GREY-SCALE MORPHOLOGY APPLIED TO SHOEPRINT DETECTION

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Abstract: In a previous paper (Snailum 2005) a method was presented which extracted a low contrast thermal human footprint from its surroundings using a novel operator. The morphological operation of dilation was demonstrated using a binary image. In this paper, greyscale images are employed with the dilation erosion and closing operations. Various structuring elements were tested. The best performance was obtained using a diagonal cross operator.

1. Introduction

Mathematical morphology, born in 1964, deals with sets in Euclidean spaces and considers functions defined in an n-dimensional space as sets of dimension n + 1. After digitisation, a Euclidean framework is maintained, which allows the structure of objects to be investigated by transforming the sets that model them, (Serra, 1984).
The usage of footprints has been a standard forensic tool almost as long as man has inflicted evil on his neighbour. Modern science may be used to further increase the toolbox of the detective using tread pattern, wear pattern and dynamic pressure pattern analysis (de Chazal, 2005, Hannah 1992). It was shown that the main portion of a shoeprint could be retrieved using binary morphology, i.e. a flat structuring element operating on a binary image, (Snailum, 2005). Binary images are most often produced by applying a threshold to a grey-scale image, which may be derived from the thermal imager, but this process is wasteful of information. Necessarily information is thrown away when the image is reduced from 8-bit grey-scale to 1-bit binary, and the information that remains depends heavily on the (sometimes arbitrary, and often heuristic) choice of threshold. The main reason for the extensive usage of binary images is that they are simple and fast to process, but as the speed of computers increases, more complex operations can be contemplated. It is for these reasons that the present work has used grey-scale morphology.

2. Shoeprint image model

The type of shoeprint image under investigation is shown in Figure 1(a) and is of particular interest as it is formed by a dual material sole. In this image (white indicates hot, and black cold), it is apparent that the outside front of the shoeprint is colder than the background while the remainder is warmer than the background. The reason for this is found in the materials used for the sole; leather around the perimeter of the sole gets damp with perspiration, cools, and absorbs energy from the floor in contact with it. It is noted that although the leather is continuous, the image shows two areas of energy transfer with a distinct ‘gap’ in the centre where no transfer occurs. This is thought to be the resultant of two additive effects: the position of the foot within the shoe, and the short duration of contact of that area with the floor. The rubber on the inside and heel is warmed by the foot and transfers energy to the floor where it is in contact. Figure 1(c) shows the area used by the program to calculate the average background grey-level, with its resolution reduced to 16 colours. By inverting all the grey levels below this, an ‘absolute’ image was produced as shown in Figure 1(b). The white rectangle top left is a control. The production of the absolute image is further illustrated in Figures 2(a) and (b).

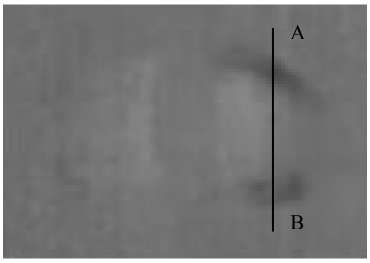

Figure 1(a) Original image

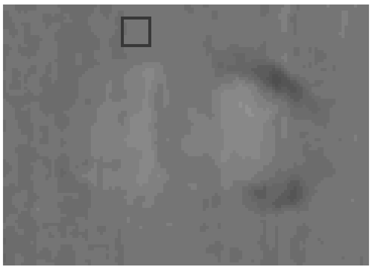

Figure 1(c) Background level used for absolute calculations

3. Morphological operators

The morphological operations of dilation and erosion are defined in equations (1) and (2) respectively. The closing operation is achieved by dilation followed by erosion, as shown in equation (3), (Gonzalez, 2002).

$$A \oplus B = \left\{ z \middle| \left(\hat{B}\right)_z \cap A \neq \varnothing \right\} \qquad (1)$$

$$A \Theta B = \left\{ z \middle| \left(B\right)_z \subseteq A \right\} \qquad (2)$$

$$A \bullet B = (A \oplus B)\, \Theta\, B \qquad (3)$$

Where: A is the image,
B is the structuring element, and
$\varnothing$ is the empty set

Dilation tends to make white foreground objects larger and black ones smaller, while erosion tends to make black foreground objects larger.

