Soft Morphological Color Image Processing: A Fuzzy Approach

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***Abstract*–Mathematical morphology is a powerful tool for image processing and analysis of binary, gray-scale and color images. Soft morphological filters form a class of filters with many desirable properties. They were introduced to improve the behavior of standard morphological filters in detail preservation and noise elimination. In this paper a framework for soft morphological color image processing using a fuzzy model is presented and implemented in hardware. The basic morphological operations of soft erosion and dilation are defined by means of a vector ordering scheme that uses fuzzy if-then rules. Experimental results of the application to real color images demonstrate that the proposed operators are less sensitive to image distortion and to small variations in the shape of the objects and perform significantly better in impulse noise removal problems, compared to standard morphological operators. Hardware implementation issues suitable for real-time application are also discussed.**

***Index terms*--color image processing, fuzzy systems, soft mathematical morphology, FPGAs**

I. INTRODUCTION

Mathematical morphology is a geometric approach to image processing, introduced by Matheron and Serra, based on geometry and the mathematical theory of order [1, 2]. It has become popular in the image processing community due to its proven applicability in a number of image processing and analysis problems (noise elimination, edge detection, feature extraction, skeletonization etc.) and its rigorous mathematical description. Its initial form is usually referred to as "standard mathematical morphology" in the literature in order to be discriminated by its later extensions. In order to improve the behavior of standard morphological filters in detail preservation and noisy environments, an extension of standard mathematical morphology called soft mathematical morphology [3] was introduced by Koskinen et al. The main difference between standard and soft morphological operations is that the min/max operators which are used in standard morphology are substituted by other weighted order statistics. The structuring element is divided is divided into two parts: the *core* (or *hard center*) and the *soft boundary*. The pixels of the core have weight k greater than or equal to 1 and the pixels of the soft boundary have weight equal to 1. In this way, the pixels of the core are repeated k times in the calculation of the results (differences or sums). The parameter k is called the *order index of the center* or the *repetition parameter*. It has been proved that soft morphological operations maintain most of the desirable properties of standard morphological operations but at the same time they are less sensitive to additive noise and small variations in object shape.

In [4] a new approach to color mathematical morphology using an efficient fuzzy model has been proposed. It is based on a new vector ordering scheme in the HSV color space that uses fuzzy if-then rules [5]. The specific ordering and the corresponding vector morphological operators of erosion and dilation (which in the following sections will be referred to as *standard operators*) are vector preserving. In this paper an extension of the standard vector morphological approach of [4] using the theory of soft morphology is presented and implemented in hardware. The basic morphological operations of soft erosion and dilation are defined. Experimental results of the application to real color images demonstrate that the proposed operators are less sensitive to image distortion and to small variations in the shape of the objects and perform significantly better in impulse noise removal problems. In order to achieve real-time operation, the fuzzy system was implemented in FPGAs and the typical characteristics of the hardware structure are also included.

II. VECTOR ORDERING SCHEME

The extension of the concepts of gray-scale morphology to color images implies the definition of an appropriate ordering of vectors (colors) in a concrete color space. The HSV color space has been chosen since it is closely related to the way in which humans perceive color. In this color space each color is a vector with three components: h (Hue), s (Saturation), v (Value), with $h \in [0,360)$, $s \in [0,1]$, $v \in [0,1]$.

The proposed vector ordering scheme may be considered as a fuzzy system in which the input variables are the h,s,v values of each pixel and the output is its *Ordering Plane Value* (OPV). The following subsections describe briefly this ordering procedure [4].

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A. Fuzzification of the h,s,v Values

Hue represents the dominant color of a pixel. The fuzzification of hue is done in such a way that the non-crisp boundaries between the colors can be represented much better. Six symbols are used in order to characterize the hue values:

HUE = {Red, Yellow, Green, Cyan, Blue, Magenta}

Every symbol is characterized by its membership function. The membership functions, which were used for the six symbols, are the classical triangular functions. The graphical representation of these functions is shown in Fig. 1.

