Noise Reduction by Fuzzy Image Filtering

Dimitri Van De Ville, *Member, IEEE*, Mike Nachtegael, Dietrich Van der Weken, Etienne E. Kerre, Wilfried Philips, *Member, IEEE*, and Ignace Lemahieu, *Senior Member, IEEE*

***Abstract*—A new fuzzy filter is presented for the noise reduction of images corrupted with additive noise. The filter consists of two stages. The first stage computes a fuzzy derivative for eight different directions. The second stage uses these fuzzy derivatives to perform fuzzy smoothing by weighting the contributions of neighboring pixel values. Both stages are based on fuzzy rules which make use of membership functions. The filter can be applied iteratively to effectively reduce heavy noise. In particular, the shape of the membership functions is adapted according to the remaining noise level after each iteration, making use of the distribution of the homogeneity in the image. A statistical model for the noise distribution can be incorporated to relate the homogeneity to the adaptation scheme of the membership functions. Experimental results are obtained to show the feasibility of the proposed approach. These results are also compared to other filters by numerical measures and visual inspection.**

***Index Terms*—Additive noise, edge preserving filtering, fuzzy image filtering, noise reduction.**

I. Introduction

THE application of fuzzy techniques in image processing is a promising research field [1]. Fuzzy techniques have already been applied in several domains of image processing (e.g., filtering, interpolation [2], and morphology [3], [4]), and have numerous practical applications (e.g., in industrial and medical image processing [5], [6]).

In this paper, we will focus on fuzzy techniques for image filtering. Already several fuzzy filters for noise reduction have been developed, e.g., the well-known FIRE-filter from [7]–[9], the weighted fuzzy mean filter from [10] and [11], and the iterative fuzzy control based filter from [12]. Most fuzzy techniques in image noise reduction mainly deal with fat-tailed noise like impulse noise. These fuzzy filters are able to outperform rank-order filter schemes (such as the median filter). Nevertheless, most fuzzy techniques are not specifically designed for Gaussian(-like) noise or do not produce convincing results when applied to handle this type of noise. Therefore, this paper presents a new technique for filtering narrow-tailed and medium narrow-tailed noise by a fuzzy filter. Two important features are presented: first, the filter estimates a "fuzzy derivative" in order to be less sensitive to local variations due to image structures such as edges; second, the membership functions are adapted accordingly to the noise level to perform "fuzzy smoothing."

The construction of the fuzzy filter is explained in Section II. For each pixel that is processed, the first stage computes a fuzzy derivative. Second, a set of 16 fuzzy rules is fired to determine a correction term. These rules make use of the fuzzy derivative as input. Fuzzy sets are employed to represent the properties `small`, `positive`, and `negative`. While the membership functions for `positive` and `negative` are fixed, the membership function for `small` is adapted after each iteration. The adaptation scheme is extensively explained in Section III and can be combined with a statistical model for the noise. In Section IV, we present several experimental results. These results are discussed in detail, and are compared to those obtained by other filters. Some final conclusions are drawn in Section V.

Manuscript received November 24, 2001; revised June 27, 2002 and November 13, 2002. The work of D. Van De Ville was supported by the Fund for Scientific Research—Flanders (Belgium) through a mandate of Research Assistant. The work of M. Nachtegael and D. Van der Weken was supported by the GOA-project 12.0513.98 by Ghent University, Belgium.

D. Van De Ville was with Ghent University, Belgium. He is currently with the Biomedical Imaging Group, the Swiss Federal Institute of Technology Lausanne (EPFL), CH1015 Lausanne, Switzerland.

M. Nachtegael, D. Van der Weken, and E. Kerre are with the Fuzziness and Uncertainty Research Modeling Unit, the Department of Applied Mathematics and Computer Science, Ghent University, B9000 Ghent, Belgium.

W. Philips is with the Department of Telecommunications and Information Processing, Ghent University, B9000 Ghent, Belgium.

I. Lemahieu is with the Department of Electronics and Information Systems, Ghent University, B9000 Ghent, Belgium.

Digital Object Identifier 10.1109/TFUZZ.2003.814830

II. Fuzzy Filter

The general idea behind the filter is to average a pixel using other pixel values from its neighborhood, but simultaneously to take care of important image structures such as edges.[1] The main concern of the proposed filter is to distinguish between local variations due to noise and due to image structure.

In order to accomplish this, for each pixel we derive a value that expresses the degree in which the derivative in a certain direction is small. Such a value is derived for each direction corresponding to the neighboring pixels of the processed pixel by a fuzzy rule (Section II-A).

The further construction of the filter is then based on the observation that a small fuzzy derivative most likely is caused by noise, while a large fuzzy derivative most likely is caused by an edge in the image. Consequently, for each direction we will apply two fuzzy rules that take this observation into account (and thus distinguish between local variations due to noise and due to image structure), and that determine the contribution of the neighboring pixel values. The result of these rules (16 in total) is defuzzified and a "correction term" is obtained for the processed pixel value (Section II-B).

A. Fuzzy Derivative Estimation

Estimating derivatives and filtering can be seen as a chicken-and-egg problem; for filtering we want a good indication of the edges, while to find these edges we need filtering.

[1]Other fuzzy filters, such as the smoothing fuzzy control based filter [12], also take care of edges, but *after* instead of *simultaneous* with the noise filtering.