Segmentation and Noise Removal on Thermographic Images of Hands

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SUMMARY

Hands are physiologically those parts of the body (together with the feet) where body radiant heat loss is highest. The temperature of the hands may be very close to the environmantal temperature and therefore may be difficult to be separated from the background in the infrared images. From all parts of the body, hands are most complex in shape and therefore difficult to segment. A correct outline, however, is needed for studying certain diseases such as arthritis, neuromusculoskeletal injuries or circulatory pathology by thermal imaging. Manual segmentation is possible but time consuming and inaccurate to reproduce.

The aim of this study was to investigate which of the many automatic edge detection algorithms known from literature produce the best performance in such low contrast thermal images. Additionally, the effect of pixel noise on this process is analysed by using a homomorphic filter prior to edge detection. This filter is appropriate because it allows pixel noise produced by the imaging system to be modelled as an additive term to the original image.

Two analyses are performed, a visual (subjective) and a quantitative (objective) for the extracted edges. Both assessment methods conclude that the best outlining results are achieved when using a probabilistic (Canny and Shen-Castan) edge detector together with homomorphic noise filter pre-processing.

KEY WORDS: Edge detection, hands, noise reduction, outline, segmentation, thermal image

SEGMENTIERUNG UND RAUSCHUNTERDRÜCKUNG IN WÄRMEBILDERN VON HÄNDEN

Physiologisch gesehen sind die Hände gemeinsam mit den Füßen die Körperteile mit dem höchsten Anteil der Abgabe von Strahlungswärme. Die Handtemperatur kann sehr nahe an der Umgebungstemperatur liegen und deswegen kann in Wärmebildern die Abgrenzung der Hände vom Hintergrund schwierig sein. Darüber hinaus gehört Form der die Hände zu den am meisten komplexen Körperteilen und deshalb ist die Segmentierung dieser Form besonders schwierig. Allerdings ist eine korrekte Umrisslinie notwendig um Krankeiten wie Gelenkentzündung, neuromuskluläre Verletzungen oder Durchblutungsstörungen mittels Thermographie zu untersuchen. Die Segmentierung von Hand ist zwar möglich, allerdings Zeit aufwändig und wenig zuverlässig.

Das Ziel der Studie war es zu untersuchen welche der zahlreichen Algorithmen in der Literatur zur Kantendedektierung von kontrastarem Wärmebildern die bestern Ergebnisse liefert. Außerdem, wurde der Einfluss des Rauschens der Pixel auf die Kantendedektierung analysiert, indem vor der Kantenentdeckung ein homomorphes Filter eingesetzt worden war. Eine solche Filterung erscheint geeignet, da es aus dem Pixelrauschen des bildgebenden Systems eine zusätzliche Eigenschaft des Originalbildes generiert.

Für die Kantendedektierung wurden eine visuelle (subjektive) und eine quantitative (objektive) Analyse durchgeführt. Beide Analysen kamen zu dem Ergebnis, dass die beste Umrissbestimmung der Hände in Wärmebildern mit dem probabilistischen (Canny and Shen-Castan) Algorithmus zur Kantendedektion nach Vorbearbeitung mit einem homomorphen Rauschfilter erzielt werden kann.

SCHLÜSSELWÖRTER: Kantendedektierung, Hände, Rauschunterdrückung, Umriss, Segmentierung, Wärmebild

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Introduction

The technique of infrared thermal imaging to measure temperatures, is an increasingly reliable clinical me thod for analysing vascular, neurological and musculoskeletal syndromes that affect hands and wrists (1). Hands, like feet, are the body areas where heat transfer with the environment occurs most frequently and effectively.

This in turn influences the boundaries of these extremities in thermal images, making them often difficult to detect as they may assume temperatures close to those of the environment. It is, however, necessary to have an accurate edge definition in each image so that the analysis of the thermal image neither includes any pixels belonging to the background or the environment nor excludes any parts actually belonging to the body.

Some authors suggest the use of Artificial Intelligence methods such as neural networks, genetic algorithms or edge maps to solve this problem (2, 3, 4). In practice, these techniques are computational intensive, time consuming, complex and often associated with a high probability of error.

