Journal of Microscopy, Vol. 146, *Pt* 2, *May* 1987, *pp.* 191–200.
Received 30 *July* 1986; *revised* 15 *October* 1986; *accepted* 17 *December* 1986

Two-dimensional top hat filter for extracting spots and spheres from digital images

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KEY WORDS. Top hat filter, gated filter, digital image processing, pattern recognition, spot extraction, particle location, background elimination, dynamic threshold setting.

SUMMARY

The top hat filter is a computer algorithm that extracts small, compact or rounded objects from digital images. Examples show application of the filter to micrographs and electron diffraction patterns.

I. INTRODUCTION

In our chemical analysis programme, we often have images with distinct small objects that need to be characterized. Often these objects are superimposed on a background that interferes with the analysis. The background might consist of a widely varying smooth background intensity or a larger object such as a fibre or the shadow of a beam stop.

We have found the top hat filter, described below, to be useful for isolating small round objects from images, as a first stage in the automated analysis of the images. One typical example is in electron diffraction analysis, where the locations of the diffraction spots are of interest. Due to the widely varying background intensity, and the presence of the beam stop, the diffraction spots are not the brightest or largest objects in the image. The filter discriminates the spots by their round shape and by predetermined information about their intensity and size. A second typical example is an image of dust particles and asbestos fibres, where this time it is the fibres that are of interest. The filter selects the dirt particles which can then be removed from the image.

II. DESCRIPTION OF FILTER

The top hat filter described here is a two-dimensional gated filter (Rosenfeld, 1984) which is like a dynamic threshold setting operation (Hsing, 1984) rather than like the convolution operations in the literature referred to by the name 'top hat' (McCarthy & Schamber, 1981; Burch, 1984) or the image transformation from mathematical morphology, which is also referred to by the name 'top hat' (Cornelisse *et al.*, 1985) or 'top-hat' (Meyer, 1977, 1986; Serra, 1982); this latter transformation selects extended objects with sufficiently narrow parts, rather than compact objects as does the top hat filter. Image analysis algorithms often require selection of regions of interest by setting thresholds on continuous grey-level images. The threshold setting operation uses an intensity range to select all of the

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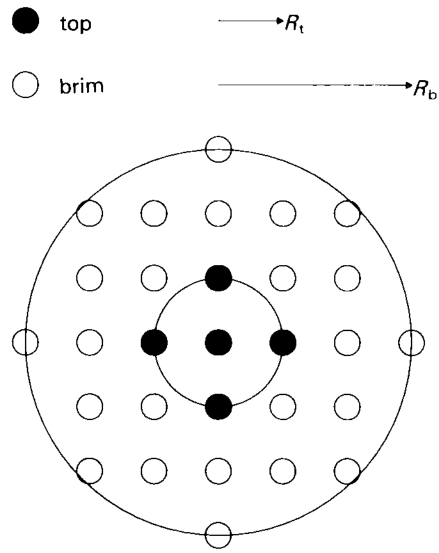

Fig. 1. Schematic depiction of a typical top hat mask. Dots: centres of 'top' pixels, small circles: centres of 'brim' pixels (see text). The actual pixels (not shown) are displayed on our equipment as squares centred on the dots and small circles. R_t and R_b are respectively the top radius and brim radius (pixel units).

pixels in an image whose intensities fall within that range. Many thresholds that are currently used in microscopy are like this in that they are held constant regardless of any variation in background intensity. These constant thresholds can lose needed information or add undesirable artefacts when the background intensity varies. On the other hand, a dynamic threshold setting operation varies the thresholds according to locally averaged intensity values. The top hat filter is an example of this dynamic thresholding where the intensity range for the filter is determined for each pixel from a set of nearby pixels as described below.

Consider a pixel at location (x, y), centered on a mask of two concentric circles (Fig. 1). The large inner circle corresponds to the top of the top hat and the large outer circle corresponds to the brim. A pixel is included in the top or brim if its centre is within that region.

To select spots from an image, the radius of the top, R_t, is set to the maximum expected spot radius, R_s. The radius of the brim, R_b, includes a suitable neighbourhood surrounding the spot, often determined by the shortest expected distance to a neighbouring spot. The height, H, of the top above the brim is set to the minimum intensity that a spot must rise above its immediate background.

