Expert Opinion in Satellite Data Interpretation*

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ABSTRACT: In this paper, the application of fuzzy set concepts in the area of remote sensing is introduced. More specifically, these concepts are employed for the interpretation of satellite data. Such interpretation can be performed through the judgment and experience of the experts who frequently use the linguistic value approach. Fuzzy set concept is used in this paper to mathematize linguistic values, leading to the development of fuzzy set models. Through the use of these models, one can obtain a consensus of several experts. Furthermore, one can obtain a consistent interpretation of a linguistic value. A relatively simple approach using various examples is demonstrated through the use of graphical representation in specific remote sensing applications.

INTRODUCTION

THE USE OF AERIAL PHOTOGRAPHS of satellite data is becoming an important tool for evaluating the general soil texture and other characteristics of a site (Lyon, 1987). An objective of this evaluation is to determine a suitable site for an engineering project, such as landfill. For example, older landfills were often developed in abandoned sand and gravel operations commonly located in glacial deposits, old alluvium, or floodplain areas. The soil texture of these sites is usually coarse and not suitable for landfills due to relatively higher rates of leachate movement (Erb *et al.*, 1981). The location of such a coarse textured soil adjacent to abandoned sites can be mapped from current and historical aerial photos, and, furthermore, the data can assist in selection of sites for monitoring the water quality adjacent to the sites.

To locate areas where leachate movement may occur, an expert could assess the soil type by photographic interpretation of color or grey-tone. Differences of color or tone indicate the general hydrological and textural variation of the soils. In black-and-white photos, coarse textured soils appear lighter grey in tone. This usually results from the relatively rapid drainage of rainfall. Subsequently, such an identification leads to an indication of paths for subsurface movement of leachate and contaminants from old landfills to the surface water (Way, 1982; Mintzer, 1983). On the other hand, black color or dark tones in black-and-white photos is indicative of wet areas of soil. Therefore, these dark tones are used as an indicator of lower areas composed of fine, textured soils that were conduits of surface or near surface runoff.

Clearly, when determining the soil characteristics of a site through aerial photos, an expert assesses the darkness of the color/tone and uses qualitative values, such as "dark" or "light" color/tone. Consequently, these values determine the coarseness or fineness of the general soil texture. Here again, the expert uses qualitative values such as "coarse," "very coarse," or "fine." These values may be classified as fuzzy sets.

FUZZY SET CONCEPT FOR IMAGE DATA INTERPRETATION

The fuzzy set concept is founded on the notion that qualitative expressions usually involve the realm of human perceptions, subject to a range of interpretations (Zadeh, 1965). While the values of these expressions are inexact in quality, they are meaningful. Zadeh stated that the way humans are able to summarize masses of information and then extract important items relevant to a particular problem is through approximation. He further maintained that "...as the complexity of a system increases, our ability to make precise yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics."

Qualitative expressions usually consist of linguistic variables and linguistic values. SOIL TEXTURE, for example, is a linguistic variable. It is information expressed in words or phrases that has a value which is not clearly defined. The linguistic value may be "coarse," "very coarse," "fairly fine," or "fine," depending on the subjective judgment of the expert. We may consider these values as fuzzy sets. However, because these values are expressed subjectively, experts may produce different values. For instance, an expert may study the image data and conclude that the soil texture is "fairly coarse" while another expert may assess it as "coarse." If a specification specified a fairly fine soil texture as a suitable measure for landfill, then making a decision based on these two values may become a problem. Furthermore, one may view the same value in different ways. For example, the meaning of "fine" textured soil for one expert may be different for another. In order to cope with the fuzzy nature of these problems, the following fuzzy set operations are employed in the study here.

FUZZY SET OPERATIONS

To fully appreciate prospective application of Zadeh's thinking to the qualitative measures used in the interpretation of aerial photographs, certain basic fuzzy mathematical operations are useful. More extensive discussions of the concept and the applications of it have been earlier presented in other papers (Hadipriono, 1985; Hadipriono and Ross, 1987).