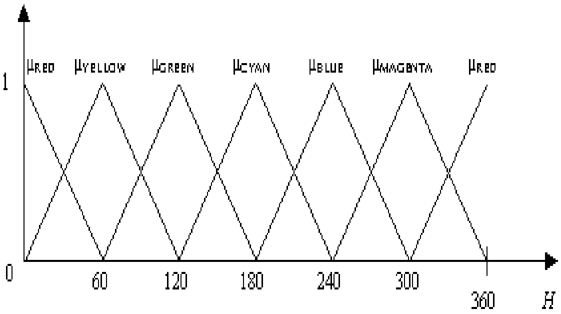


Fig. 1. Fuzzy sets used for the input variable *Hue*.

Saturation is used to express the amount of white mixed with a hue and value is used for the amount of black. Three symbols are used to characterize these quantities:

Saturation = {SMALL, MEDIUM, LARGE}
Value = {SMALL, MEDIUM, LARGE}

The design of the membership functions that were used for the three symbols for the case of saturation and value are shown in Fig. 2. Each design is based on the choice of two thresholds: S_{SMALL} and S_{LARGE} for saturation, and V_{SMALL} and V_{LARGE} for value. These values are tuned after experimentation and depend on the characteristics of the fuzzy system to be developed. Due to the linear shape of the membership functions, the results are not too sensitive to small changes of these two values. Typical values are: $S_{SMALL} = 20$, $S_{LARGE} = 80$, $V_{SMALL} = 20$, $V_{LARGE} = 80$.

B. Ordering Plane and Fuzzy Rules

The ordering plane is the output of the fuzzy system and its value ranges from 0 to 100. The general diagram of the ordering plane is shown in Fig. 3. It should be noticed that each combination of the symbols of hue, saturation and value corresponds to a different level of the ordering plane. The different levels of the ordering plane are denoted as L1, L2…L54. The rule-base used in the fuzzy system is defined by a set of 54 if-then rules. Each rule maps a combination of the fuzzy descriptions of the h,s,v values to a level of the ordering plane.

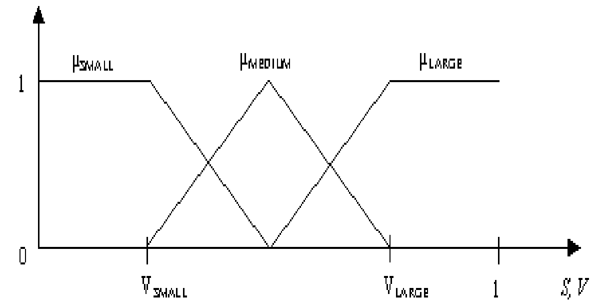


Fig. 2. Fuzzy sets used for the input variables *Saturation* and *Value*.

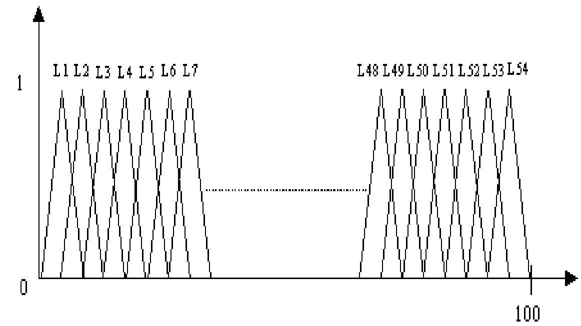


Fig. 3. The ordering plane.

