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Integrated GUI Environment of Parallel Fuzzy Inference System for Pattern Classification of Remote Sensing Images

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Abstract

In this paper, we propose an integrated GUI environment of parallel fuzzy inference system for pattern classification of remote sensing data. In this, as 4 fuzzy variables in condition part and 104 fuzzy rules are used, a real time and parallel approach is required. For fast fuzzy computation, we use the scan line conversion algorithm to convert lines of each fuzzy linguistic term to the closest integer pixels. We design 4 fuzzy processor unit to be operated in parallel by using FPGA. As a GUI environment, PCI transmission, image data pre-processing, integer pixel mapping and fuzzy membership tuning are considered. This system can be used in a pattern classification system requiring a rapid inference time in a real-time.

Key words : remote sensing data, pattern classification, parallel inference, GUI

1. Introduction

At present, fuzzy logic models are successfully being used in many engineering applications involving control, expert system and pattern recognition. The pattern classification of multi-spectral image data obtained from satellites or aircrafts has become an important tool for generating ground cover maps. . In this paper, We use fuzzy theory for pattern classification of the remote sensing images. The digital images for experimentation are acquired with the airborne multi-spectral scanner(AMS) sensor. The test images consist of 388 lines, with 388 pixel per line, one pixel size of about 3× 3m, and the 3 visible and 1 near-infrared bands among the 6 bands. Using these 4-band images, the pattern classification is performed by applying the fuzzy inference to each pixel and the entire fuzzy rules. However, There needs very lange fuzzy computation because of many fuzzy floating-point operations. To reduce the drawback of real valued operation in [0,1], in this paper, we use an integer pixel conversion algorithm. In this, we select and plot the only integer pixel from 0 to 31 for fuzzy membership grades. Therefore, a fuzzy membership degree of [0, 1] is mapped into the closest integer from 0 to 31. The same procedure is applied to the universe of discourse (integer value 0 ~ 255 in x-axis). In this paper, we design 4 fuzzy processing units to be operated in parallel by FPGA to each band.

We also use the PCI interface bus between PC and the parallel fuzzy inference system to be proposed in order to transmit the large volumes of data rapidly. For the GUI environment for pre-processing of images and tuning of the membership functions, an integrated GUI application program is implemented by VC^{++}.

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2. Pattern classification of remote sensing images

2.1 Analysis of remote sensing data

The given test image is covered over Daeduk Science Complex Town, Daejon, Korea and consists of 3 visible and 1 near infrared band. Fig. 1 shows this image represented by gray-scale levels.

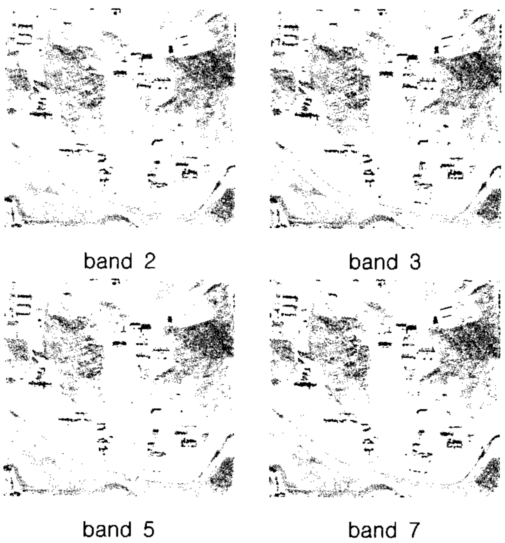

Fig. 1 Remote sensing images about each band

From the 3 (7-5-3 band, 7-3-2 band) among 4 bands, false color images are generated form their gray-scale levels. Using these images, we choose the 8 classes as shown in the Table. 1 for the land cover map.

