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Applications of Fuzzy Logic in Image Processing – A Brief Study

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Abstract: The subject of this study is to show the application of fuzzy logic in image processing with a brief introduction to fuzzy logic and digital image processing. Digital image processing is an ever expanding and dynamic area with applications reaching out into our everyday life such as medicine, space exploration, surveillance, authentication, automated industry inspection and many more areas. Fuzzy logic, one of the decision-making techniques of artificial intelligence, has many application areas. Although it has been subjected to criticisms since its birth, especially in recent years, fuzzy logic has been proven to be applicable in almost all scientific fields. This shows that the concept of fuzzy logic will maintain its validity and the number of fields where it draws attention will increase further.

Keywords: Fuzzy Logic, Image Processing, Fuzzy Image Processing, Fuzzy Inference System.

1. INTRODUCTION

This work is structured into three parts. The first part gives a brief introduction to digital image processing [1]. Given the importance of digital image processing and the significance of their implementations on hardware to achieve better performance, this work addresses image processing algorithms like median filter, morphological processing, convolution operation and edge detection. The second part gives an introduction to fuzzy logic [2] and also covers topics concerning a range of technologies used in the fuzzy image processing systems, e.g. image sensors, signal processing units, memory technologies and displays. Finally, the applications of fuzzy logic in image processing are briefly explained.

2. THE CONCEPT OF IMAGE PROCESSING

An image may be defined as a two-dimensional function f(x, y), where x and y are spatial coordinates. The amplitude of f at any pair of coordinates (x, y) is called intensity or gray level of image at that point. When x, y, and the amplitude values of f are all finite, discrete quantities, the image is called a digital image. The processing of digital images by means of digital computer is called digital image processing. Note that, a digital image is composed of finite number of elements, each of which has a particular location and value. These elements are referred to as image elements, picture elements, pels, or pixels (see Figure 1). Pixel is the term used most widely to denote the elements of a digital image [3].

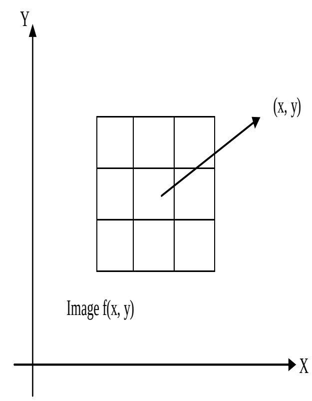

Figure 1: Digital Image.

The most commonly used image processing algorithms like, 1) Filtering, 2) Morphological Operations, 3) Convolution, and 4) Edge detection [1].

2.1 Procedures for Hardware Implementation

There are two types of technologies available for hardware design. Full custom hardware design also called as Application Specific Integrated Circuits (ASIC) and semi custom hardware device, which are programmable devices like Digital signal processors (DSPs) and Field Programmable Gate Arrays (FPGA's). Full custom ASIC design offers highest performance, but the complexity and the cost associated with the design is very high. The ASIC design cannot be changed and the design time is also very high. ASIC designs are used in high volume commercial applications. In addition, during design fabrication the presence of a single error renders the chip useless. DSPs are a class of hardware devices that fall somewhere between an ASIC and a PC in terms of the performance and the design complexity. DSPs are specialized microprocessors, typically programmed in C, or with assembly code for improved performance. It is well suited to extremely complex math intensive tasks such as image processing. Field Programmable Gate Arrays are reconfigurable devices. Hardware design techniques such as parallelism and pipelining techniques can be developed on a FPGA, which is not possible in dedicated DSP designs. Implementing image processing algorithms on reconfigurable hardware minimizes the time-to-market cost, enables rapid prototyping of complex algorithms and simplifies debugging and verification. Therefore, FPGAs are an ideal choice for implementation of real time image processing algorithms. A comparison is made for the areas where each of these technologies prevails. This is shown in Table 1.1 and 1.2.