The above operations are repeated for each pixel in the image, less a border with a width equal to the radius of the brim, R_b. For this border, some top or brim pixels are lacking. This border is not defined, and thus set to zero in the filtered image.

A pixel in the filtered image at (x, y) is given the value of the pixel at (x, y) in the original image, if the maximum of the top pixels (see Fig. 1) is H intensity units or greater than the maximum of the brim pixels. Otherwise, the pixel in the filtered image is given the value zero. The parameters of a one-dimensional, continuous (rather than discrete) analogue of such a filter are given in Fig. 2(a). Example responses are illustrated in Fig. 2(b). Some signal is passed by the filter in the second and third examples, where the intensity (ordinate) of the signal is great enough to extend past the top of the top hat and is also small enough on either side of that position to be below the brim of the top hat. The top hat can be

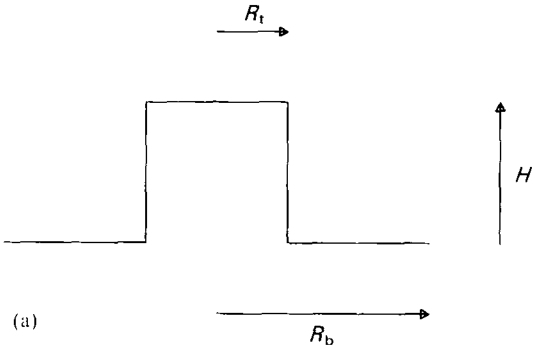

Fig. 2(a). One-dimensional (cross section of the) top hat filter. R_t, R_b and H are respectively the top radius, brim radius (pixel units) and height (intensity units) of the top hat.

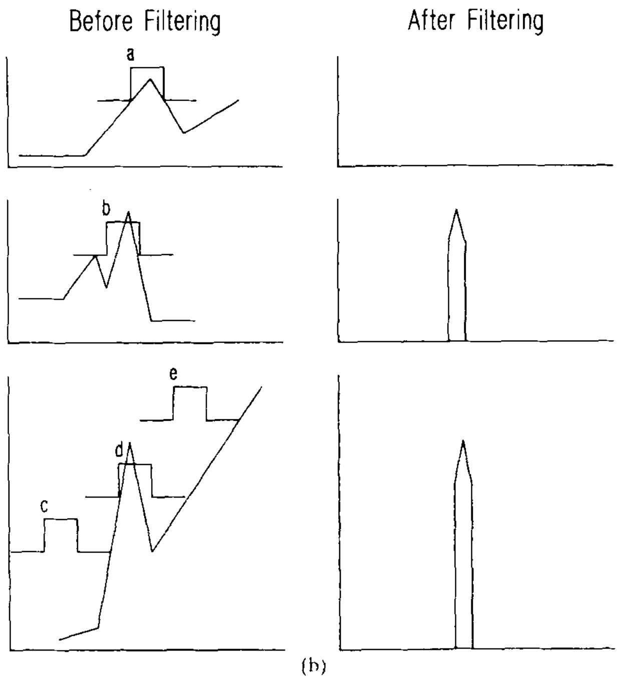

Fig. 2(b). One-dimensional, continuous, schematic analogues to illustrate the action of the top hat filter. Ordinate represents intensity, and abscissa, position or distance in pixels: (a) no signal passed; (b) part of second peak passed—it penetrates the top of the top hat; (c) and (e) large primary peak (only the side shown) not passed; (d) part of secondary peak passed.

thought of as sliding along on top of the signal with the brim just touching it, usually at one point. Several illustrative positions for the top hat are shown as a–e in the left column of the figure.