Table. 1 Class for land cover map

Class	color	classification
C1	Red	Coniferous Tree
C2	Green	Deciduous Tree
C3	Blue	Water
C4	Black	Asphalt Road
C5	White	Cement Road
C6	Gray	Shadow
C7	Violet	Bare Soil
C8	Orange	Dried Grass

2.2 Fuzzy membership function for pattern classifications

We use 104 fuzzy rules for the pattern classification. There are 12 fuzzy linguistic terms in the condition part. The shapes of fuzzy membership functions are shown in Fig. 2.

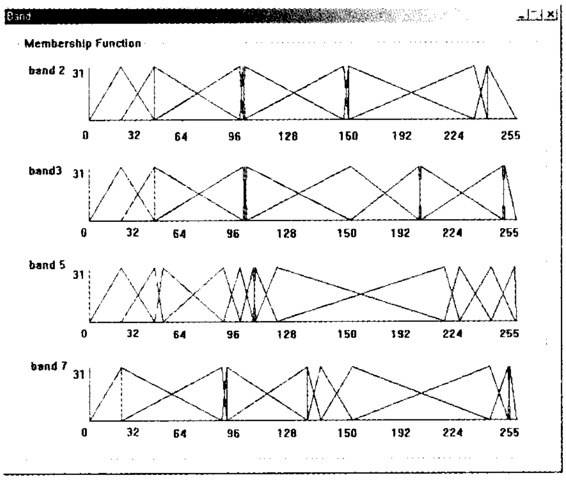

Fig. 2 Membership function in the condition part

The membership value of each fuzzy rule for a given pixel's image is computed by fuzzy implication. The output of the fuzzy controller is inferred from the input and the fuzzy rule by compositional rule of inference. The inferred fuzzy output is defuzzified by taking a deterministic value which represents one out of 8 classes. There are 8 fuzzy linguistic terms as shown in Fig. 3 in the consequent part.

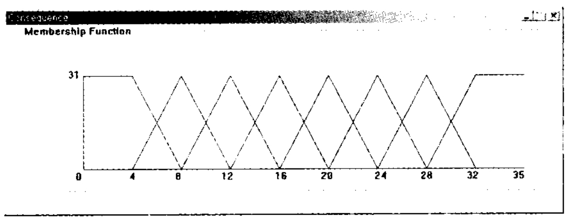

Fig. 3 Membership function of the consequent part

2.3 Fuzzy control rule

In this paper, we use 104 fuzzy rules out of 778 fuzzy rules produced to classify the test image from the training set. The form of the fuzzy rules is as following.

Rule 1 : IF I1 IS -3 AND I2 IS -3 AND I3 IS -3 AND I4 IS 3 THEN C1
Rule 2 : IF I1 IS -3 AND I2 IS -3 AND I3 IS -3 AND I4 IS 2 THEN C1
Rule 3 : IF I1 IS -3 AND I2 IS -3 AND I3 IS -4 AND I4 IS 3 THEN C1
.
.
.
Rule 103 : IF I1 IS 2 AND I2 IS 2 AND I3 IS 3 AND I4 IS 4 THEN C8
Rule 104 : IF I1 IS 1 AND I2 IS 2 AND I3 IS 2 AND I4 IS 4 THEN C8

2.1.2 Defuzzification

The defuzzifier procedure accepts a set of singletons, one from the consequent of each rule, to produce a single value as a final conclusion. Since a crisp output is required, the center of gravity method is used to achieve defuzzification.

$$\varphi^{0} = \frac{\sum w_i \varphi_i}{\sum w_i}, \quad w_i = \bigwedge_{j=1}^{n} \mu_i x_i \quad (n=12)$$

Here, w_i is the intermediate degree of fulfillment. The class of land cover is finally determined by the range of the values of the defuzzification stage. Table. 2 shows the class and its range of the values.

