Non-Parametric Image Subtraction for MRI

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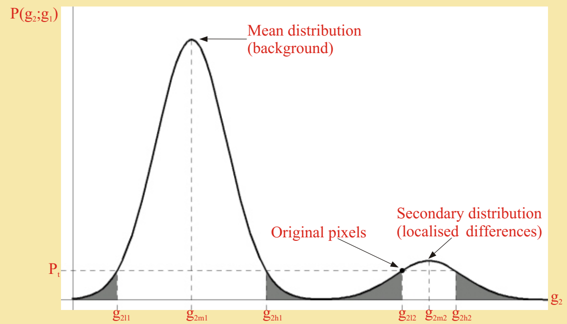
Introduction

Image subtraction is a common tool for the analysis of change in pairs of images, but interpretation of the resulting difference image can be problematic. In order for the technique to be used successfully great care has to be taken to ensure that the only differences between the two images are due to the physical mechanisms of interest, so pre-processing of the data prior to subtraction may be required. Ultimately we would also like to be able to place a quantitative statistical interpretation on the significance of the observed change. The formation of such an interpretation is generally prevented by the lack of a known statistical model of the expected scene contents. However, most images contain sufficient data that in theory we might extract sensible models of data behaviour from the data itself. Non-parametric image subtraction uses a scattergram of an image pair to produce statistically well-defined measures of difference for arbitrary image pairs.

Method

Non-parametric image subtraction uses a scattergram of an image pair to model data behaviour. A vertical cut in the scattergram isolates a set of pixels in the first image that all have the same grey level. The distribution of data along the cut gives the frequency of occurrence of grey levels at the corresponding pixel positions in the second image, or the probability distribution for the grey levels if the data is normalised. Taking pixel pairs from the original images, an integration is performed along the normalised cut on which the pixels lie, summing all values smaller than at the position of the pixels.

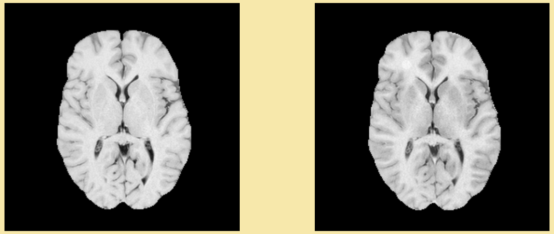


A vertical cut through the scattergram. The integration is performed across the shaded region, summing all values smaller than that at the position of the original pixel pair (the black point).

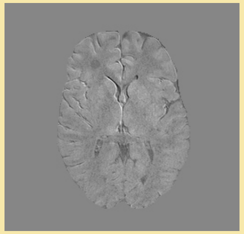
This is directly equivalent to the construction of a confidence interval, using an ordering principle which gives the shortest interval. The result is the probability of finding a more uncommon pairing of grey-levels than that seen in the original pixels, and is used as the value for the corresponding pixel in the difference image. This is precisely the kind of statistic needed to identify outlying combinations of pixel values in a fully automatic manner.

Results

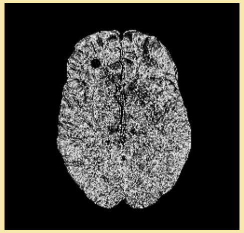
Since non-parametric image subtraction measures differences in relation to an implicit model of data behaviour, it automatically ignores global differences between the image pair, and identifies only localised differences (i.e. those covering subregions of image features). Therefore, a potential application is the detection of MS lesions in pre and post contrast MRI scans, where the contrast agent highlights the lesions but also affects the global parameters of the scans. Synthetic data was prepared to simulate this in a controllable way. Two MRI scans of the same brain region were taken with different echo train times, to produce global differences. A grey level offset of 2 was added to a circular region in one of the images to simulate a lesion.



Simulated MS data: MRI scans of the same region, taken with different echo train times to simulate global differences caused by GdDTPA contrast agent. A 2 grey-level offset was added to a 5 pixel radius circular region of the right-hand image to simulate an MS lesion.

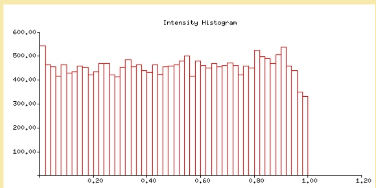


Pixel-by-pixel subtraction result.



Non-parametric image subtraction result.

The altered region is difficult to detect visually in either the original scans or the simple subtraction result. It is clearly visible as the dark region in the non-parametric subtraction result, against a background of random noise. The result appears noisy since it has a flat probability distribution, a consequence of the integration.



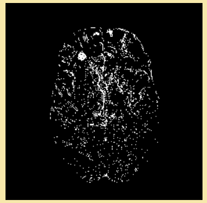
Histogram of the non-parametric image subtraction result, showing the flat distribution.

Flat Probability Distribution

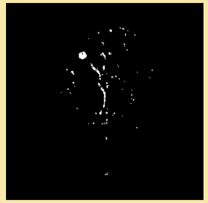
The flat probability distribution of pixel values in the difference image is a major advantage of this technique. Such probability distributions are honest i.e. thresholding at 0.1 extracts 10% of the pixels. Furthermore, a standard technique exists for renormalising (reflattening) any quantity P that is the product of n quantities , each of which has a flat probability distribution,

$$P' = P \sum_{j=0}^{n-1} \frac{(-\ln P)^j}{j!}$$

Since P' also has a flat distribution this process is potentially nestable, providing a statistically principled route to data fusion. In addition, the renormalisation can be used to analyse spatial correlation in the non-parametric image subtraction result, by forming and renormalising the product of each image pixel and its four nearest neighbours.



1% thresholding of the non-parametric subtraction result.



0.5% thresholding of the reflattened five-pixel product.

The spatially correlated low-probability pixels in the non-parametric subtraction result are pushed to very low probabilities in the renormalised five-pixel product, and so can be extracted by thresholding at a lower level, leading to less contamination by background pixels. Since the probability distribution of the result is flat only for background pixels (localised differences form a spike near zero), the number of such pixels extracted in the threshold is known, so the volume of the localised differences can be found.

Conclusions and Further Work

The non-parametric image subtraction technique solves several of the problems inherent in simple pixel-by-pixel image subtraction, by identifying only localised differences, and by returning an answer in terms of a statistically well-defined quantity. In addition, the resulting difference image has a flat probability distribution, leading to simple yet statistically rigorous methods for data fusion and other further processing. The new technique has been shown to be superior to simple subtraction in detecting abnormalities in medical images. We are currently obtaining MRI scans from MS patients with enhancing lesions for further testing of the technique. The source code for this method, together with all our other machine vision algorithms, is freely available from our website:

http://www.niac.man.ac.uk/Tina