C. Definitions of new Min and Max Operators

Let S_n be a subset of the HSV space that includes n vectors: $x_1(h_1,s_1,v_1)$, $x_2(h_2,s_2,v_2),\ldots,$ $x_n(h_n,s_n,v_n)$. For the n vectors of S_n the output values of the fuzzy system will be denoted as: $OPV(x_1)$, $OPV(x_2),\ldots,$ $OPV(x_n)$. Based on the previous discussion, we define the min operator in S_n as follows:

$$\min(S_n) = x_k : OPV(x_k) = \min\{OPV(x_1), OPV(x_2), \ldots, OPV(x_n)\}, \text{ with } 1 \le k \le n$$

In a similar way we define the max operator in S_n as follows:

$$\max(S_n) = x_k : OPV(x_k) = \max\{OPV(x_1), OPV(x_2), \ldots, OPV(x_n)\}, \text{ with } 1 \le k \le n$$

It is important to notice that the application of these two operators results to only *one* output vector which *is* included in the input set S_n. Consequently, the proposed operators are *vector preserving*, since no vector (color), which is not present in the input data is generated.

III. Soft Morphological Operations

In the following we denote the repetition operation of any item by ◊, which means that $k◊x$ denotes the k-times repetition of the object x. The term *multiset* is used to describe a collection of objects, where the repetition of objects is allowed [3].

Let us consider S_n to be a subset of the HSV space that includes n vectors $x_1(h_1,s_1,v_1)$, $x_2(h_2,s_2,v_2)$,…, $x_n(h_n,s_n,v_n)$ and the corresponding output values of the fuzzy system, which are denoted as $OPV(x_1)$, $OPV(x_2)$,…, $OPV(x_n)$. If we order the output values $OPV(x_1)$, $OPV(x_2)$,…, $OPV(x_n)$ from smaller to bigger we can form the set $S_{n(\mathrm{ord})}$ of the corresponding ordered vectors:

$$S_{n(\mathrm{ord})} = \{ x_{(1)}, x_{(2)}, \ldots, x_{(n)} \},$$

with $OPV\{x_{(1)}\} \le OPV\{x_{(2)}\} \le \ldots \le OPV\{x_{(n)}\}$

Furthermore, we can now define:
The k-est smallest value of the set S_n : $\min^{(k)}(S_n) = x_{(k)}$ The k-est largest value of the set S_n : $\max^{(k)}(S_n) = x_{(n-k+1)}$

Let us consider two functions $f, g : R^2 \to \mathrm{HSV}$ (two color images), with domains D[f] and D[g], respectively, where f denotes the image under process (the input image) and g denotes the structuring element. The core and the soft boundary of the structuring element $g(z)$ are denoted by $\alpha(z_\alpha)$ and $\beta(z_\beta)$, respectively, where $z_\alpha \in D[a]$, $z_\beta \in D[\beta] = D[g] \setminus D[\alpha]$ and \ denotes the set difference. We can extract the following definitions of *soft erosion* and *soft dilation*.

A. Soft Erosion

Soft erosion of f by g at a point x is defined as follows:

$(f \Theta [\beta, a, k])(x) = \min^{(k)}(MS_{n1})$, for x: $D[g_x] \subseteq D[f]$
where MS_{n1} denotes the following multi-set of the HSV color space:
$MS_{n1} = \{ k \Diamond (f(z_1) - a_x(z_1)) \} \cup \{ f(z_2) - \beta_x(z_2) \}$
for $z_1 \in D[f] \cap D[a_x]$ and $z_2 \in D[f] \cap D[\beta_\chi]$

The previous definition implies that in order to perform soft erosion of an input image f by the structuring element g at a point x the color of the eroded image at point x obtains the h, s and v components of the k^{th} minimum vector of the multi-set MS_{n1}.

B. Soft Dilation

Soft dilation of f by g at a point x is defined as follows:

$(f \oplus [\beta, a, k])(x) = \max^{(k)}(MS_{n2})$, for x: $D[f] \cap D[g'_{-x}] \neq \varnothing$
In this case MS_{n2} denotes the following multi-set of the HSV color space:
$MS_{n2} = \{ k \Diamond (f(z_1) + a_{-x}(-z_1)) \} \cup \{ f(z_2) + \beta_{-x}(-z_2) \}$
for $z_1 \in D[f] \cap D[a'_{-x}]$ and $z_2 \in D[f] \cap D[\beta'_{-x}]$

Soft dilation is performed in a similar way to soft erosion.

