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AUTOMATIC MORPHOLOGIC FILTER DESIGN FOR IMAGE PROCESSING

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Aperture filters are a relatively new class of image operators, and as such require more research for further improvements. Authors researched two different approaches. The first approach was to improve the filter definition itself, providing a way to balance the constraint cost against the estimation cost for a given application. The second approach was to implement an optimisation framework in order to find a better-suited filter structure.

1. INTRODUCTION

In most non-linear image processing tasks, the filter design can be carried out in roughly two different approaches. In a heuristic approach, the filter estimation algorithm is generally used to exploit the knowledge about the underlying process in which the signal was produced. This is usually done by providing an analytical model and adjusting its parameters to suit a given application. In practice, the heuristic approach is often a very complex and difficult task. Another approach for a non-linear filter design is a statistical approach. Here the task of non-linear filter design is performed automatically, estimating a desired filter operator with the use of statistics from a training dataset consisting of a number of input and ideal output signal pairs. Usually in the training dataset there exists only a fraction of all possible signal representations. The main concern about statistical estimation is to find sufficient estimates of optimal non-linear operators, because of the limited training sets available in practice. To counteract this problem, various forms of constraint are introduced into the design methodology. Constraints limit the number of possible observations, which reduces the number of samples required to achieve good estimates. The constraint on the random process improves the design precision for a given class of operators, reducing estimation error, but at the same time it can lead to a different error, i.e. the constraint error. This error occurs due to the fact that while constraining the process, the designer also puts a limit on possible operators configuration. In practice, the design of good suboptimal filters depends on finding a balanced compromise between the design (estimation) error and the constraint error.

2. APERTURE FILTERS

Aperture filters [1, 2] are a relatively new constraint that has been introduced to the design of grayscale operators. The constraint is applied by gray level reduction that can appear within the observation window. In general, grayscale images have 256 levels. This gives 256^W configurations (patterns) in an W–point window for the estimates to be assigned. The aperture operators are designed based only on observations seen trough the window in a grayscale range, around some central grayscale value (aperture position). Such a window only has K^N configurations, where K is the number of aperture levels. Thus the design complexity is greatly reduced.

The optimisation of the aperture filter structure is aimed at finding the best compromise between constraint and estimation errors. This compromise can be achieved by extracting from the signal only the most important signal properties, at the expense of statistically less important details. In order to capture a more dominant signal characteristic various techniques can be used i.e.: the choice of window size, window shape and aperture shape, the multi-mask approach [3] or the multi-resolution pyramidal approach [4].

3. APERTURE FILTER CONSTRAINTS

The idea behind an aperture filter with standard basic constraints of domain (windowing) and range (clipping) is indeed a simple concept, straightforward to implement. However, standard aperture filters, due to the range constraint, perform well only with slowly changing signals. If the signal change is large over a few pixel span (for instance on the edges), the range constraint will introduce a significant error. The main source of error when using aperture operators, (assuming adequately trained output estimates), arises from the constraints, which limit the potential filter performance.

The idea behind aperture operators is that the filter is only observing a section of the input signal, and is able to filter the subtle signal changes inside this section. According to the originators of the aperture operator concept, the operator’s output should also be clipped to the aperture boundaries. In this way the probability mass of the output random variable is more condensed, which – in practice – means fewer class labels for the Machine Learning output mapping described above. The constraining output range will obviously introduce an error, as for a particular input pattern; even if it fits into the aperture without clipping, output signal does not always fall into the aperture range. Research results suggest that this constraint can have a large impact on the filter performance.