III. RESULTS

There are many possible applications for the top hat filter. The filter was initially created to overcome problems in finding the locations of maxima (spots) on electron

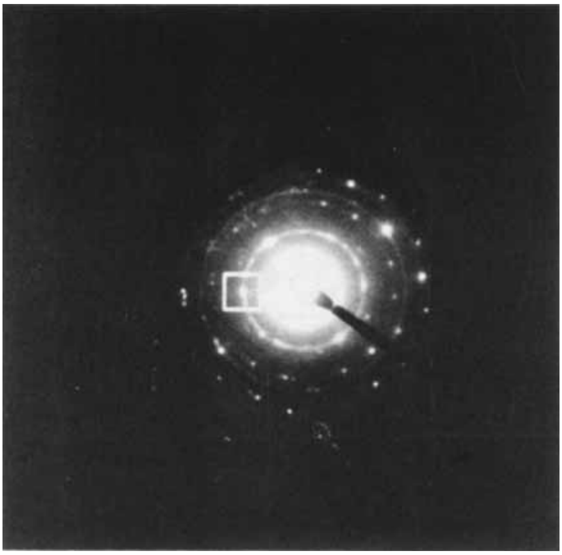

Fig. 3. Example image–electron diffraction pattern with the desired spots along with the undesired features: beam stop, centre beam spot, diffuse background and diffraction rings.

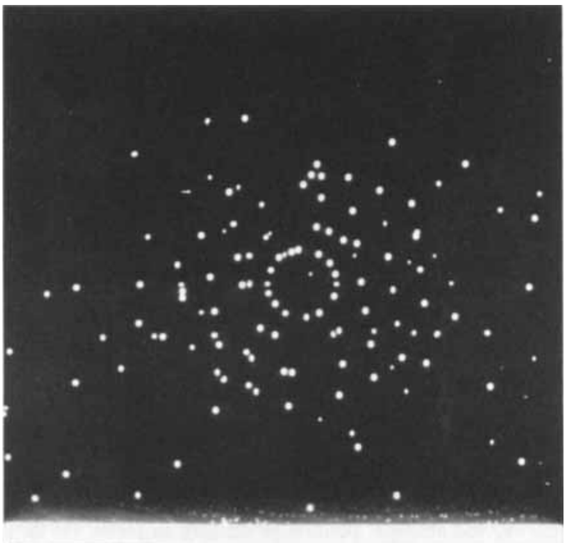

Fig. 4. Result of applying top hat filter to image in Fig. 3, with all spots artifically brightened for display.

diffraction patterns taken with a transmission electron microscope. The electron diffraction patterns of particles are often complex, with spots, rings, a beam stop shadow, and a broad background of diffuse scattering. No simple static threshold can find the discrete maxima or 'spots' on this dynamic background, but the top hat filter successfully isolates the spots.

The top hat filter is sensitive to both size and brightness, but reasonable parameters can be selected for the filter to find most diffraction maxima in such images as discussed below.

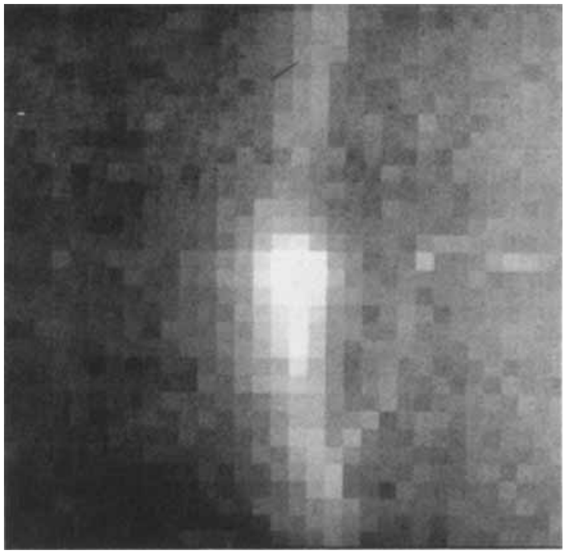

Fig. 5. Single spot magnified. The mask in Fig. 1 is appropriate for this spot.

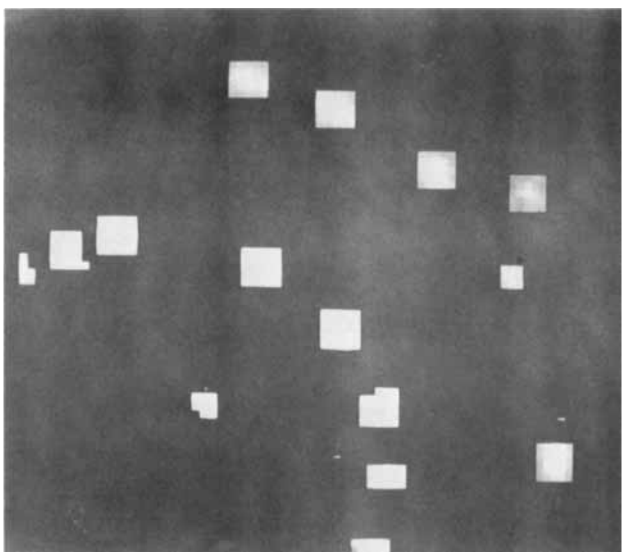

Fig. 6. Magnified area of top hat filtered image in Fig. 3 showing how the filter selects areas of the images with the desired features and leaves the original intensity information of these areas unchanged.