Table 1.1: Comparisons of different types of signal processing technologies [1]

Technology	Performance	Power	Flexibility	Price
ASIC	Excellent	Good	Poor	Excellent
DSP	Excellent	Excellent	Excellent	Excellent
FPGA	Excellent	Fair	Excellent	Poor

Table 1.2: Comparisons between ASICs and FPGAs [1]

Performance Metric	ASICs	FPGAs
Power	Low	High
Flexibility	Low	High
Clock Speed	High	Low
Logic Integration	High	Low
Integrated Features	Low	High
Back-end Design Effort	High	Low
Unit Cost with Volume Production	Low	High

No perfect technology exists that is competent in all areas. For a balanced embedded system design, a combination of some of the alternative technologies is a necessity. FPGAs have traditionally been configured by hardware engineers using a Hardware Design Language (HDL). The two principal languages used are Verilog HDL (Verilog) and Very High Speed Integrated Circuits (VHSIC) HDL (VHDL), which allows designers to design at various levels of abstraction. Verilog and VHDL are specialized design techniques that are not immediately accessible to software engineers, who have often been trained using imperative programming languages.

Consequently, over the last few years there have been several attempts at translating algorithmic oriented programming languages directly into hardware descriptions. C-based hardware descriptive languages have been proposed and developed since the late 1980s. Some of the C-based hardware descriptive languages include Cones, HardwareC, Transmogrifier C, SystemC, OCAPI, C2Verilog, Cyber, SpecC, Nach C], CASH. A new C like hardware description language called Handel-C introduced by Celoxica, allows the designer to focus more on the specification of an algorithm rather than adopting a structural approach to coding.

Application Specific Integrated Circuits (ASICs) represent a technology in which engineers create a fixed hardware design using a variety of tools. Once a design has been programmed onto an ASIC, it cannot be changed. Since these chips represent true, custom hardware, highly optimized, parallel algorithms are possible. However, except in high-volume commercial applications, ASICs are often considered too costly for many designs. In addition, if an error exists in the hardware design and is not discovered before product shipment, it cannot be corrected without a very costly product recall. Digital Signal Processors (DSPs) are a class of hardware devices that fall somewhere between an ASIC and a PC in terms of performance and design complexity. They can be programmed with either assembly code or the C programming language, which is one of the platform’s distinct advantages. Hardware design knowledge is still required, but the learning curve is significantly lower than some other design choices, since many engineers have knowledge of C prior to exposure to DSP systems. However, algorithms designed for a DSP cannot be highly parallel without using multiple DSPs. Algorithm performance is certainly higher than on a PC, but in some cases, ASIC or FPGA systems are the only choice for a design. Still, DSPs are a very common and efficient method of processing real-time data. Field Programmable Gate Arrays (FPGAs) represent reconfigurable computing technology, which is in some ways ideally suited for video processing. Reconfigurable computers are processors which can be programmed with a design, and then reprogrammed (or reconfigured) with virtually limitless designs as the designer’s needs change. FPGAs generally consist of a system of logic blocks (usually look up tables and flip-flops) and some amount of Random Access Memory (RAM), all wired together using a vast array of interconnects. All of the logic in an FPGA can be rewired, or reconfigured, with a different design as often as the designer likes. This type of architecture allows a large variety of logic designs dependent on the processor’s resources, which can be interchanged for a new design as soon as the device can be reprogrammed.

3. THE CONCEPT OF FUZZY LOGIC

Fuzzy control techniques have attracted significant interest and have become an important part of modern control engineering. The use of linguistic knowledge in the form of IF-THEN rules gives a fuzzy system the ability to work as a universal approximator to nonlinear functions.

Fuzzy logic is a logical system which is an extension of multi-valued logic. In logics system multi-valued logic is a propositional calculus in which there are more than two truth values. There are only two possible values true or false for any proposition but extension to classical two valued logic is an n-valued logic or n greater than two.

Fuzzy logic is conceptually easy to understand and is flexible and is tolerant of imprecise data. Fuzzy logic is to map an input space to an output space and for doing this a list of if then statements called rules are evaluated in parallel .These Rules are useful because they use variables and adjectives that describes those variables.

A typical fuzzy logic controller (FLC) consists of a fuzzification module, fuzzy inference engine, defuzzification module (see Figure 2) and pre- and post-processing modules [4].