IV. Experimental Results

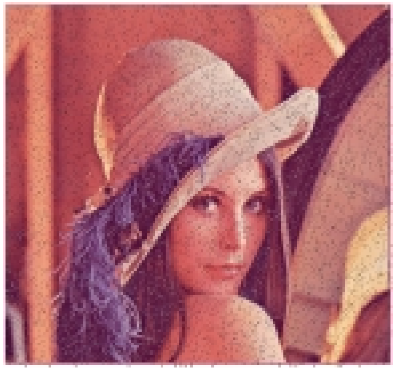
Soft morphological filters have been proven to perform better in detail preservation and impulse noise suppression. The shape and the pixel values of the structuring element used play a very important role, but, in general, the greater the value of the repetition parameter k the better the detail preservation. This is a feature of great importance for various applications, especially for filtering and noise elimination applications. The proposed soft morphological operators act in a similar way to their gray-scale counterparts. They remove impulse noise from color images better and they are advantageous regarding shape and small detail preservation in the original color image, compared to the corresponding standard morphological transforms.

This can be observed in Fig. 4. We have performed morphological filtering using the color image "Lenna" for different values of the repetition parameter k. The color impulse noise model that has been used in our experiments has been proposed by Plataniotis et al. in [6] and we consider the case of both positive and negative impulse noise. In Figs 4(a) and 4(b) the original image and the image contaminated by 4% positive and negative noise are illustrated, respectively. The results of standard and soft operators for k=1 and k=4 are depicted in Fig. 4(c) and 4(d), respectively. It can be noticed that in the second case impulse noise has been completely eliminated, while in the case of standard operators, although noise has been suppressed, it has not been eliminated. Moreover, a comparison of Fig. 4(c) to 4(d) clearly demonstrates the superior performance of the proposed soft operators in detail preservation. In Table 1 the most common similarity measures (Normalized Mean Square Error, NMSE and Normalized Color Difference, NCD) estimated for the cases of standard and soft operators are also provided.

V. Hardware Implementation

Real-time operation is critical in industrial systems where fast processing is required. Thus, hardware implementation is necessary for such applications. The previously presented operators were implemented by using field programmable gate arrays (FPGAs), claimed to offer an attractive combination of low cost, high performance and apparent flexibility. The digital fuzzy processor was designed, compiled and simulated using the MAX+PLUS II Programmable Logic Development System by Altera Corporation. The proposed system performs the morphological operations of erosion and dilation for a 3×3-pixel image neighborhood and for color images of 24-bit resolution. The fuzzy processor comprises five basic functional units- the *input add/subtract and normalization unit*, the *knowledge base unit* (main memory containing the

(a)



(b)

(c)

(d)

Fig. 4. Positive and negative impulse noise removal

k value	NMSE			NCD
	H	*S*	*V*	
1	0,1842	0,0279	0,0273	0,1461
4	0,1582	0,0186	0,0045	0,1056

Table 1. Similarity measures

fuzzy set base for the h, s, v values), the *rule control* unit, the *defuzzification unit* and the *output selection* unit. A block diagram of the hardware structure of the processor is depicted in Fig. 5. For its realization two FPGA chips have been used, the EPF10K200SRC240-1 and EPF10K130EQC240-1 of the FLEX10KE device family, a device family suitable for designs that require high densities and high I/O count. The total number of the system inputs and outputs are 79 and 24 pins, respectively. For the first chip, the percentage of the memory bits and the logic cells utilized are 19% and 94%, respectively. For the second chip, no memory bits are used and the percentage of the logic cells utilized is 99%. The typical system clock frequency is 65 MHz, and the fuzzy processor exhibits a level of inference performance of 601 KFLIPS with 54 rules.

