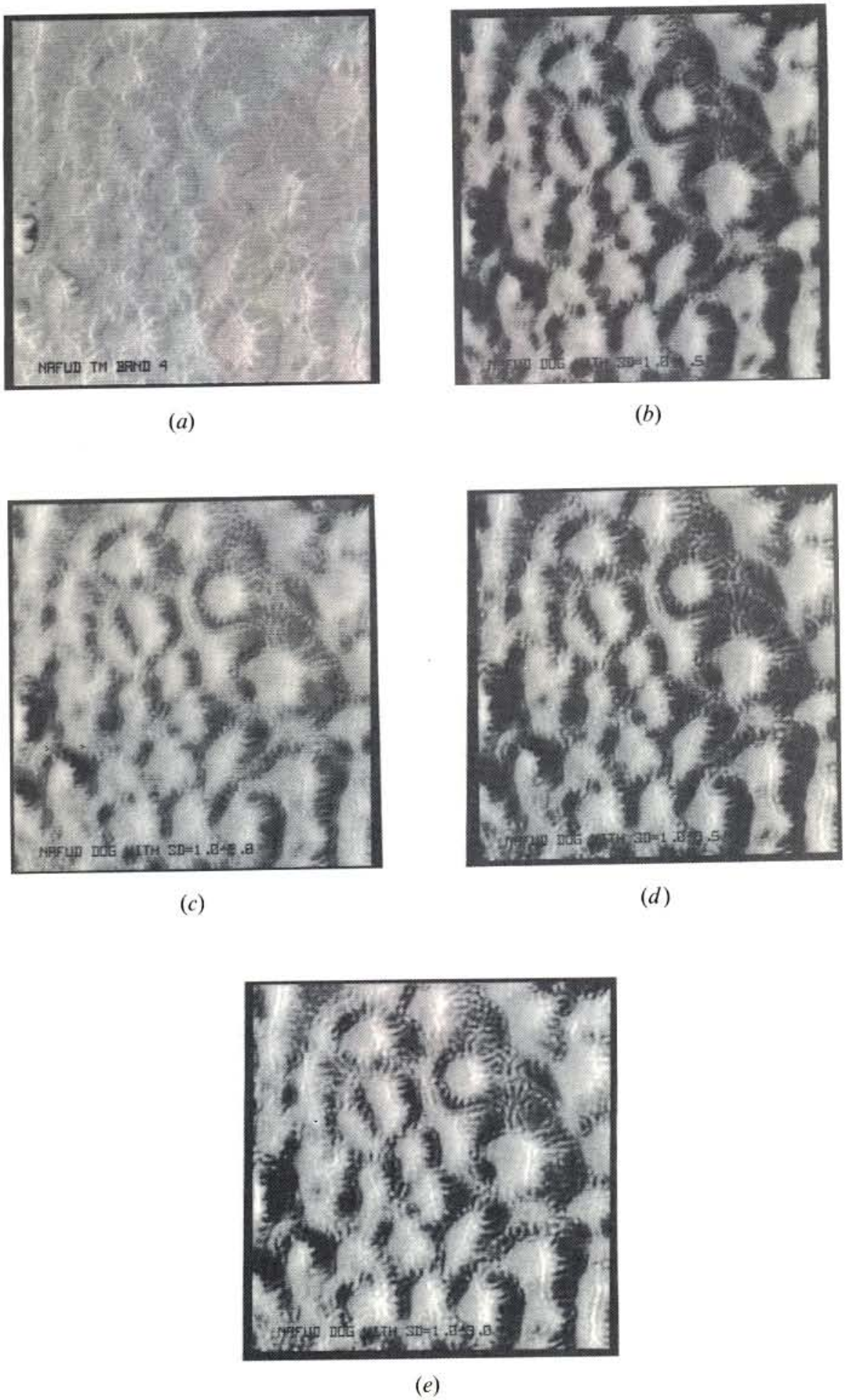
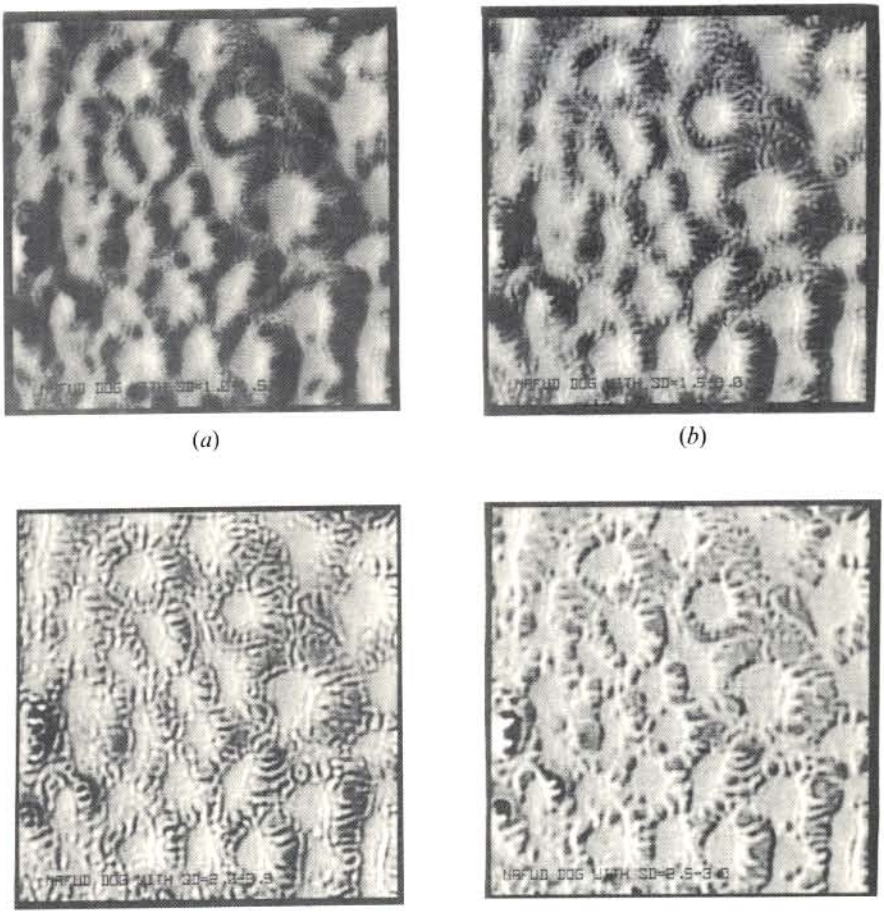


Figure 4. (*a*) Original image; DOG 7 × 7 mask filtered images. (*b*) $\sigma = 1{\cdot}0$–$1{\cdot}5$; (*c*) $\sigma = 1{\cdot}0$–$2{\cdot}0$; (*d*) $\sigma = 1{\cdot}0$–$2{\cdot}5$; and (*e*) $\sigma = 1{\cdot}0$–$3{\cdot}0$.



(*a*) (*b*)

(*c*) (*d*)

Figure 5. DOG filtered images with 7×7 masks. (*a*) $\sigma = 1{\cdot}0$–$1{\cdot}5$; (*b*) $\sigma = 1{\cdot}5$–$2{\cdot}0$; (*c*) $\sigma = 2{\cdot}0$–$2{\cdot}5$; and (*d*) $\sigma = 2{\cdot}5$–$3{\cdot}0$.

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