AN ENHANCED SYSTEM FOR PATTERN RECOGNITION AND SUMMARISATION OF MULTI-BAND SATELLITE IMAGES

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Abstract: This paper presents an enhanced system developed in Java® for pattern recognition and pattern summarisation in multi-band (RGB) satellite images. Patterns such as island, land, water body, river, fire, urban settlement in such images are extracted and summarised in linguistic terms using fuzzy sets. Some elements of supervised classification are utilised in the system to assist in the development of linguistic summaries. Results of testing the system to analyse and summarise patterns in SPOT MS images and LANDSAT images are also discussed.

1 INTRODUCTION

Data mining includes a broad spectrum of processes and techniques that analyse raw data to discover implicit patterns that are useful for decision-making. Pattern recognition is considered as another form of data mining because both focus on the extraction of information or relationships from data. All data mining techniques are not universally applicable to all types of multimedia. A particular data mining technique may be successful with one type of multimedia such as images, but the same technique may not be well suited to many other types of multimedia due to varying structure and content.

In (Zaine et al., 1998), the objective is to mine internet-based image and video. The results generated could be a set of characteristic features based on a topic (keyword), a set of association rules which associate data items, a set of comparison characteristics that contrast different sets of data, or classification of data using keywords. From another perspective, (Barnard et al., 2003a), (Barnard et al., 2003b) describe the approach involved in matching images to text. Their work describes models used for automatic image annotation, browsing support and auto-illustration of blocks of text. Such models are focussed on prediction of words (from an available pool) that match with specific image regions. At this juncture, a comparison is made with some other commercially available software that has similar functionality. Definiens® eCognition (Definiens Industrial Profile, 2001) is based on object-oriented image analysis. Some rules for pattern classification are employed by the tool. Contextual information and data are used as input for this process. Definiens® Professional (Definiens, 2006) works with panchromatic, multi/hyper-spectral imagery, infrared, and polarimetric SAR data from space-borne and air-borne imaging platforms.

A system that classifies and summarises patterns such as water body, river, land, island, and fire, was described in (Nair, 2004). The system utilised fuzzy logic to describe these patterns. (Nair, 2006) introduced some significant changes to the system. A few of these changes have been implemented in C.T.R.F's LSGENSYS. LSGENSYS (Linguistic Summary Generation System) draws upon the earlier techniques of utilising fuzzy logic, but also adds a new significant element of user interaction via the blackboard architecture component (described in Section 2). This paper is organised as follows. Section 2 explains the architecture and design of the system. Section 3 explains the methodology and approach. Section 4 presents results of testing the system for image analysis, pattern recognition and summarisation on LANDSAT and SPOT MS satellite images. Section 5 presents the conclusions and future work.

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2 SYSTEM ARCHITECTURE

This paper presents an enhanced version of LSGENSYS (Nair, 2007). LSGENSYS is an integrated system that allows the user to analyse images, extract feature descriptors such as area, length, location etc of patterns and then use these descriptors to form linguistic summaries of these patterns. This system also provides an interactive environment, wherein, the user may suggest some possible linguistic summaries for the image patterns. The system would evaluate the fitness of these user-summaries. Alternately, the system could, without user intervention, generate some possible summaries and evaluate their fitness and suitability with respect to the image patterns.

The system architecture is shown in Figure 1. The input image is analysed and some feature descriptors extracted. These descriptors are stored thereafter in a relational table in the database. The blackboard holds the current state in the process of developing summaries. The user has the choice of suggesting concepts such as descriptions of area, length, location of patterns etc. The knowledge base uses geographic facts to define feature descriptors using fuzzy sets. It interacts with a built-in library of linguistic labels, which also interacts with the summariser as it supplies the necessary labels to it. The summariser receives input from these components and performs a comparison between actual feature descriptors of the image patterns stored in the database, the concepts suggested by the user, and the feature definitions stored in the knowledge base. After this comparison, the summariser uses the linguistic labels supplied by the library to formulate some possible summaries for each pattern/object in the database. These summaries are stored in the blackboard. From among these summaries, the most suitable one describing each pattern is selected by interaction with the engine (genetic algorithm). As the GA evolves through several generations, it generates better summaries (indicated by higher fitness, as defined in Section 4) which are then stored and indicated on the blackboard. Thus, the system includes some elements of supervised classification and summarisation. The following set of rules is developed to perform pattern classification and identification in multi-band satellite images.