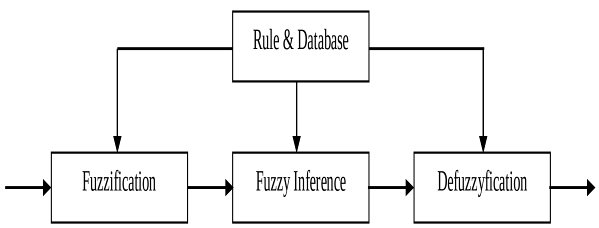

Figure 2: General Fuzzy Logic Controller.

4. FUZZY IMAGE PROCESSING

Fuzzy image processing [5, 6] is the collection of all approaches that understand, represent and process the images, their segments and features as fuzzy sets. The representation and processing depend on the selected fuzzy technique and on the problem to be solved. Fuzzy image processing has three main stages: image fuzzification, modification of membership values, and, if necessary, image defuzzification as shown in Figure 3.

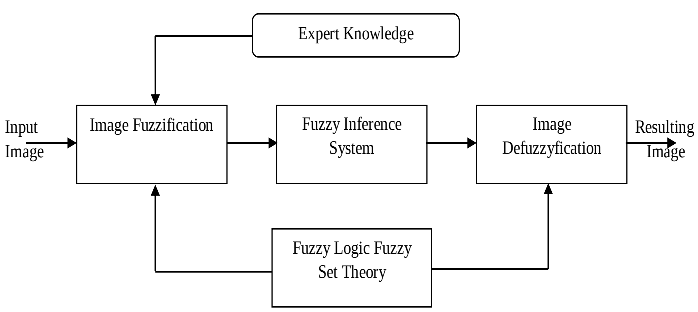

Figure 3: The General Structure of Fuzzy Image Processing.

The fuzzification and defuzzification steps are due to the fact that we do not possess fuzzy hardware. Therefore, the coding of image data (fuzzification) and decoding of the results (defuzzification) are steps that make possible to process images with fuzzy techniques. The main power of fuzzy image processing is in the middle step (modification of membership values).After the image data are transformed from gray-level plane to the membership plane (fuzzification), appropriate fuzzy techniques modify the membership values. This can be a fuzzy clustering, a fuzzy rule-based approach, a fuzzy integration approach and so on.

5. APPLICATIONS OF FUZZY LOGIC IN IMAGE PROCESSING

In our investigation of papers on utilization of fuzzy logic in image processing, we have reached many papers on many application areas. However, in this study, we consider the fields of agriculture, medicine and industry the most remarkable ones in general. Typical applications of studies in such fields are given below:

5.1 Fuzzy Color Credibility Approach to Color Image Filtering

With this study, fuzzy modeling of the concept of color credibility was applied to color image filtering. On the basis of the perceptual notion of color resemblance, the colors are modeled as fuzzy sets in the CIELAB color space. The principle of filtering is to select at the filter output the color that is the most credible with respect to the rest of colors within the filtering window. Although this approach does not make any assumption on the desired filter type, the result is similar to a vector median type filter [7].

5.2 Vision Intelligence for Farming Using Fuzzy Logic Optimized Genetic Algorithm and Artificial Neural Network

This study aimed at an intelligent vision system for autonomous vehicle field operations. Fuzzy logic was used to classify crops and weeds. A Genetic Algorithm (GA) was used to optimize and tune the fuzzy logic membership rules. Field study confirmed that the method developed was able to accurately classify crop and weeds through the entire growing period. After segmenting out the weed, an artificial neural network (ANN) was used to estimate the estimates crop height and width. The r2 for estimation of the crop height was 0.92 for the training data and 0.83 for the test data. Finally, a geographic information system (GIS) was used to create a crop growth map [8].

5.3 Fuzzy Logic Approach to Numerical Water Level Gauge

The watermarking system proposed in this paper offers an expert system technique to help solve the ownership claim for accidental attacks on digital images. The proposed spatial domain watermarking system is based on fuzzy logic and was designed with the intent of embedding watermark features such that they are undetectable to the human visual system. In order to achieve this, it is necessary to develop and design watermarking scheme targets three of the five perceptual holes of the human visual system. The resulting watermarking scheme was evaluated using image processing techniques typical of an accidental attack process. The evaluation of the embedded watermark was subjected to a limited sample of human visual system observers [9].