Consider as an example the value "very fine" which can be represented by the following fuzzy set: "very fine" = [7/0.0, 8/1.0, 9/0.0], where "/" is a delimiter; 7,8, and 9 are the fuzzy set elements; and 0.0, 1.0, and 0.0 are the respective membership values. For example, when assessing the soil texture of a site from photographic images, the fuzzy set elements indicate the texture level. Here, the fuzzy set elements for "very fine," may range from "totally unacceptable level of soil texture for landfill project" or 0, to "totally acceptable level of soil texture for landfill project" or 10. The membership values are the corresponding degree of belief which ranges from 0.0 to 1.0. In this example, the fuzzy set elements gravitate at a range between 7 and 9, with the highest degree of belief at 8. The fuzzy set "very fine" can also be represented graphically as show in Figure 1 where the ordinate represents the membership values, $m(x)$, and the abscissa represents the elements, x. A linear relation is assumed between $m(x)$ and x, and the model takes a triangular form.

In general, a fuzzy set may have a negative, positive, or neutral characteristic. Examples are "coarse," "fine," or "medium,"

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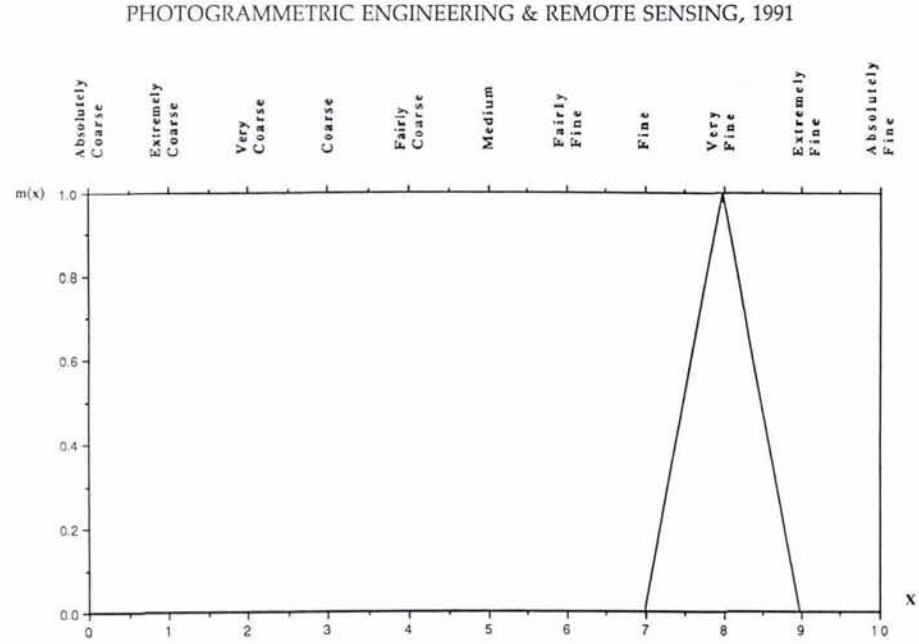

FIG. 1. A fuzzy set model for "very fine."

