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Optimization of interval type-2 fuzzy systems for image edge detection

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ABSTRACT

This paper presents the optimization of a fuzzy edge detector based on the traditional Sobel technique combined with interval type-2 fuzzy logic. The goal of using interval type-2 fuzzy logic in edge detection methods is to provide them with the ability to handle uncertainty in processing real world images. However, the optimal design of fuzzy systems is a difficult task and for this reason the use of meta-heuristic optimization techniques is also considered in this paper. For the optimization of the fuzzy inference systems, the Cuckoo Search (CS) and Genetic Algorithms (GAs) are applied. Simulation results show that using an optimal interval type-2 fuzzy system in conjunction with the Sobel technique provides a powerful edge detection method that outperforms its type-1 counterparts and the pure original Sobel technique.

1. Introduction

The optimal design of fuzzy inference systems is a difficult task, beginning by defining the number of antecedents and consequents, number of membership functions, the type of membership functions, and it is also complicated to choose the optimal parameters and the number of ideal fuzzy rules to get a good result. In several works researchers present their design of fuzzy inference systems obtained under experimentation approaching an acceptable result after a series of tests. However, some researchers have applied meta-heuristics algorithms to find the optimal design for fuzzy inference systems with good results [1,2]. In the last years different meta-heuristics algorithms have been proposed for solving a wide range of optimization problems, such as Genetic Algorithms (GAs) [3], Ant Colony Optimization (ACO) [4], Bee Algorithms (BA), Particle Swarm Optimization (PSO) [5–7], the Firefly Algorithms (FA) [8,9], Bat-inspired Algorithms (BAT) [10], Cuckoo Search (CS) [11–14] and others.

The main contribution of this paper is to optimize a fuzzy edge detector based on the Sobel technique and interval type-2 fuzzy logic (IT2-FLS), applying Cuckoo Search (CS) [11–14] and Genetic Algorithms (GA) with the idea of finding the optimal design of the antecedent parameters for an IT2-FLS and achieve better results than the non-optimized IT2-FLS in edge detection applications for digital images. The CS algorithm is a relatively new technique that is considered for the first time in this paper in the optimization of interval type-2 fuzzy systems for edge detection. In addition, the enhanced interval type-2 fuzzy Sobel edge detector is presented for the first time in this paper. Related works have proposed interval type-2 fuzzy edge detectors, but in combination with the morphological and Canny methods [15–18], but not with the Sobel edge detector, which is the one proposed here. Of course, the aim of enhancing the traditional Sobel edge detector with interval type-2 fuzzy logic is to provide the edge detection method with the ability to handle the uncertainty in real images, which is not a characteristic that the pure traditional mathematical edge detectors have.

In order to evaluate objectively the performance of the edge detectors presented in this paper; for the simulation results we used synthetic images, these images are presented in Section 6, and the quality of the edge detection is evaluated with the figure of merit of Pratt (FOM), described in Section 5.

The rest of the paper is organized as follows. The basic concepts of the fuzzy logic systems are defined in Section 2. The theory of the Cuckoo Search (CS) algorithm is presented in Section 3. In Section 4, the Sobel operator is described. The models proposed to achieve the optimization of type-1 FLS and interval type-2 FLS using CS and GA, are presented in Section 6. In Section 7, the obtained simulation

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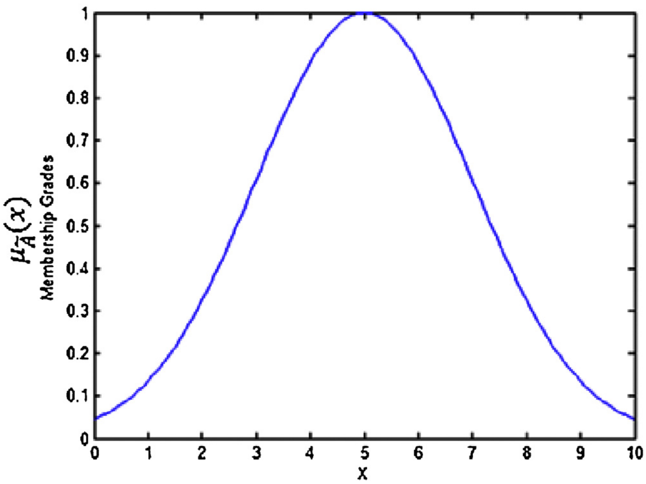

Fig. 1. Type-1 Gaussian membership function.

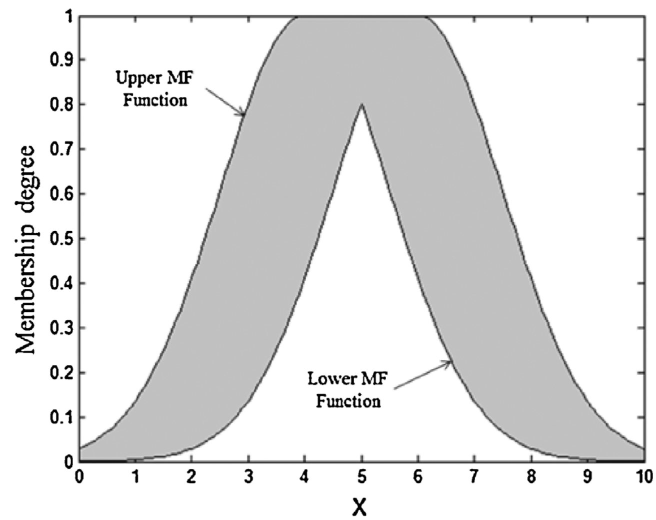

Fig. 2. Interval type-2 membership function.

results are shown, and finally, conclusions are presented in Section 8.