Table. 2 Classes and their range

Class	Range	Class	Range
C1	0-8	C5	16-24
C2	4-12	C6	20-28
C3	8-16	C7	24-32
C4	12-20	C8	28-36

3. Fuzzy inference system environment

3.1 Fuzzy inference system interface

In this paper, we implement an integrated GUI environment system by VC^{++} under the Win2000. This program transmits data from PC via PCI to the parallel fuzzy processor and receives the computed from the parallel fuzzy inference system result via PCI and shows the classified image on the screen. This application program (Satellite Image Pattern Classification) consists of 3 stages as shown in the Fig. 4.

3.2 Images analysis (Stage 1)

In the stage 1, convert remote sensing data, and save integer value. Remote sensing data has several band values and this is saved in Low Image. In this paper, Data about pixel of each band have integer type that correspond to intensity values between 0 to 255. Each intensity value is used by single input value in parallel fuzzy processor.

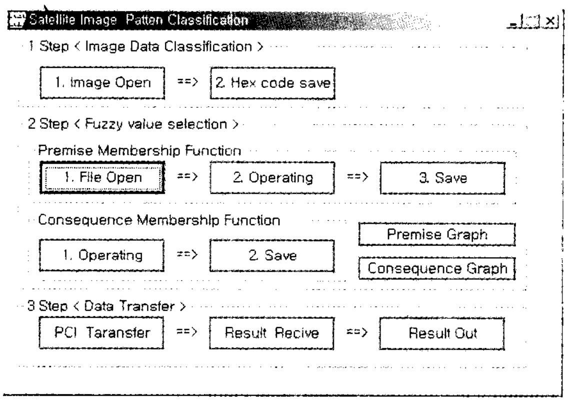

Fig. 4 Application program for fuzzy inference

3.3 Membership function value arithmetic (Stage 2)

In the stage 2, find membership function value of condition and consequent parts.

Compute the determinate fuzzy membership function value of each band and save particularly fuzzy term. Membership function of trigonometric function form has 3 summits and compute fuzzy membership value to data of this values. Each fuzzy term has membership value of real number value between 0 and 1. Do 0 and 1 interval 32 division into equal parts about fuzzy value that have float value to solve operand speed decline problem by float arithmetic in this paper. Do fuzzy membership value of real type to have integer type changing real value between [0, 1] to integer value between [0, 32] using integer conversion algorithm.

In general, a line is represented as

$$F(x,y) = ax + by + c = 0.$$

If $dy = y_{k+1} - y_k$, and $dx = x_{k+1} - x_k$, this line can be written as $y = \frac{dx}{dy}x + B$

Therefore,

$$F(x,y) = dyx - dxy + Bdx = 0.$$

Here, $a = dy, b = -dx$ and $c = Bdx$.

To apply the mid-point scan algorithm, we have to compute $\left(F(x_k+1,\ y_k+\frac{1}{2}\right)$ to test its sign. Therefore, the decision variable is represented as

$$d = F(x_k+1,\ y_k+\frac{1}{2} = a(x_k+1) + b\left(y_k+\frac{1}{2}\right) + c$$

Here, we select the next pixel E if $d \le 0$. When E is chosen, dnew and dold can be written as

$$d_{new} = F(x_k+2,\ y_k+\frac{1}{2}\Big) = a(x_k+2) + b\left(y_k+\frac{1}{2}\right) + c$$

$$d_{old} = a(x_k+1) + b\left(y_k+\frac{1}{2}\right) + c$$

Therefore, $\Delta E = d_{new} - d_{old} = a + dy = 2dy$

If $d<0$, then we choose the pixel NE. when NE is chosen, dnew and dold can be written as

$$d_{new} = F\left(x_k+2,\ y_k+\frac{3}{2}\right) = a(x_k+2) + b\left(y_k+\frac{3}{2}\right) + c$$

$$\Delta NE = d_{new} - d_{old} = a + d + dy - dx = 2(dy - dx)$$

Therefore,

$$\Delta NE = d_{new} - d_{old} = a + d + dy - dx = 2(dy - dx)$$

The value of decision variable at the start point is

$$d_{start} = F\left(x_0+1,\ y_0+\frac{1}{2}\right) = a + \frac{b}{2} = 2dy - dx$$

We can select and plot the next integer pixel point by point whose fuzzy membership degree is closest to the line path. This efficient scan line conversion algorithm converts lines of fuzzy terms by using only incremental integer computations.