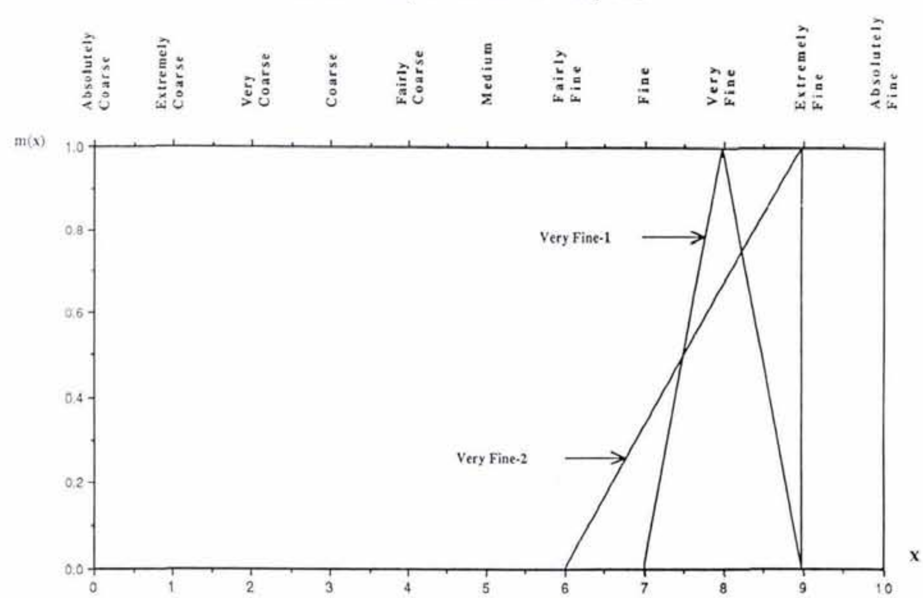

FIG. 2. A fuzzy set model for "very fine" soil texture.

respectively. In the example in Figure 1, the more the model gravitates to the right, the more positive is its characteristic. However, if the models are of different shapes, such as those shown in Figure 2, to find which one is the more positive may not be too straightforward. Hence, the following ranking index is recommended to determine the characteristic of a linguistic value (Juang and Kalidindi, 1987):

$$R = A_r - A_l + A \tag{1}$$

where
- R = ranking index;
- A_r = area enclosed to the right of the membership function;
- A_l = area enclosed to the left of the membership function; and
- A = area of the universe of discourse.

For example, Figure 2 shows two fuzzy set models, both of which, represent the value "very fine." Using Equation 1, the ranking index of the first value yields

$$R_1 = 0.5(1+2) - 0.5(7+8) + 10 = 4.0$$

With a similar procedure, the ranking index of the second assessment, R_2, is found to be 3.5. Because R_2 is less than R_1, the second value is more positive than the first one.

Clearly, the fuzzy set model allows the experts to indicate the meaning of their assessment. Furthermore, the value can be ranked to determine its characteristic and, thus, its variability. In order to overcome the problems we discussed earlier concerning the subjectivity of expert interpretations, integration of fuzzy set models is required. Essentially, the integrated fuzzy set model is given by the following:

$$C = \frac{\sum_i (A_i \times W_i)}{\sum_i W_i} \tag{2}$$

where
- C = Integrated or Consensus model;
- A_i = Individual Assessment; and
- W_i = Weight of a particular assessment.