Our approach consists of testing which of the currently existing and well documented traditional edge detection techniques for digital images is best suited for the demands of medical thermal imaging.

A second important aspect of thermal images is the presence of noise at a level of up to 5% of the dynamic signal range which is a result of the underlying sensor technology. It is therefore a second objective of this work to verify the hypothesis that noise pre-processing by a conservative noise reduction filter can improve boundary detection. It is thought that in this context one of the most appropriate filters should be the Homomorphic filter. It allows noise to be modelled as an additive term to the original image data (5) which is a close approximation of the physical processes inside the thermal camera sensor and electronics. Eleven classical edge detection techniques were selected and divided into five groups according to their underlying principle. The filters are:

-Gradient based (Roberts, Sobel, Prewitt and Kirsch);

-Second order difference based (Laplacian, Laplacian of Gauss, Marr-Hildreth);

-Probability based (Canny, Shen-Castan);

-Segmentation based (Watershed);

-Contour following based (Snakes).

The gradient based algorithms are the most simple ones. They detect both edges and their orientations, although they are sensitive to noise and due to their simplicity too inaccurate for certain applications.

Second order difference operators have fixed characteristics for all edge orientations. They find the correct place of edges and also test a wider area around the pixel than gradient based strategies. The disadvantages of these operators are their sensitivity to noise, multiple detection of the same edges, malfunctioning at corners/curves and problems in places where the grey level function varies.

Edge orientation detection is affected due to the properties of the Laplacian approach. Probabilistic methods have good localisation capabilities and response even in the presence of noise, they compute probability values for determining an error rate. Their major disadvantages are poor detection of zero crossings and the complexity of computations (6).

Segmentation based operators filter the objects boundaries and effectively remove some of the image noise, but they treat the image foreground and background asymmetrically (7). Contour following methods finally are able to reduce a second order problem to just one dimension and optimise locally. They are, however, relatively slow (8).

Material and Methods

The FLIR A40 (thermal) infrared camera with a resolution of 320x240 pixels, a measurement accuracy (bias, offset) of ±2°C and a precision (repeatability) of ±0.1°C was connected to a PC using the CTHERM software package developed at the Medical Imaging Research Unit and used to capture thermal images. (9).

The approach used was to follow a standard image capture protocol (10) for the collection of thermograms from the hands of volunteers. Repeatable positioning of the hands was achieved by overlaying standardised masks over the camera's life video output. This also allows to control the distance between hands and camera (11).

After capturing 35 images into a database the 5 thermograms with the poorest contrast between background and extremity were selected to be used as inputs to the edge detection and noise reduction algorithms. From the CTHERM software thermograms were exported as standard grayscale Bitmaps (BMP) for subsequent processing in Matlab™.

The selected Bitmap images were processed in two ways: the first using pre-process noise reduction filtering with a Matlab™ implementation of the Homomorphic filter followed by the edge detections, the second employed edge detection algorithms only without pre-processing.

All edge detection algorithms were implemented as Matlab™ scripts (12). The parameters used for defining the Homomorphic filter were: 'low filter' value equal to 0.1 and 'high filter' value equal to 1 in order to decrease the illumination contribution and increase the reflectance contribution. The value used for the 'delimiter' was 7.

The gradient based edge detectors had the usual automatic threshold based on the average grey-level of the image to