The analysis of constraint impact on filter performance was tested on an example of a deblurring application. The example application of blur removal was chosen, because, unlike for noise removal applications, it is required to shift almost every pixel's value in order to restore the original image, and the correlation between blurred and original values is more difficult for statistical representation. Hence, such an application is a very demanding task for aperture filters capabilities, providing a good benchmark of performance improvement introduced by the proposed methods of constraint releasing. The set of 100 grayscale pictures (8 bit) of Glasgow suburbs in 640_480 resolution was blurred with a Gaussian low-pass filter with 3_3 kernel and standard deviation of 3. From this dataset, 20 pairs were selected for testing purposes. The remaining 80 image pairs were used for training. In the experiment the range constraint impact on the overall filtering error was evaluated. In this experiment 24 aperture filter configurations were tested. For each of the six different window shapes (fig. 1), an aperture filter was designed with 3, 5, 7 and 9 aperture levels. The aperture was positioned on the centre pixel value. Each filter was extended by scaling with 8 scaling factors: 1, 4, 8, 12, 16, 20, 24, and 28. If the observed pattern was clipped by the aperture, then it was scaled by a successively higher factor until the signal could be observed through the aperture without clipping (or the maximum scaling factor was reached). The training was performed using a dataset ranging from 10 images (636 x 476 x 10 = 3027360 sample patterns) to 80 images (24218880 patterns). Every filter was trained in two versions: a standard version with the output constrained to the aperture boundaries and scaled appropriately; and an unconstrained version, where the output value was neither clipped nor scaled. After the training, the filters were applied on the blurred images in the test set. The filtering results are presented in fig. 2 as a Mean Square Error (MSE) measure between the original and filtered images, calculated over the entire test set (20 image pairs) to get an average value.

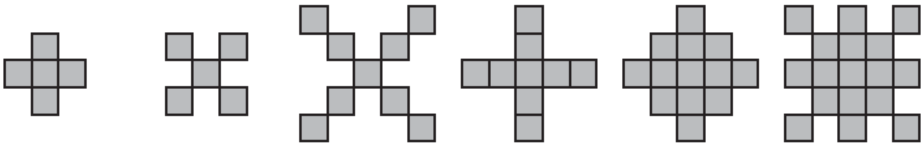

Fig.1. Window shapes of aperture filters used

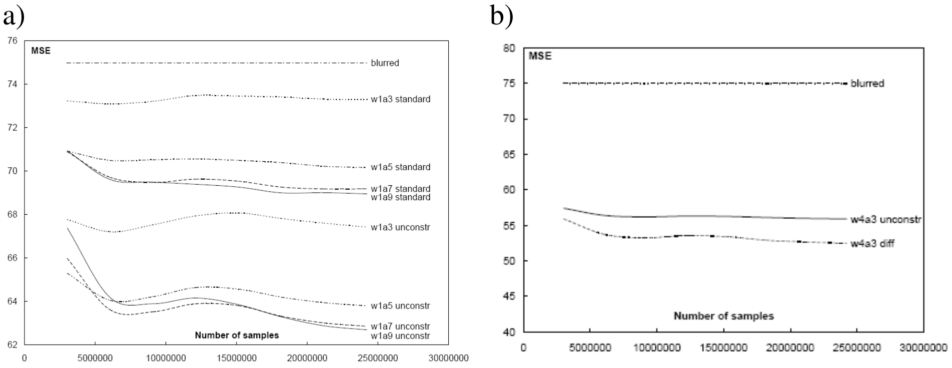

Fig. 2. a) Comparison of standard aperture and aperture with unconstrained output for filters with W_1 window shape; b) Comparison of unconstrained aperture with 1 and with 10 range dependent output estimates for window W_4

It was shown in this experiment that releasing some of the aperture filter constraints could improve filtering performance by a factor of up to 3. The release of the output value constraint to the aperture boundaries was beneficial for this particular dataset for all of the tested filter configurations, and it gave a massive performance improvement. Estimating separate output values for several grayscale ranges was shown to be beneficial in many cases, however, for larger apertures this method was not effective, possibly due to undertraining. The research results prove thesis 1 of the dissertation, i.e. it is possible to relax aperture filter constraints in order to achieve a better filtration quality for a given application, without a significant increase in the estimation error.