By making the slope of the line less than 1.0, the aliasing effect of line drawing is reduced. In this paper, we define the x coordinate as 0 ~ 255, and the y coordinate as 0 ~ 31, so the slope of each line of fuzzy terms is always set less than 1.0. Compute value for membership function of the condition and the consequent part by this method, and save values in integer type.

3.4 Data transmissions and result (Stage 3)

In the stage 3, transmit data of input value, condition part and consequent part fuzzy membership function value, 104 fuzzy rules received from stage 1 to PC by parallel fuzzy inference system via PCI bus.

Receive the result via PCI bus pattern in parallel fuzzy inference system, and shoe the pattern classed result on screen.

4. Parallel fuzzy inference system

4.1 Organization of parallel fuzzy inference system

4 gray-scale images of each band for remote sensing data are inputted to the parallel fuzzy inference system. Fig. 5 illustrates the organization of the proposed parallel fuzzy inference system.

Each Component in the Fig. 5 performs the following function.

(1) PCI 9054 Interface Chip

It controls the PCI bus and conducts the transmission of the instruction and data between application program and the PCI board.

(2) MC (Main Controller)

It saves the Fuzzy rules and fuzzy membership functions sent from the application program via PCI bus to the corresponding memories, and controls 4 FAUs (Fuzzy Arithmetic Unit) simultaneously.

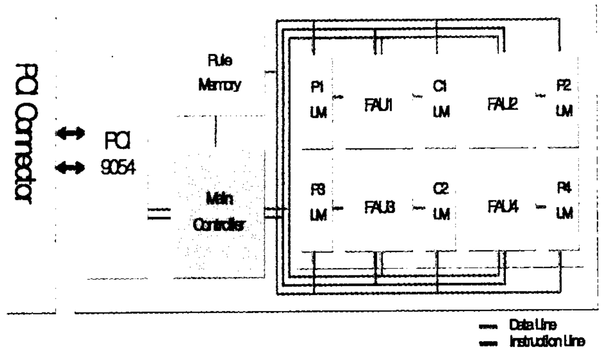
Fig. 5 Organization of parallel fuzzy system

(3) FAU (Fuzzy Arithmetic Unit)

It performs the computations of the fuzzy MIN/MAX operations by using the fuzzy input values and fuzzy terms saved in the local memory The proposed system can process the 4 FAU operations in parallel.

(4) PiLM(Premise i Local Memory)

It saves the values of all fuzzy terms belong to the i-th condition part. In this paper, the number of the fuzzy terms in the condition part is 12.

(5) CjLM (Consequent j Local Memory)

It saves the values of the fuzzy membership functions in the j-th consequent part. The number of the fuzzy terms in the consequent part is 8. It also has the t1 and t2 regions in order to save the intermediate value in computing of the consequent part..

(6) RM (Rule Memory)

It saves the entire fuzzy rules and each value of the degree of fulfillment in the condition part.

4.2 Detailed organization of parallel fuzzy inference system

4.2.1 MC(Main Controller)

Registers in the MC are illustrated in Fig. 6 C field selects the memory location to be saved for data

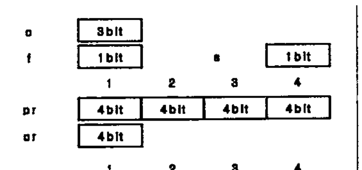
Fig. 6 Registers of MC interior

among the 7 memories (Rm, P1LM, P2LM, P3LM, P4LM, C1LM and C2LM). f flag shows the state representing the condition or consequent part. s flag means the start signal. pr and cr save the indexes of fuzzy rules in the condition and consequent part, respectively. pv value are used in finding the minimum values of the 4 α-level values in the condition part. t1 and t2 are temporary registers for magnitude comparison to the results in the consequent part.