Figure 1
Original thermal image

Figure 2
Optimal Outline drawn manually

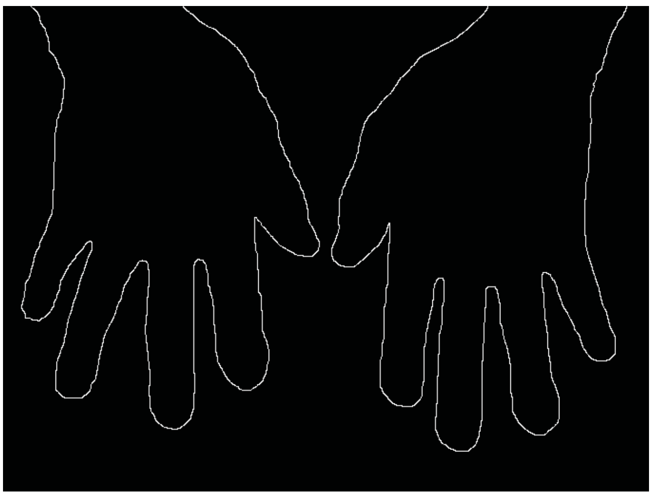
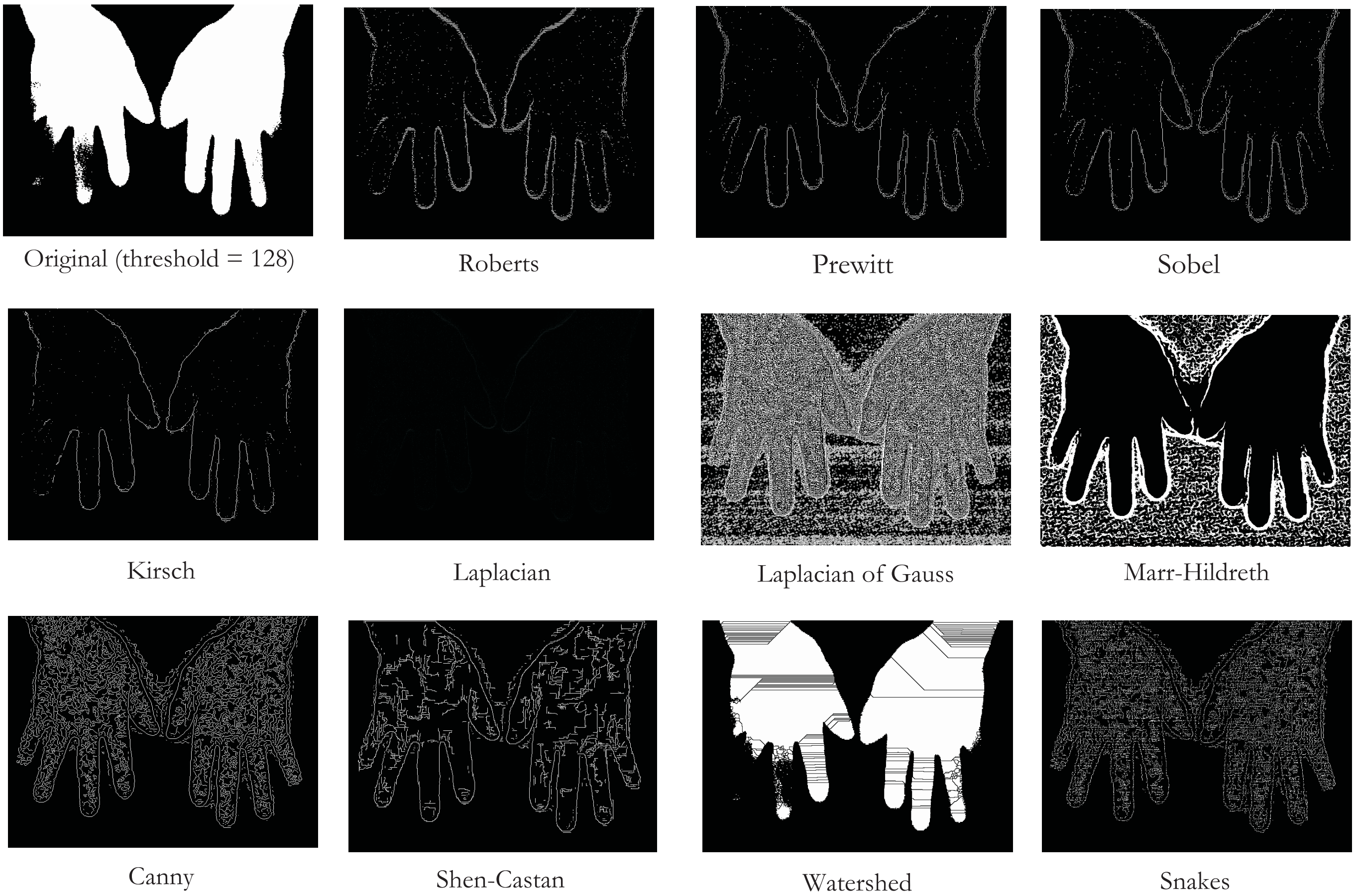


Table 1
Edge detection without noise pre-processing



maintain consistency for subsequent comparisons. Line thinning was applied and all detectors (with the exception of the Sobel one where the direction was rotated in multiples of 45º) used both horizontal and vertical directions of edge detection.