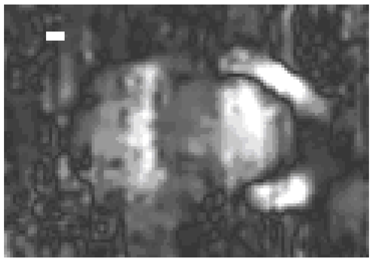

Figure 1(b) Absolute image

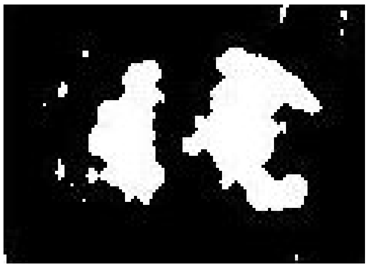

Figure 1(d) Previous resultant image using binary dilation

It is noted that the definition of the dilation operation contains the element $\hat{B}$ which reflects the structuring element about its origin in a manner similar to that used in convolution. This is not apparent unless the structuring element is non-symmetrical as for the example in Figure 4(a).

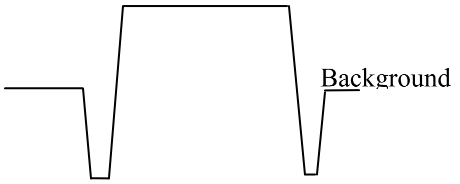

Figure 2(a) Shoeprint profile A-B

Figure 2(b) Absolute Shoeprint profile A-B

4. Applying a grey-scale operator

Previously a binary image had been obtained by applying two thresholds to the greyscale image in order to obtain those areas 1) hotter and 2) cooler than the background. The values of the thresholds themselves were found by observation of the image grey-value histogram. An attempt was made to join up the resulting disparate blobs using a binary dilation operator. Though partially successful, the resultant image (shown in Figure 1d) contained artefacts of the processing and therefore defeated the purpose, (Snailum 2005). In this further study, use has been made of grey-level morphology in an attempt to avoid throwing away information by applying thresholds and thus causing the problem mentioned.
The image is considered to be an x-y plane with a topology in 3D given by the grey level at each coordinate. One grey-scale dilation operator is known as a 'ball', which applies a spherical structuring element of a given radius to each coordinate of the image. To picture its operation, the ball is lowered onto the 3D structure until prevented from going further by the image topology. The centre of the ball at this point is the new grey value at that coordinate. It is apparent that the larger the ball radius, the more obstructed it will be by the topology, and thus produce more dilation. The result of such an operation with a 10-pixel radius ball is shown in Figure 3, and again shows artefacts of the process. (The image is 85x120 pixels.)

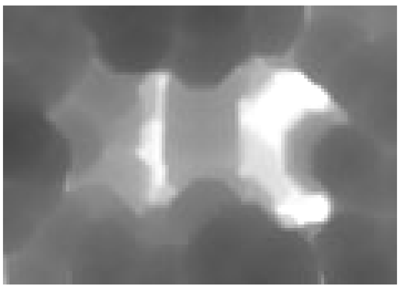

Figure 3 Dilated using 10-pixel radius ball

Various shaped structuring elements were tested to find the optimal solution, i.e. as clear an imprint as possible, without introducing noise.
Matlab allows the shape of a structuring element to be specified by an array. Both unidirectional and omnidirectional operators may therefore be devised as shown in Figures 4(a) and (b).