4. APERTURE FILTER OPTIMIZATION

A large set of aperture filter parameters can be tuned for specific application, naturally influencing (improving or degrading) the quality of filtration. Choosing optimal values for the parameters can be a difficult task for a human operator, as there are no straightforward means for deducing them. It would seem that the most sensible solution for finding optimal aperture filter parameter values is to define the fitness function, which allows one to compare and qualify the performance of aperture filters with different parameters. Parameter values can than be found by optimising such a function with the use of well known optimisation (minimisation) frameworks. The first necessary step in aperture filter optimisation was to implement a flexible filter definition to describe such a structure. The XML was chosen as it is naturally suited for hierarchical object description; it is human readable and supported by a number of programming libraries. In this research, the choice of an optimisation algorithm was determined by the definition of fitness function. Since there is no algebraic description of the function, and its domain cannot be represented by a vector, due to a hierarchical parameter structure and mixed continuous/discreet values, it is not possible to use deterministic nor hybrid algorithms. From among the stochastic optimisation algorithms tested, Genetic Algorithm was found to be the best suited for the problem domain and the way the fitness function is found. In the research Simulated Annealing was also tested, but with worse results.

The optimisation process was presented in diagrams by plotting the fitness value of the best solution found against the iteration number (fig. 3).

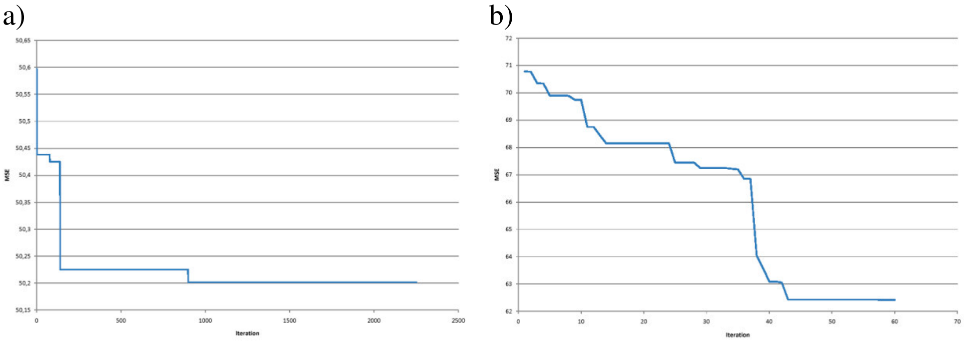

Fig. 3. a) Results of filter structure optimization by Simulated Annealing; b) Results of filter structure optimization by Genetic Algorithm

Fig. 4. Image fragment filtered by initial random and optimized filters

It can be seen that the optimization improved filter performance by a significant factor. The filtering results are presented in fig. 4. The images filtered with the optimized filter are visually better than the blurred ones, as well as the images filtered by the initial random filter.

5. CONCLUSIONS

The main task of this research was to improve the overall performance quality and usability of aperture filters. In the first step, the possible extensions of aperture filter definitions, while maintaining the basic principle, were investigated. In the second step, the aim was to implement and research the possibility and usability of automatic design process, by means of stochastic optimisation. The obtained results proved the initial assumptions, expressed in the form of theses to be correct:

- The constraints of the standard Aperture Filter proposed by the original definition by Hirata [1] can be relaxed in order to improve filtering quality without the significant increase of the estimation cost.
- It is possible to optimise aperture filter parameters in the sense of a filtration error with the use of stochastic optimisation.

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AUTOMATYCZNE PROJEKTOWANIE FILTRÓW MORFOLOGICZNYCH

Głównym celem badań było poprawienie użyteczności i wydajności filtrów aperturowych. W pierwszym etapie zbadano możliwości rozszerzenia samej definicji tych filtrów. Sprawdzono tutaj rozwiązania różnego rodzaju, zarówno znalezione w literaturze, jak i opracowane oryginalnie przez autora. Drugim etapem było opracowanie metodologii automatycznego procesu projektowania filtrów aperturowych. Rozwiązanie zostało oparte na wybranym algorytmie optymalizacji stochastycznej. Jako problem testowy zostało wybrane zagadnienie wyostrzania krawędzi rozmytych zdjęć. Uzyskane wyniki badań potwierdziły przyjęte założenia i koncepcje autora, wyrażone w formie tez.

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