1. If a pattern/object is to be classified as an island, it should have a water envelope surrounding it such that it has a uniform band ratio at at least eight points on this envelope (corresponding to directions E, W, N, S, NE, NW, SE, SW). Also grey level values on the envelope could be lower than the grey level values on the object.
2. If an object does not have an envelope in all directions as described in rule (1) above, then it is classified as land.
3. If an object is to be classified as water body (expanse of water, river), it is necessary that it should have a uniform band ratio.
4. Fire is classified as a separate pattern. It is identified by applying colour density slicing to the image and by viewing the histogram of the affected area. The histogram would show a majority of pixels at lower intensity for the burnt scar area near the fire.
5. The enhanced system presented in this paper includes the capability to recognise and summarise urban settlements in an image. This new rule for classification is described as follows. Urban settlements are classified based on their shape and their grey level intensity. In this paper, an attempt is made to identify only rectangular and circular-shaped urban settlements. The shape ratio (defined as ratio of the area of the urban settlement to the area of the bounding rectangle or bounding circle, as the case may be, provided both shapes equal in perimeter or circumference) is a major parameter in this classification process. Shape ratio closest to a value of 1 is ideal. The grey level intensity (closeness to white colour, where the triplet (R,G,B) = (255,255,255), for urban settlement) is another parameter used in this process. (Younes et al., 2004) provided the basis for the development of this criterion. A percentage of accuracy is calculated (Section 4) and associated with this classification. No attempt is made to describe the size of the urban settlement.

The summaries generated by the system for patterns such as land, island, water body, and river are also more descriptive as shown in Section 4.

3 APPROACH

The attributes of patterns that are used to develop their linguistic summaries are area, length, location (X, Y pixel co-ordinates of centroid of pattern in image), Additional Information or Pattern Id, grey level intensity, and Shape Id. These attributes are calculated /extracted automatically by the GUI tool.

The linguistic summary of patterns/objects is evaluated as follows.

If $Y = y_1, y_2, \ldots y_p$ (1)

then

$$truth(y_i is F) = \mu_F(y_i) : i = 1,2,\ldots,p, \quad (2)$$

where $\mu_F(y_i)$ is the degree of membership of y_i in the fuzzy set F and $0 \le \mu_F(y_i) \le 1$. The linguistic proposition y_i *is* F could be instantiated as for example, *Island is moderately large*.

In order to generate such summaries, it is necessary to formulate fuzzy sets that quantify area/length attributes of the object/pattern. Triangular and trapezoidal fuzzy sets (totally twenty nine sets) have been formulated. The linguistic description is calculated as follows:

$$T_j = m_{1j} \wedge m_{2j} \wedge \ldots m_{nj} \;, \quad (3)$$

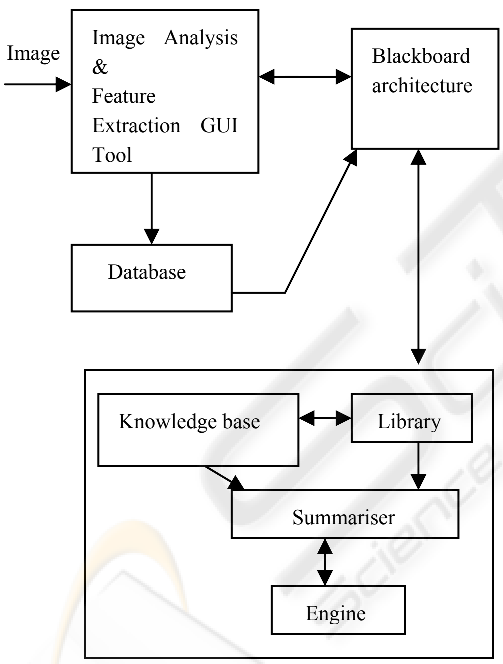

Figure 1: System architecture.

where m_{ij} is the matching degree (Kacprzyk, Ziolkowski, 1986) of the *ith* attribute in the *jth* tuple. $m_{ij} \in [0,1]$ is a measure of degree of membership of the *ith* attribute value in a fuzzy set denoted by a fuzzy label. The logical AND ($\wedge$) of matching degrees is calculated as the minimum of the matching degrees (Kacprzyk, Ziolkowski, 1986).

$$T = \sum_{j=1}^{k} T_j \quad \forall m_{ij} \ne 0, \quad (4)$$

T in equation (4) is a numeric value that represents the truth of a possible set of summaries of the k objects in the database. The next section discusses how the GA evolves the most suitable linguistic summary for all the objects by maximising T.

4 IMPLEMENTATION ISSUES

This section explains the implementation of the system, including the genetic algorithm approach and then discusses the results from applying this approach to analysing images.