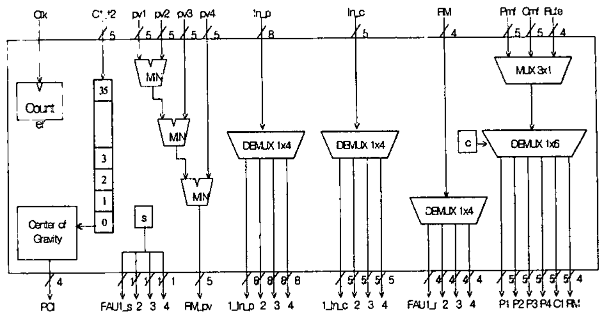
Fig. 7 Inside architecture of MC

To send the data from PCI to each memory module, the sequence is controlled by counter. Inside architecture of MC is illustrated in Fig. 7 and performs as follows.

1) Incoming data from PCI bus are sent to the appropriate memory module according to the c register.

2) in_p, in_c sends input value of condition part and consequent part by relevant FAU's in_p and in_c according to control order of MC.

3) Send the fuzzy control rules saved in RM to appropriate r in FAU.

4) s signal start the fuzzy computations.

5) In the case of the condition part, saves the computed value of in_p and r of each FAU to pv and finds the smallest value among the values of pv and saves it to RM_pv.

6) Compute the center of gravity of the t2 in the C1 memory, and transmit the controled to the application program via PCI bus.

4.2.2 FAU(Fuzzy Arithmetic Unit)

FAU performs the fuzzy computation about the input value of each band. Fig. 8 shows the internal registers in the FAU.

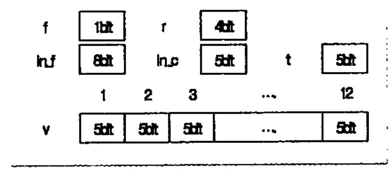
Fig. 8 Registers in the FAU

f flag indicates the state whether the system is computing on the condition or consequent part. In-p and In-c have the input values for operation in the condition and consequent part, respectively. t is a temporary register used in comparing input value and fuzzy membership value in the consequent part. r register has the index value of fuzzy term coming from the current fuzzy rule. v register save the fuzzy membership degree.

1) In the care of the condition part, find the appropriate value among the 12 fuzzy terms, according to in-p and r, and sent it to pv in the MC.

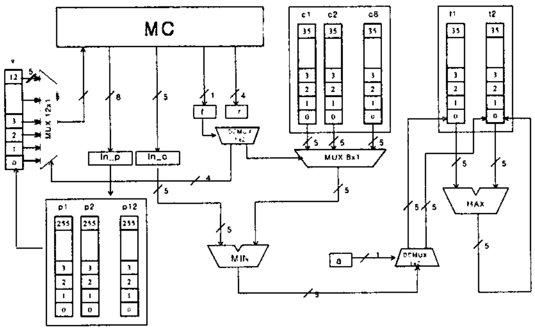

Fig. 9 Inside architecture of FAU

2) In the care of the consequent part, after comparing in_c with the corresponding fuzzy term in C1 memory by the value of r, save the minimum value of them to register t2 on the first data of in_c.

3) From the second data, save the minimum value to register t1. After comparing t1 and t2, save the maximum value of them to register t2.

4.2.3 RM(Rule Memory)

RM has the index numbers of fuzzy terms about entire fuzzy rules. Fig. 10 shows the structure of RM.

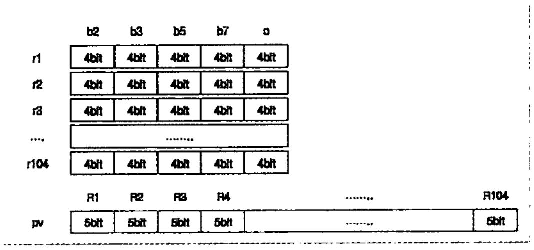

Fig. 10 Organization of RM

Register from r1 to r104 have fuzzy rules for the fuzzy operations. Find degrees of fulfillment in the condition part are saved in register pv.