Figure 3, a 512×512×8 bits per pixel image, is an electron diffraction pattern with small spots of uniform size, and with several unwanted features. The centre locations of the spots was easily obtained from the top hat filtered 512×512 pixel image shown in Fig. 4, where all the selected pixels have been shown at full intensity for display. Figure 5 is an expanded view of one of the spots where each pixel can be discerned as a square of uniform intensity. The filter mask in Fig. 1 is appropriate for such a spot, as both the spot and the

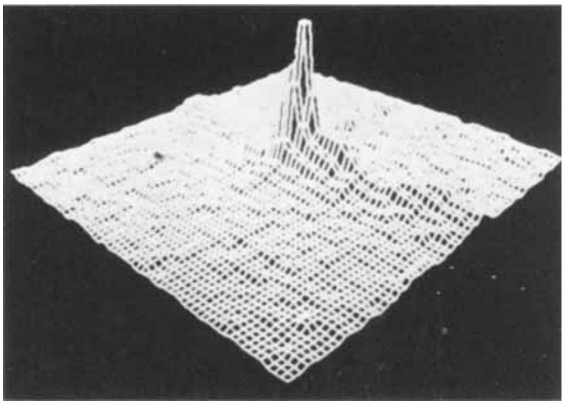

Fig. 7. Mesh plot of Fig. 6; intensity is displayed as height. A part of a ring is superimposed on the spot. The top hat filter selects the spot from the ring.

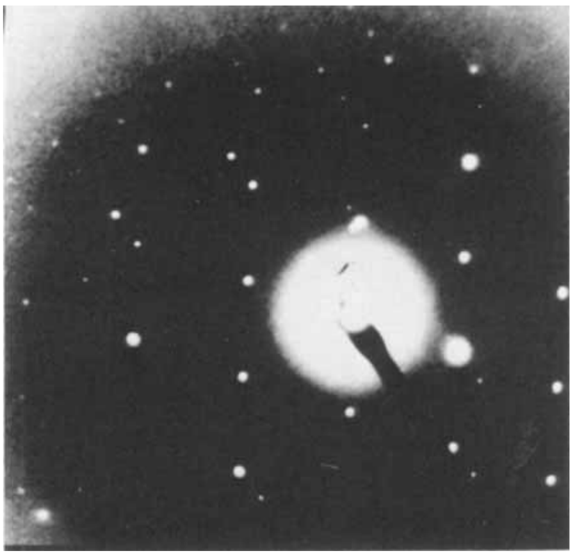

Fig. 8. Example image of another electron diffraction pattern with much larger spots.

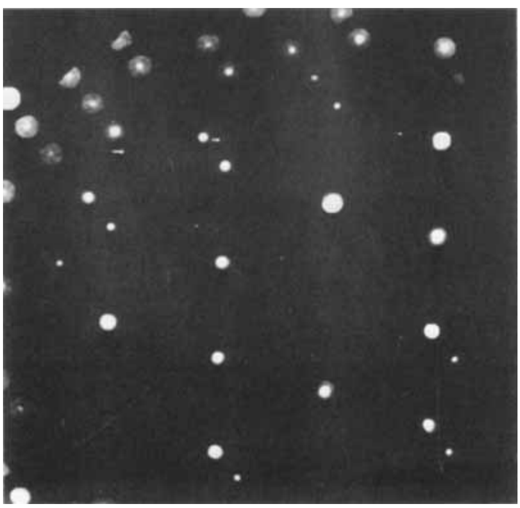

Fig. 9. Result of applying top hat filter to Fig. 8. Spots are selected.

