ELSEVIER

Expert Systems with Applications 28 (2005) 483–494

Expert Systems with Applications

www.elsevier.com/locate/eswa

An intelligent image agent based on soft-computing techniques for color image processing

Shu-Mei Guo[a], Chang-Shing Lee[b,*], Chin-Yuan Hsu[a]

[a]Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, 701, Taiwan, ROC
[b]Department of Information Management, Chang Jung Christian University, Tainan, 711, Taiwan, ROC

Abstract

An intelligent image agent based on soft-computing techniques for color image processing is proposed in this paper. The intelligent image agent consists of a *parallel fuzzy composition mechanism*, a *fuzzy mean related matrix process* and a *fuzzy adjustment process* to remove impulse noise from highly corrupted images. The fuzzy mechanism embedded in the filter aims at removing impulse noise without destroying fine details and textures. A learning method based on the genetic algorithm is adopted to adjust the parameters of the filter from a set of training data. By the experimental results, the intelligent image agent achieves better performance than the state-of-the-art filters based on the criteria of Peak-Signal-to-Noise-Ratio (PSNR) and Mean-Absolute-Error (MAE). On the subjective evaluation of those filtered images, the intelligent image agent also results in a higher quality of global restoration.

Keywords: Impulse noise; Image filtering; Fuzzy inference; Genetic algorithm

1. Introduction

Nowadays, the techniques of image processing have been well developed, but there are still some bottlenecks that are not solved. For example, many image processing algorithms cannot work well in a noisy environment, so the image filter is adopted as a preprocessing module. The process of image transmission could be corrupted by impulse noise and the corrupted image is different from the original image. A number of approaches have been developed for impulse noise removal. For example, a median filter (Arakawa, 1996) is the most used method, but it will not work efficiently when the noise rate is above 0.5. Abreu and Mitra (1995) proposed an efficient nonlinear algorithm to suppress impulse noise from highly corrupted images while preserving details and features. The algorithm is based on detection–estimation strategy, called Signal-Dependent Rank Ordered Mean (SD-ROM) filter. SD-ROM filter can achieve an excellent tradeoff between noise suppression and detail preservation, and outperform a number of well-known techniques for highly corrupted images. Weighted Fuzzy Mean (WFM) filter (Lee, Kuo, & Yu, 1997) has a better ability for removing high impulse noise. Especially, when the noise rate is above 0.5, WFM filter still maintains a steady result. Adaptive Weighted Fuzzy Mean (AWFM) filter (Kuo, Lee, & Chen, 2000) can improve the WFM filter's incapability in a low noisy environment, and still retains its capability of processing in the heavily noisy environment. Russo (1999, 2000) presented the hybrid neuro-fuzzy filters for images, which are highly corrupted by impulse noise. The network structure of the filter is specifically designed to detect different patterns of noisy pixels typically occurring in highly corrupted data. The proposed filters are able to yield a very effective noise cancellation and to perform significantly better than the other approaches. Wang, Liu, and Lin (2002) presented a histogram-based fuzzy filter (HFF) to the restoration of noise-corrupted images, which is particularly effective at removing highly impulsive noise while preserving image details. Lukac (2003) proposed an adaptive vector median filter for impulse noise suppression and outliers rejection in multichannel images. Pok, Liu, and Nair (2003) proposed a decision-based, signal-adaptive median filtering algorithm for removal of impulse noise. Chang and

* Corresponding author. Tel.: +886 6278 5123x2059; fax: +886 6278 5657.

E-mail addresses: leecs@mail.cju.edu.tw (C.-S. Lee), leecs@cad.csie.ncku.edu.tw (C.-S. Lee).

0957-4174/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2004.12.010

Chen (2004) proposed a classifier-augmented median filter for impulse noise removal from images. Liu (2002) presented a representation of digital image by fuzzy neural network, by which the predetermined fuzzy system can be constructed to express a given two-dimensional (2D) digital image. Tsai and Yu (1999, 2000) proposed adaptive fuzzy hybrid multichannel filters for removal of impulsive noise from color images. Lin and Hsueh (2000) proposed a multichannel filtering by gradient information. Barni, Buti, Bartolini, and Cappellini (2000) proposed a quasi-Euclidean norm to speed up vector median filtering. Vardavoulia, Andreadis, and Tsalides (2001) proposed a new vector median filter for color image processing.