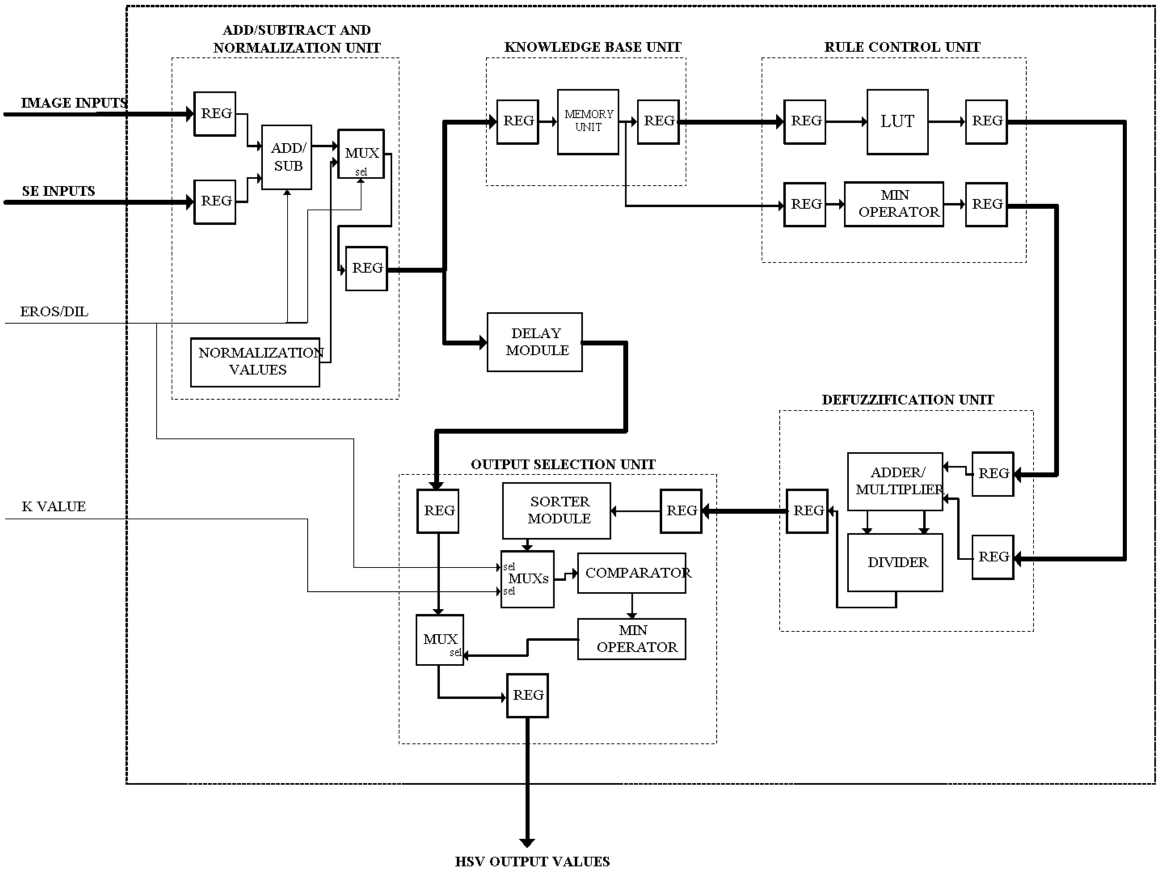


Fig. 5. Hardware structure of the digital fuzzy processor.

As a comparison, the time required to perform the soft erosion of a color image with dimensions 260×244 pixels using Matlab® software on a Pentium III/1GHz system is approximately 14 minutes, whereas the corresponding time using hardware is approximately 8.8ms.

VI. Conclusions

In this paper a new approach to soft morphology for color images using an efficient fuzzy model is presented. The fundamental morphological operations of soft erosion and dilation are defined. The proposed soft operators, like their gray scale counterparts, achieve better detail preservation and perform significantly better in impulse noise removal problems compared to the corresponding standard morphological transforms. Comparative experimental results that demonstrate the advantageous characteristics and the applicability of the new framework in real color images are included. Finally, hardware implementation issues suitable for real-time application are also discussed.

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