4.2.4 PiLM(Premise i Local Memory)

Fig. 11 shows the organization of PiLM. In each register from p1 to p12, the membership values of the corresponding fuzzy term in the condition part are saved in the quantization form. Each FAU has its own PiLM memory.

4.2.5 CjLM(Consequence j Local Memory)

Fig. 12 illustrates the organization of CjLM. In each register from c1 to c8, the membership values of the corresponding fuzzy term in the consequent part are saved in the quantization form. t1 and t2 registers save the result values computed in the consequent part.

4.3 Sequence of parallel fuzzy inference

In our system, the condition and consequence part have 12 and 8 fuzzy terms, respectively. Inferred results are come for the entire 104 rules. The sequence of the system is as following as

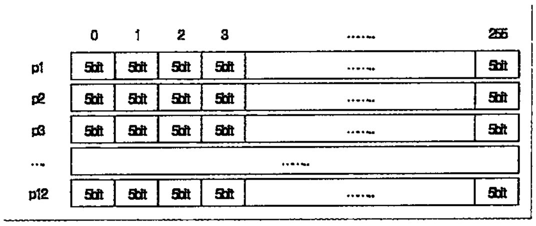

Fig. 11 Organization of PiLM

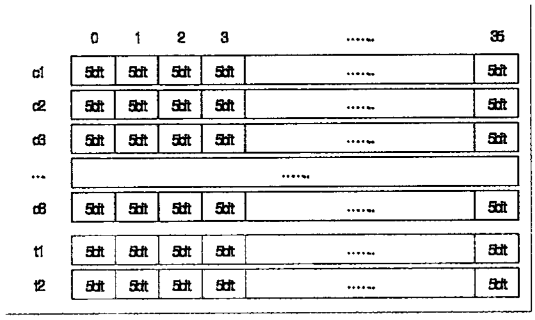

Fig. 12 organization of CjLM

1) Save the membership values of each fuzzy term of the condition and consequent part to the PiLM and CjLM, respectively, according to the control of MC.

2) Save the entire fuzzy rules to RM.

3) Save the fuzzy singleton input(gray level) to the register(in_p) in the FAU, operated 4 units in parallel.

4) Find the matched row of the local memory according to the in_p, and save them to v-register.

5) MC transmits the partial fuzzy rules of the condition part to each FAU.

5. Experiments

In this paper, we have implemented the integrated GUI environment system with 4 parallel fuzzy processing units to be operated in parallel. In this, we have solved the drawback of taking longer times as the fuzzy floating-point computation by using the integer pixel conversion algorithm. This gives the inferred results as faster as 20.7 times rather than conventional methods. We used the PCI interface bus between PC and the proposed parallel fuzzy inference system in order to transmit the large volumes of data rapidly. Fig. 13 shows the result image of the proposed method. Considering all the pixels from test image, it performs well with 92.57% correct classification. This is caused by the rounding operation of integer pixel mapping. However, only integer computations with 4 parallel inference unit give much faster classification result.

6. Conclusions

There are several advantages and new possibilities found in the proposed GUI environment for the parallel fuzzy inference system:

Fig. 13 Pattern classification image

1) The system architecture was implemented by FPGAs and can be processed in a real-time and parallel manners.

2) This system brought a fast fuzzy computation time by the integer pixel conversion algorithm.

3) PCI interface was used for the fast transmission of the large volumes of image data.

4) The integrated GUI environment gives users easy approaches to the parallel fuzzy inference system, the fuzzy tuning procedure, and the monitoring of the classified images.

The proposed system can be applied to the ground cover map, an environmental control and GIS system that require the fast processing time with large volumes of data. As a further research, an implementation as an embedded system is left. And Interfacing with the RDRAM memory modules possible to process upto 128 bits at one time will be considered.

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