Intelligent agents are a new paradigm of modern Artificial Intelligence (AI) research in computer science. An agent is a physical or virtual entity, which is capable of acting in an environment and communicating directly with other agents (Ferber, 1999). Soft computing differs from conventional (hard) computing in that, unlike hard computing, it is tolerant of imprecision, uncertainty and partial truth. Neural network theory, fuzzy logic, probabilistic reasoning, genetic algorithms, chaos theory and parts of learning theory all are in soft computing. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves membership functions, fuzzy logic operators, and if–then rules.

In this paper, we propose an intelligent image agent to remove impulse noise from highly corrupted images. The proposed filter consists of a *parallel fuzzy composition mechanism*, a *fuzzy mean related matrix process*, and a *fuzzy adjustment process*. The genetic learning approach proposed by Cord'on, Herrera, and Villar (2001) and Lee and Pan (2004) is applied to tune the parameters of the membership functions. The intelligent image agent performs better than our previous AWFM operator (Kuo, Lee, & Chen, 2000) and is able to largely outmatch state-of-the art methods in the literature. The rest of this paper is organized as follows. In Section 2, we briefly introduce the knowledge base of the image agent. Section 3 describes the novel structure of the intelligent image agent. Section 4 focuses on parameter encoding and genetic learning. The experimental results for intelligent image agent are described in Section 5. Finally, we make the conclusion in Section 6.

2. Knowledge base construction for intelligent image agent

An intelligent image agent is a special fuzzy system having an image knowledge base and a fuzzy inference mechanism. Fig. 1 shows the structure of the intelligent image agent.

In this system, the RGB color space is adopted to represent color images. $X(i,j)$ denotes the color image that

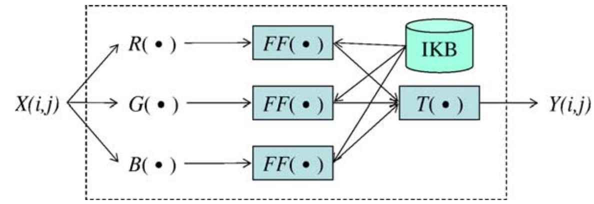

Fig. 1. The structure of intelligent image agent.

may be corrupted by impulse noise, and $Y(i,j)$ is the output image after filtering. $R(\cdot)$, $G(\cdot)$ and $B(\cdot)$ are the functions to produce the projections of $X(i,j)$ in the red axis $X^R(i,j)$, green axis $X^G(i,j)$, and blue axis $X^B(i,j)$, respectively, i.e. the functions can be represented as following formulas:

$$X(i,j) = (X^R(i,j), X^G(i,j), X^B(i,j)) \tag{1}$$

$$R(X(i,j)) = X^R(i,j) \tag{2}$$

$$G(X(i,j)) = X^G(i,j) \tag{3}$$

$$B(X(i,j)) = X^B(i,j) \tag{4}$$

After filtering in individual color channel, the function $T(\cdot)$ aggregates the partial results to construct the filtered color image $Y(i,j)$, that is,

$$Y(i,j) = T(FF(X^R(i,j)), FF(X^G(i,j)), FF(X^B(i,j))) \tag{5}$$

In this paper, we propose a new construction algorithm of image knowledge base (IKB), where the trapezoidal function is adopted to be the membership function of fuzzy sets. Eq. (6) denotes the membership function $f_A(x)$ of fuzzy set A.

$$f_A(x) = \begin{cases} 0 & x < a_A \\ (x-a_A)/(b_A-a_A) & a_A \le x < b_A \\ 1 & b_A \le x < c_A \\ (d_A-x)/(d_A-c_A) & c_A \le x < d_A \\ 0 & x \ge d_A \end{cases} \tag{6}$$

The trapezoidal membership function of fuzzy set A is denoted by the parameter set $A=[a_A,b_A,c_A,d_A]$. Fig. 2 illustrates an example for *luminance* fuzzy variable with five linguistic terms. The membership degree is usually a value

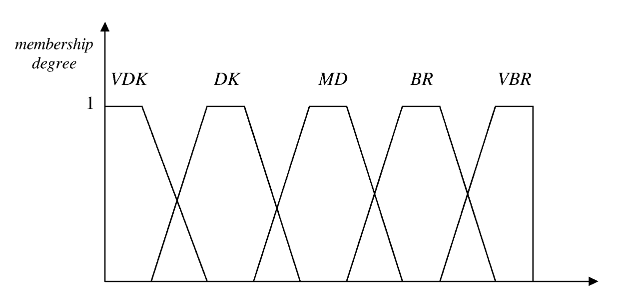

Fig. 2. The *luminance* fuzzy variable with five linguistic terms.