In the Laplacian filter the 'shape value' was set to 0.2, whereas the Laplacian of Gauss filter used an automatic threshold and a standard deviation value of 2. The Marr-Hildreth algorithm used a Gaussian kernel of size 11, a standard deviation value of 1 and the median of Gaussian was set to 0.

In the probability based operators, the Canny filter used automatic low and high thresholds and 6 as standard deviation preset. The Shen-Castan filter used 1 as the 'smoothing factor', 0 for the low and 3 for the high threshold value (chosen empirically). The watershed segmentation based edge algorithm used an automatic threshold calculated using the average image grey level together with an 8 pixel connected neighbourhood for each individual location. The parameters used for the Snake algorithm were 0 for the 'energy' contributed by the distance between control points, 0.1 as 'energy' contributed by the curvature of the snake and 1 pixel for each incremental move of the snake in order to reduce computation time. For the initial seeding outline the output of the Canny filter was used.

Two evaluation methods were used to compare and assess the edge detection algorithms and to verify any improvements as a result of noise filter pre-processing. In the first (subjective) method, 5 image processing professionals graded the edge detection algorithms on a 10 point scale. The algorithm with the cumulative smallest score was considered the best. If the images resultant from noise filter pre-processing obtained better scores than the ones without, the conclusion was that in this instance noise filtering enhanced the results of the respective outlining process. On occasions where the subjective judgement resulted in a draw a second review stage was used to arrive at a ranking.

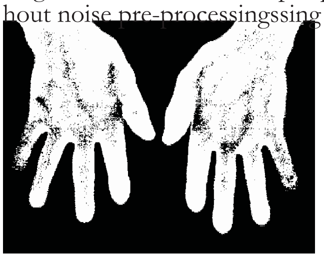
The second (quantitative) method is based on a reference outline that was produced in a graphics package under high magnification and aided by contrast enhancement techniques. The performance measure here is the total length of the outline (in pixels). The same quantitative method was used to assess noise filtering.

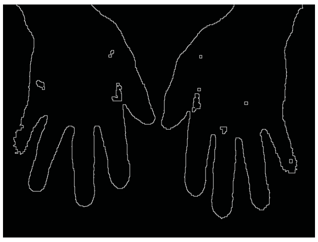
Results

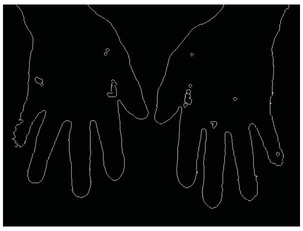
Figure 1 shows a typical input image selected from the database with poor edge to background contrast. Figure 2 shows the corresponding optimal outline drawn by hand.

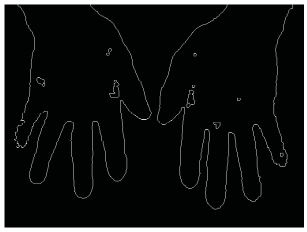
Table 1 shows the images resulting from the application of the edge detection algorithms without applying any noise

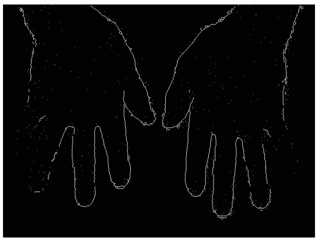
Table 2
Edge detection with noise pre-proceDifference between optimum edge length and algorithmically produced edges with and without noise pre-processingssing

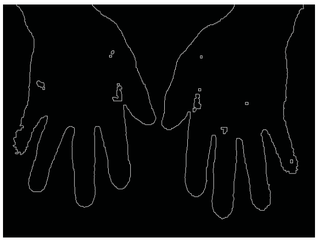

Original (threshold = 128)