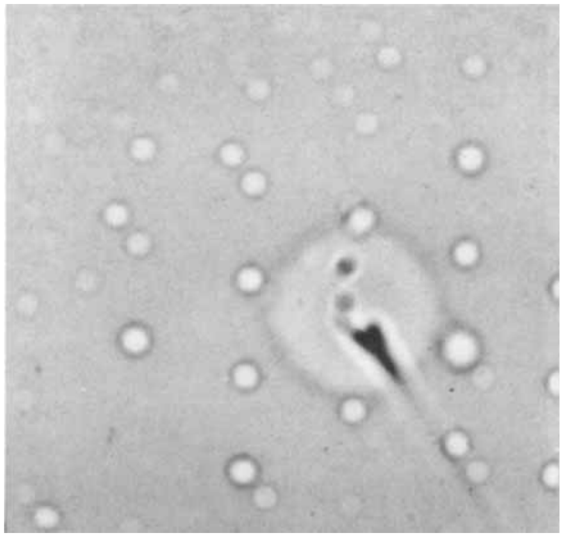

Fig. 10. Result of applying a mask filter, i.e. of convolving the image with a kernel similar in shape to that in Fig. 1, where the top (values are +1) is set to the size of the larger spots and the brim (values are −1) is set to have an equal number of pixels as the top. Spots are brightened but not selected.

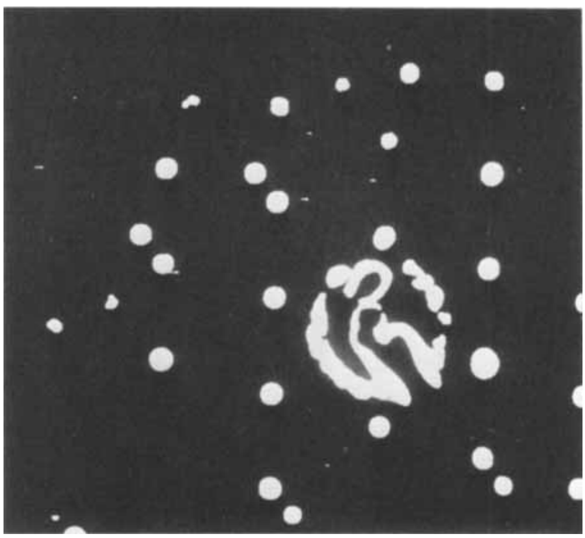

Fig. 11. Same image as in Fig. 10 but with the threshold set in an attempt to select the spots. Extraneous features are evident that are not present in Fig. 9.

top of the top hat mask have widths of about three pixels. Figure 6 is an expanded view of the filtered image showing in more detail how the filter behaves. The square or irregular shapes of the set of passed pixels in the neighbourhood of each spot do not noticeably degrade the determination of the spot centres because the spots are particularly bright, as shown by the mesh plot of intensity versus position for a single spot in Fig. 7, and because the centres are averaged pixel positions, weighted by intensity. Also, due to the bright and

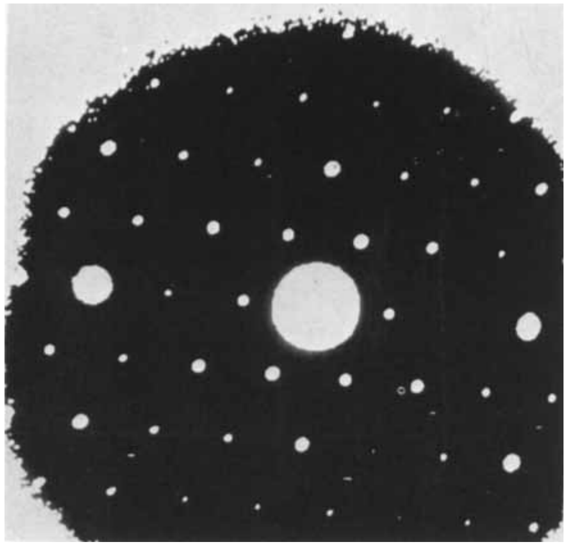

Fig. 12. Another diffraction pattern with the threshold set in an attempt to select the spots. Some spots are very small at this threshold, and the background is still present.