4.1 GA Approach

Genetic algorithms are derived from the theory of evolution. Biological evolutionary theories are emulated by the genetic algorithm (GA) as it attempts to solve optimisation problems (Filho et al., 1994), (Goodman, 1996), (Smith et al., 1994). Each binary chromosome string in a population represents a possible linguistic summary for a pattern. Such a population of strings is manipulated by selection, cross-over and mutation operators in the GA (Filho et al., 1994) such that as the GA evolves through several generations, only those strings with highest fitness survive. The evaluation or fitness function for the linguistic summaries or descriptions of all objects in the table is

$$f = max(T), \quad (5)$$

where T is evaluated as shown in the previous section.

4.2 Results and Discussion

Image objects/patterns are classified at the highest level into land, water or fire. Land is further classified into island and other land. Water is further classified into river and other water body. Urban settlement is a pattern that can be identified on land or island. The fuzzy sets that quantify area or length are defined with reference to geographic facts such as:

- Largest continent is Asia with area of 44579000 km^2
- Largest freshwater lake is Lake Superior with area of 82103 km^2

- Smallest continent is Australia/Oceania with area of 7687000 km^2
- Longest river is the Nile with length 6669 km

In (6), the triangular fuzzy set for *considerably large expanse of water* is shown. The triangular fuzzy set for *fairly large expanse of water* is shown in (7).

$$\mu_{\text{considerably large expanse of water}}$$
$$\begin{aligned}(x) &= 1-(55068.66-x)/27034.33, \quad \textit{for } 28034.33 \le x \le 55068.66 \\ &= 1-(x-55068.66)/27034.33, \quad \textit{for } 55068.66 \le x \le 82103 \\ &= 0,\ x < 28034.33 \\ &= 0,\ x > 82103 \qquad (6)\end{aligned}$$

$$\mu_{\text{fairly large expanse of water}}$$
$$\begin{aligned}(x) &= 1-(1000-x)/900, \quad \textit{for } 100 \le x \le 1000 \\ &= 1-(x-1000)/27034.33, \textit{for } 1000 \le x \le 28034.33 \\ &= 0,\ x < 100 \\ &= 0,\ x > 28034.33 \qquad (7)\end{aligned}$$

An example SPOT MS satellite image to be analysed is shown in Figure 2. Figure 2 shows the image analysis tool of the system as it extracts the area attribute of two patterns in the image. These attributes are calculated and displayed in the data table in the figure. Pattern id attribute denotes numbers as follows: 0= River, 1=Water Body, 2=Island, 3=Land, 4=Fire, 5 = Urban settlement. For urban settlements, Shape ID = 1 indicates an approximately rectangular urban settlement, and Shape ID = 2 indicates an approximately circular urban settlement. Location is indicated by X, Y pixel co-ordinates of centroid of pattern/object. For river, its length is the most significant attribute for calculation, whereas for all other patterns, area is the most significant attribute for calculation.

The user may choose, at this stage, to interact with the system and suggest some possible summaries. The system can evaluate the fitness of the user-summaries and inform the user if they are most suitable to describe the image patterns in the table. After the user chooses triangular fuzzy sets in the knowledge base, the system displays triangular fuzzy set definitions in order to guide the user to select the appropriate fuzzy set for area or for length of different patterns such as land, island, water body, river etc. With the aid of these fuzzy set definitions, the user then constructs some possible pattern summaries as shown in Window 1. The fitness value (1.0) of these possible summaries is calculated and displayed in Window 1. Thereafter, the user may verify the correctness of these summaries and their suitability with respect to the image patterns by running the GA Inference Engine.

Figure 3 shows a snapshot of the GA Inference Engine as it runs (in the bottom left window) and evolves the most suitable summaries with higher fitness, over several generations. The summaries generated by the engine are captured in a text file as displayed in the top right window of Figure 4. The user may also chose to bypass the summary construction process, and directly invoke the inference engine (by pressing the Run button in Figure 2) to construct and generate the most suitable summaries. This would resemble automatic classification and description.

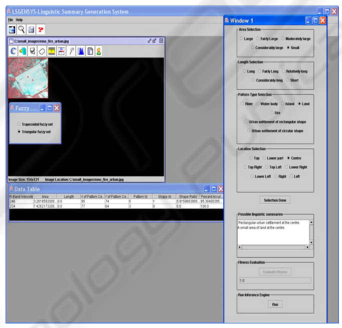

Figure 2: The image analysis tool of the system as it extracts area of patterns in a SPOT MS image. Approximate scale of image 1: 0.0003764.

The GA is run with following input parameter set. These parameter values are set after several trial runs.