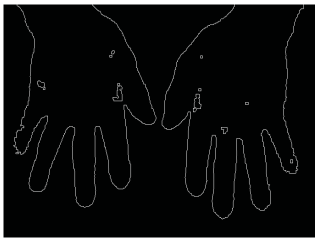

Roberts

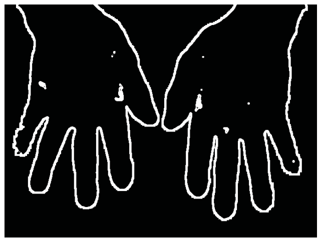

Prewitt

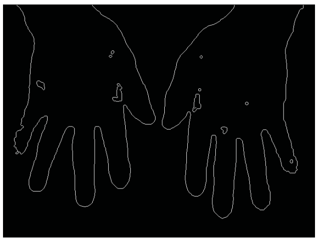

Sobel

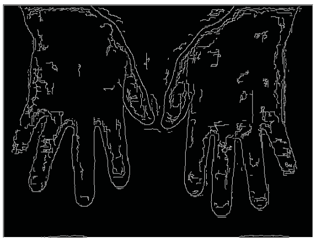

Kirsch

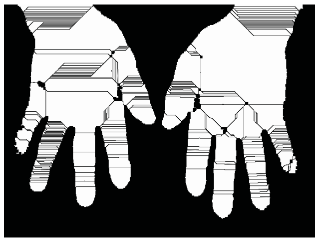

Laplacian

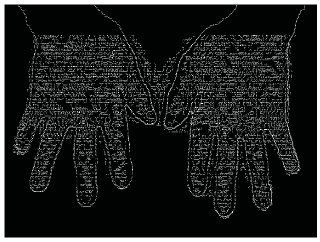

Laplacian of Gauss


Marr-Hildreth


Canny


Shen-Castan


Watershed


Snakes

reduction filtering. Subjective grading selected probabilistic methods and contour following methods as best performers.

Table 2 presents algorithm outputs with homomorphic pre-processing applied. According to the subjective grading scale the best output was produced by second order based methods, followed by gradient based methods (excluding the Kirsch algorithm and probabilistic methods). It can be observed that homomorphic filtering enhances the results for all algorithms.

Table 3
Comparison of the number of outline pixels

		Hand Images	
		Non-Filtered	Non-Filtered
Outlining Algorithms	Optimal	4562	4562
	Roberts	7217	5442
	Sobel	5989	4320
	Prewitt	5991	4224
	Kirsch	4007	4221
	Laplacian	15097	4630
	Laplacian of Gauss	122374	10838
	Marr-Hildreth	70199	24415
	Canny	29888	2804
	Shen-Castan	16853	16246
	Watershed	138456	150622
	Snakes	26428	22806

Table 3 lists the result of the objective classifying method on the average of the 5 selected thermograms, (i.e. the number of pixels that form the outline). The best edge detection algorithms when not using noise filtering are the classical gradient based methods (Roberts, Sobel, Prewit, Kirsch). When using pre-process noise filtering the best results are produced by the gradient based, probabilistic based and second order based methods (excluding Marr-Hildreth).

Figure 3 demonstrates the benefit of the homomorphic filter by plotting the line length percentage difference between the optimum edge and the output of the respective filters.

Discussion

The subjective performance evaluation method used human judgement. The number of characteristics that a human eye can reliably distinguish is, however, limited (13). For this study a combination of subjective and objective validation was therefore used. The number of pixels forming the outline was used as an objective comparison method as it is simple to compute and provides a single figure for grading results. It could be argued that the difference between the areas enclosed by the outlines would be a more suitable measure since it is these areas that are used for subsequent clinical analysis and this approach will thus be studied in future work.

The results of this work support previous studies that used other types of digital images (6, 13). It demonstrates that traditional techniques which are usually computationally inexpensive and thus fast and simple to implement can produce adequate if not superior results (2, 3, 4) to more complex recent approaches such as those based on artificial intelligence, edge maps or neural networks.

Conclusions

From this study it can be concluded:

1.Probability based and gradient based edge detection techniques are the most suitable methods to outline hands in medical thermal images.