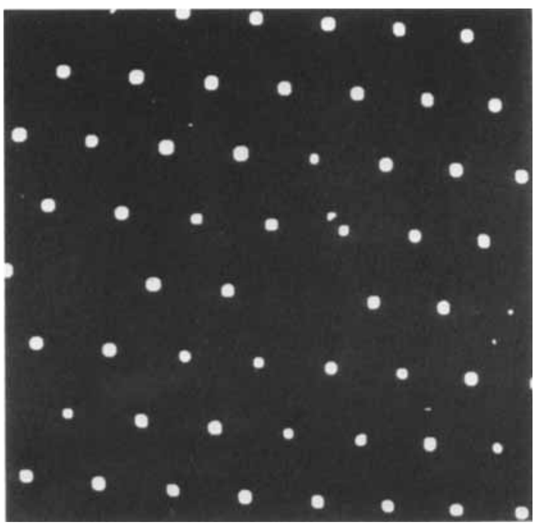

Fig. 13. Top hat filtered version of the diffraction pattern of Fig. 12, again with the threshold set for display to show even the dimmer spots.

narrow nature of the spots shown in this figure, the choice of H for this type of image is not critical.

Figure 8 shows an electron diffraction pattern with larger spots of varying size and with a background of more uniform intensity. The tophat filter, with a mask adjusted for the larger spots, selects the spots as shown in Fig. 9. Ordinary mask filtering, or convolution (Pratt, 1978; Rosenfeld & Kak, 1982) to cross correlate the image with a mask the shape of the larger spot, does not select the spots. The result of the convolution is shown in Fig. 10, and an attempt to select the spots from Fig. 10 by setting the threshold is shown in Fig. 11. All of the images here and following are 512×512×8 bit images.

Figure 12 is another example of an electron diffraction pattern with the threshold set to select some of the spots. However, some spots are missing, the background with a very noisy edge is present, and there are three spots that are too large to have confidence in the determination of their centre locations. Figure 13 shows the top hat filtered result, which has only the desired smaller diffraction spots. The threshold in Fig. 13 has again been set for display purposes to show even the dimmer spots.

While the top hat filter was initially designed for use on electron diffraction patterns, it can be used on any image where one wants to find compact or rounded objects. An example

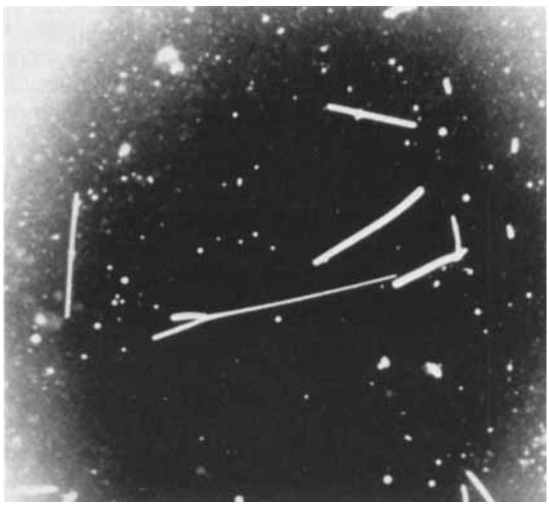

Fig. 14. Example of a transmission light micrograph of spheres mixed with fibres.

Fig. 15. Spheres in Fig. 14 selected and isolated from the fibres with the top hat filter.

of this is shown in Fig. 14. Particle or grain mounts viewed on the light microscope often have many fine particles that are at or below the resolution of the objective. These particles often appear round and have enough contrast to allow them to be found by the top hat filter. Once identified, these particles can then be counted or eliminated as desired.

Figure 14 shows an image with prominent fibres, with smaller spheres which appear as small dots, and with uneven background illumination. Here, a count of the spheres was desired. Figure 15 shows the selected spheres, from which the computer can generate the count.

IV. CONCLUSION

The top hat filter is useful in a variety of applications where it is desired to select small rounded objects from digital images on the basis of their size, their intensity above the local background and the assumption that they are rounded or compact. the top hat filter can give satisfactory results under some conditions where mask filtering or static threshold setting do not. The three filter parameters define the size of the objects being extracted from the image—the filter does not automatically adjust to the size of the objects. A method for extracting objects that does not depend object size or shape and that is different from the above-mentioned top hat transformation will be described in a forthcoming paper.

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