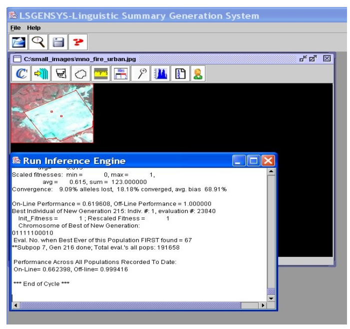

Figure 3: Snapshot of the GA Inference Engine as it runs and evolves the most suitable summaries that fit all the patterns extracted from the image.

No: of bits in a chromosome string of the population = 11

Generations per cycle = 27

Population size = 200 strings

Probability of cross-over = 0.545
Probability of mutation = 0.001

After 216 generations, the linguistic summaries generated for the data in Table 1 are:

- Rectangular urban settlement at the centre
- A small area of land of approximate area 7.428217 sq km at the centre

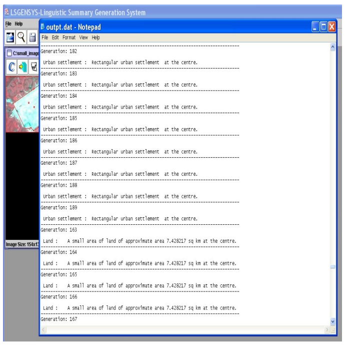

Figure 4: Snapshot of some of the final summaries generated by the GA Inference Engine.

Table 1 also shows the percentage accuracy of the classification of the patterns, as per the rules of classification in Section 2.

Thus, the possible summaries formulated by the user compare well with the summaries generated by the inference engine.

Table 1: Data calculated from image in Figure 2.

R-band grey level	Approx Area sq km	X	Y	Pattern Id	Shape Id	Shape Ratio	Percent Accuracy
246	3.28	95	74	5	1	0.916	95.3
234	7.43	77	64	3	0	0.0	100

Figure 5 and Figure 6 show the same procedure as applied to a LANDSAT image. Table 2 shows the data calculated from the image patterns. From the image in Figure 5, the system evaluates the fitness of the summaries formulated by the user. In this case, the fitness value calculated is 0.8736. The user-formulated summaries are:

- A moderately large expanse of water at the centre
- A small area of land at the top
- A small area of land in the lower part

The GA Inference Engine is invoked by the user to verify and validate the suitability of the possible set of summaries. The resulting summaries from the inference engine are enumerated below. The GA is run with the same input parameter set as before, with the exception that cross-over probability is set to 0.548.

After 216 generations, the linguistic summaries generated for the data in Table 2 are:

- A small area of land of approximate area 12172.15 sq km at the top
- A small area of land of approximate area 5474.89 sq km in the lower part
- A moderately large expanse of water of approximate area 17783.18 sq km at the centre.

These summaries match the user-formulated summaries.

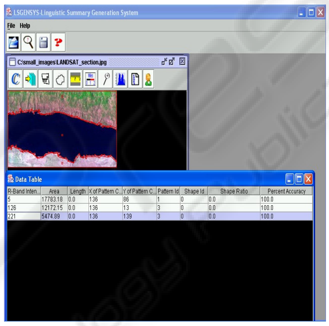

Figure 5: A LANDSAT image is analysed by the system. Approximate scale of image is 1: 0.952 sq km.

5 CONCLUSIONS AND FUTURE WORK

This paper has presented an enhanced system developed in Java for image analysis and pattern recognition in multi-band satellite images. The system architecture and design have been described. The system has been tested successfully with a SPOT MS image and a LANDSAT image and the results have been presented and discussed.

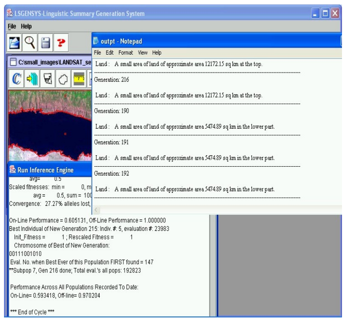

Figure 6: For the image in Figure 5, the GA is run and summaries generated are displayed in top right window.

Some directions of future work include:

- Adding a scripting feature that allows the user to program a sequence of image analysis instructions in a user-friendly language
- Adding the provision to upload ground data in order to help classify more patterns such as vegetation in satellite images using supervised classification techniques
- Adding enhancements to image analysis functions.

Table 2: Data calculated from image in Figure 5.

R-band grey level	Approx Area sq km	X	Y	Pattern Id	Shape Id	Shape Ratio	Percent Accuracy
5	17783.18	136	86	1	0	0.0	100
126	12172.15	136	13	3	0	0.0	100
221	5474.89	136	139	3	0	0.0	100

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