5.4 A Fuzzy Data Fusion Method for Improved Motion Estimation

As previous work has shown, information from different artificial image approaches to the same problem can be combined to produce more robust results. Often, information from a technique looking at a completely different aspect of an image (object) can also be of use. Fuzzy set theory has yielded useful results in combining the results of image processing techniques for different problems. This approach is illustrated by the use of texture information to improve the results of motion estimation methods [10] Fuzzy Subset hood Based Color Image Processing This study presents uses the concept of fuzzy subset hood for defining a new class of color image processing operations. By considering a color value as a fuzzy set, the fuzzy subset hood becomes applicable to color images. From this, a simple color threshold operation can be defined, which gives a gray value image from the degrees of subset hood. Also, mathematical morphology can be applied to color images this way. This gives the Fuzzy Pareto Morphology (FPM), which fulfills basic requirements for a generalized morphology. An extension of the difference image to color images and an operation given by the intermediate result of FPM are called as new operations. The fuzzy subset hood allows for the definition of a new class of comprehensive color image processing operations [11].

5.5 Fuzzy Rules and GIS in Three Dimensional Prediction

While a full soil survey based on intensive sampling is probably the best way to determine soil conditions at a large scale, this is not always feasible or necessary. In many cases, predictions by an experienced soil surveyor, based on less expensive information such as topography, aerial photography, or land use data, can be an alternative. The three-dimensional rule-based continuous soil modeling system (TRCS) provides an environment for formulating fuzzy rules that link soil conditions to landscape information. Soil information is represented in the form of fuzzy profiles based on a set of horizon classes optimized for their predictive powers.

5.6 Object Recognition in Robot Football by Using One Dimensional Image

Robot football is an increasingly developing area in the world of autonomous robots and related research fields. One of the main problems in this task is to determine the presence and location of objects from the robot's point of view. This method is tested on a simulator of a Khepera autonomous mobile robot with an onboard one dimensional 256 gray level black-white camera. The objects in the field are the light gray walls, a simulated yellow tennis ball, and a black goal area. Three methods are introduced in this work: In the threshold based method, a high pass filter is used multiple times to detect the rising and falling edges, and then a threshold is applied over the detected edges to eliminate the false edges. After the detection of the edges, regions are detected. By using the number of regions, the mean value of each region, and the standard deviation of the regions, several rules, which are needed to classify the regions, are extracted. These rules use the relations between the objects, relative to each other. The second method is based on a neural network, and the last method uses fuzzy expert systems, to recognize the objects [12].

6. CONCLUSIONS

Present day applications require various kinds of images as sources of information for interpretation and analysis. When an image is converted from one form to another (such as digitizing, scanning, transmitting, storing, etc.) degradation occurs. Hence the output image has to undergo a process called image enhancement, which consists of a collection of techniques that seek to improve the visual appearance of an image. Image enhancement is basically improving the interpretability or perception of information in images for human viewers and providing 'better' input for other automated image processing systems [1].

The fuzzy set theory is incorporated to handle uncertainties (arising from deficiencies of information available). The fuzzy logic provides a mathematical framework for representation and processing of expert knowledge. The concept of if-then rules plays a role in approximation of the values like crossover point. The fuzzy if-then rules are a sophisticated bridge between human knowledge on one side and the numerical framework of computers on the other side. They are simple and easy to understand. It can be used to achieve a higher level of image quality considering the subjective perception and opinion of human observers. Fuzzy theory can be used to overcome the drawbacks of spatial domain methods like thresholding and frequency domain methods like Gaussian low pass filter to improve the contrast of an image. In future Nuro-Fuzzy techniques can be used to enhance the quality of images.

The uncertainties within image processing tasks are not always due to randomness but often due to vagueness and ambiguity. Fuzzy technique enables us to manage these problems effectively.

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