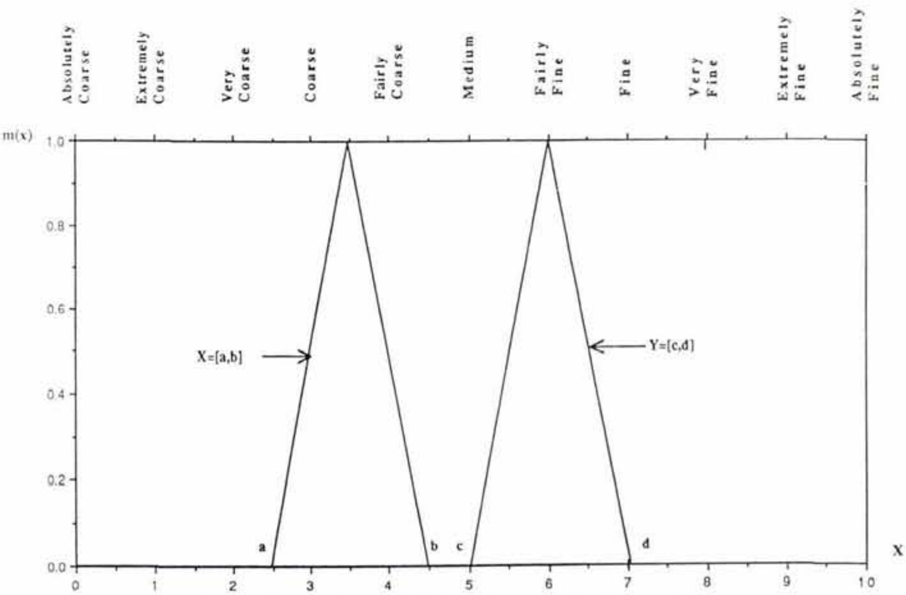

FIG. 3. Triangular models for fuzzy algebraic operation.

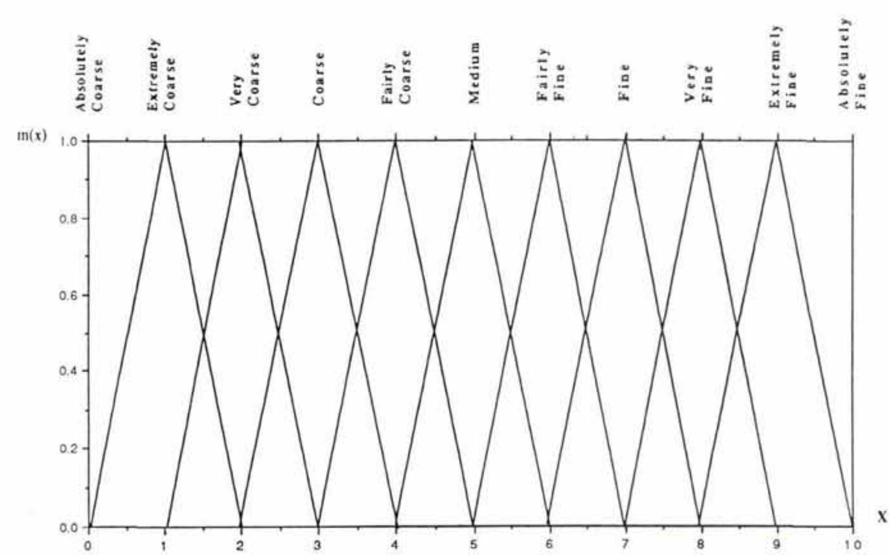

FIG. 4. A standard model for soil texture values.

Because A_i and W_i are fuzzy sets, the arithmetic manipulations in Equation 2 should follow a special process based upon Zadeh's extension principle. This principle extends the ordinary algebraic operations to fuzzy algebraic operations. The general algebraic operations between two fuzzy sets X and Y are defined as

$$Z = X * Y$$

$$m_z(z) = \bigvee_{z=x*y} [m_X(x) \wedge m_Y(y)] \tag{3}$$

where $*$ = ($\times$, :, +, or $-$);
$\vee$ = disjunction or maximum;
$\wedge$ = conjunction or minimum; and
$m_X(x)$ = membership function of fuzzy set X.

Suppose that both X and Y represent a linguistic value "medium" of a specific soil texture. Figure 3 shows the triangular models of $X=[a,b]$ and $Y=[c,d]$, where a, b, c, and d are the parameters that determine the location of the triangles. Then, fuzzy operations in Equation 3 can be extended as follows (Boissonnade *et al.*, 1985):

$$\begin{aligned} [a,b] &+ [c,d] = [(a+c),(b+d)] \\ [a,b] &- (c,d] = [(a-c),(b-d)] \\ [a,b] &\times [c,d] = [\wedge(ac,ad,bc,bd),\vee(ac,ad,bc,bd)] \\ [a,b] &: [c,d] = [(a/c),(b/d)] \end{aligned} \tag{4}$$

The following example illustrates the application of these fuzzy operations.