2. Fuzzy logic systems

The term fuzzy logic was introduced by Zadeh in his seminal work "Fuzzy sets," which described the mathematics of fuzzy theory [19]. Fuzzy logic provides the ability to solve problems in which objects are associated with imprecise information [19–21].

In the last 15 years great progress has been made in transitioning from type-1 fuzzy logic systems (T1-FLS) to interval type-2 fuzzy logic systems (T2-FLS). Type-2 fuzzy logic is an extension of the concept of type-1 fuzzy logic. The idea of going into higher orders or types of fuzzy logic is to achieve better models of uncertainty.

In this section, we define type-1 fuzzy logic, interval type-2 fuzzy logic, and other important associated concepts that are used throughout this paper.

2.1. Type-1 fuzzy sets

Fuzzy sets are mostly used in a fuzzy logic system (FLS), which includes a fuzzifier, fuzzy rules, inference engine, and defuzzifier.

A fuzzy set A on a universe of discourse X is characterized by a membership function $\mu_A(x)$ that takes values in the interval [0,1]. A fuzzy set A, is denoted by [19–21]

$$A = \{(x, \mu_A(x)) | x \in X\} \tag{1}$$

where $\mu_A(x)$, is known as the membership function for the type-1 fuzzy set, A

The membership function maps each element of X to a degree of membership between 0 and 1. The construction of a fuzzy set is dependent of the identification of a suitable universe and the specification of a membership function. The membership functions more frequently used are the trapezoidal, triangular, Gaussian, singleton, and others. In Fig. 1 the type-1 Gaussian membership function is illustrated.

2.2. Interval type-2 fuzzy sets

In this part we provide some important definitions and properties about interval type-2 fuzzy sets [22,23].

An interval type-2 fuzzy set, denoted by $\tilde{A}$, is characterized by the membership function $\mu_{\tilde{A}}(x, u)$ where $x \in X$ and $u \in J_x \subseteq [0, 1]$:

$$\tilde{A} = \{((x, u), \mu_{\tilde{A}}(x, u)) | \forall u \in J_x \subseteq [0, 1]\} \tag{2}$$

in which $0 \le \mu_{\tilde{A}}(x, u) \le 1$. $\tilde{A}$ can also be expressed as

$$\tilde{A} = \int_{x \in X} \int_{u \in J_x} \frac{\mu_{\tilde{A}}(x, u)}{(x, u)} \quad J_x \subseteq [0, 1] \tag{3}$$

where $\int\int$ denotes the union over all admissible input variables x and u. In fact $J_x \subseteq [0, 1]$ represents the primary membership of x, and $\mu_{\tilde{A}}(x, u)$ is a type-1 fuzzy set known as the secondary set. Hence, a type-2 membership grade can be any subset in [0,1], the primary membership, and corresponding to each primary membership, there is a secondary membership (which can also be in [0,1]) that defines the possibilities for the primary membership [22–24]. Uncertainty is represented by a region, which is called the footprint of uncertainty (FOU). When $\mu_{\tilde{A}}(x, u) = 1, \quad \forall u \in J_x \subseteq [0, 1]$, we have an interval type-2 membership function, as shown in Fig. 2. The uniform shading for the FOU represents the entire interval type-2 fuzzy set and it can be described in terms of an upper membership function $\bar{\mu}_{\tilde{A}}(x)$ and a lower membership function $\underline{\mu}_{\tilde{A}}(x)$ [22,23,25].

2.2.1. Interval type-2 fuzzy logic system

An interval type-2 fuzzy logic system contains four components: rules, fuzzifier, inference engine, and the output processor, which is formed by a type-reducer and the defuzzifier that are interconnected, as shown in Fig. 3. An IT2-FLS can be viewed as a mapping

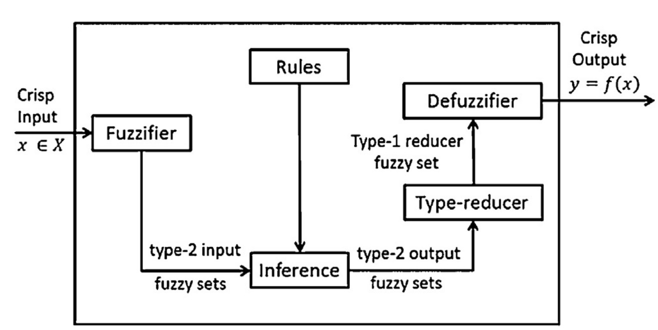

Fig. 3. Interval type-2 fuzzy logic system.