2.The homomorphic filter enhances boundary detection by reducing noise and 'clearing up' previously undetectable constructive features that assist edge detection algorithms.

3.Some post-processing such as such as thinning, artifact removal, etc. is needed to improve the results.

The outcomes of this work are now used in an ongoing project that introduces template outlines in addition to the edge detection process in regions where contrast between background and extremity is low or non- existent and edge detection therefore fails completely. This approach is using anatomical control points (i.e. well defined points such as finger tips) to assist the alignment between the template outline and the outline produced by edge detection. Eventually this work will assist hand pathology studies, clinical 'cold stress' examinations and the production of an atlas of normal infrared medical images as a reference source for clinicians (14).

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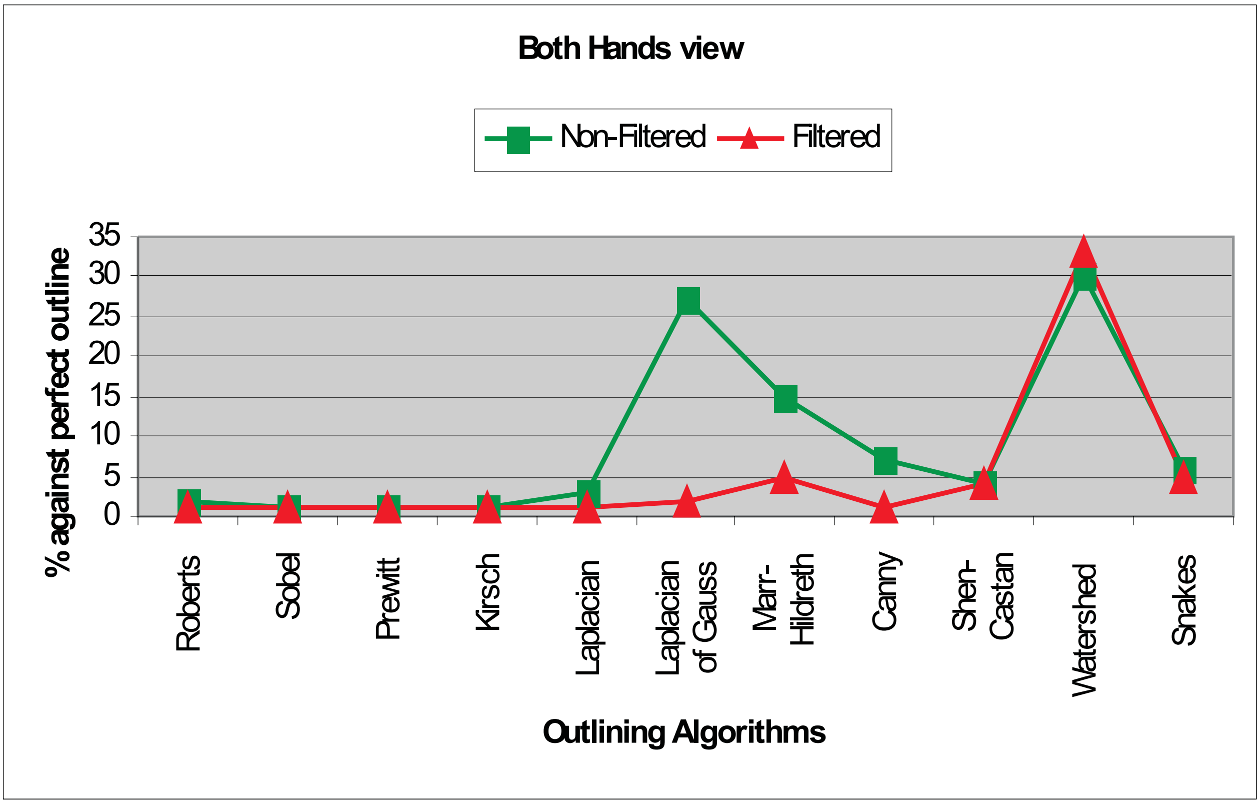
Figure 3
Difference between optimum edge length and algorithmically produced edges with and without noise pre-processing



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