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0
0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	1

Figure 4(a) 'South East' diagonal structuring element

1	0	0	0	0	0	0	0	1
0	1	0	0	0	0	0	1	0
0	0	1	0	0	0	1	0	0
0	0	0	1	0	1	0	0	0
0	0	0	0	1	0	0	0	0
0	0	0	1	0	1	0	0	0
0	0	1	0	0	0	1	0	0
0	1	0	0	0	0	0	1	0
1	0	0	0	0	0	0	0	1

Figure 4(b) Diagonal cross structuring element

There are four structuring elements similar to the one shown in Figure 4(a), each dilating in a different diagonal direction. These operators performed satisfactorily, but did not provide a completed result unless used in sequence. Combining the four operators into a single structuring element, shown in Figure 4(b), provided the best performance. The results of the processing are shown in Figures 5(a) to (d). The absolute image is repeated again for convenience in Figure 5(a). The image dilated by the diagonal cross structuring element is shown in Figure 5(b); the image closed by the same structuring element is shown in Figure 5(c), and finally the closed image is shown smoothed with a linear 3x3 filter. Although there are artefacts of the processing present, they are not considered troublesome, and the structure of the shoeprint is more readily apparent than in the original or the absolute image.

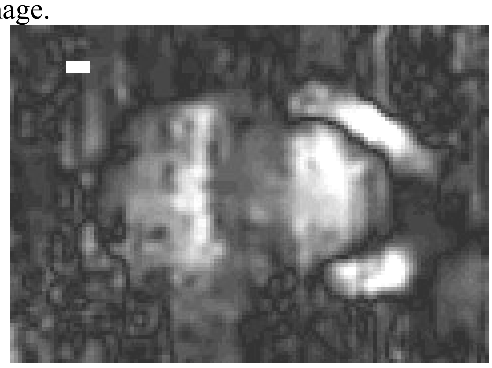

Figure 5(a) Absolute image

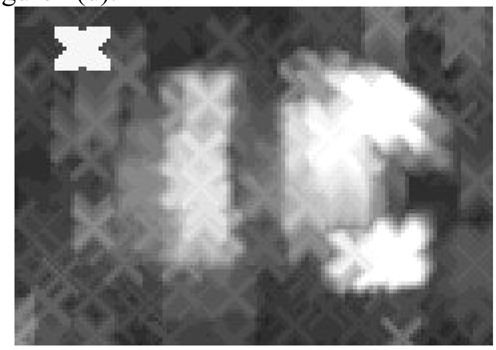

Figure 5(b) Dilated image

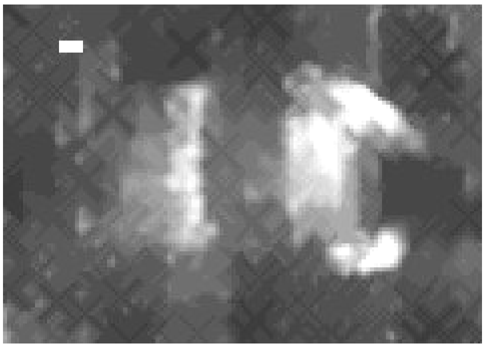

Figure 5(c) Closed image

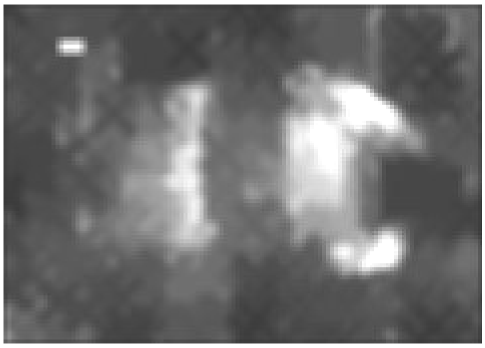

Figure 5(d) Closed and smoothed image

5. Conclusion

The method of extracting footprints from low-contrast thermal images presented in a previous paper (Snailum 2005) used primarily morphological operations on binary images. This involves two heuristic thresholds, and thus discards much of the information in the image: although quick to process, it is not ideal. The work presented in this paper avoided discarding information by applying similar techniques to greyscale images. Additionally, several structuring elements were tested to determine the one with the best performance, which was found to be the diagonal cross. Although there are artefacts of the processing in evidence, they are not considered to be problematic as the underlying structure of the shoeprint may clearly be observed. The resultant image after closing with the diagonal cross and smoothing is shown in Figure 5(d), and may be contrasted with the result of binary morphology shown in Figure 1(d).

6. References

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