ILLUSTRATION

Suppose that three experts are asked to assess satellite image data for determining a landfill project. Suppose that standard ratings are already in existence represented by models ranging from "absolutely coarse" to "absolutely fine" such as shown in Figure 4. Both extreme values are represented by vertical lines (deterministic), and the values in between, from "extremely

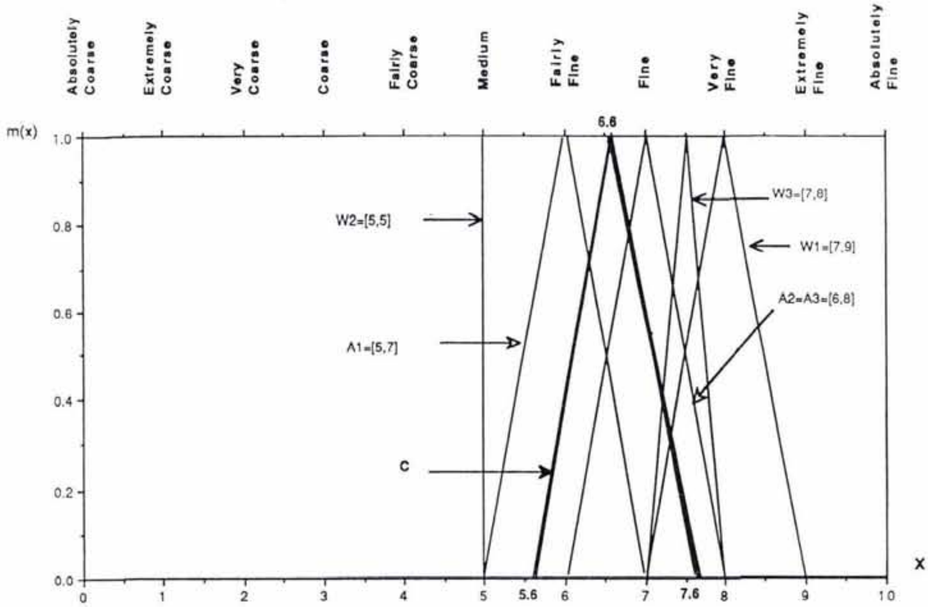

FIG. 5. An illustration of finding an overall assessment.

coarse" to "extremely fine," are represented by equilateral triangles.

Suppose that the first expert assesses the soil texture of a site in an image data as "fairly fine," and both the second and the third engineers assess the same image as having a value of "fine." These values can be written in fuzzy sets as $A_1 = [5,7]$, $A_2 = [6,8]$, and $A_3 = [6,8]$. Suppose that the experts' expertise and experience are also rated based on equilateral triangles with the weight of $W_1 = [7,9]$, $W_2 = [5,5]$, and $W_3 = [7,8]$, respectively. Using Equations 2 to 4, the consensus rating for the performance is computed as

$$C = \frac{[5,7]^*[7.9] + [6,8]^*[5,5] + [6,8]^*[7,8]}{[7,9] + [5,5] + [7,8]}$$

$$= [5.6,7.6]$$

Figure 5 illustrates the result. The overall soil texture value, C, is represented by the triangle with the dashed line. Using Equation 1, the ranking index, R, for the overall assessment yields 6.8. Compared to Figure 4, the overall assessment lies between "fine" ($R = 6.0$) and "fairly fine" ($R = 8.0$), but closer to "fine."

SUMMARY AND CONCLUSION

Observations of satellite data or aerial photos are usually performed subjectively by the expert based on his/her judgment and experience. Experts assess the color and tone of the image in order to determine the soil texture of a site for an engineered project. The result of this assessment is frequently expressed qualitatively using linguistic values. These qualitative expressions are inevitable because humans tend to think approximately instead of exactly. But presently there are no consistent standards or methods for interpreting these measures. Misinterpretation of such measures may result in an error in making decisions for an engineered project. The concept of fuzzy sets was used in this paper to obtain consistent measures of values provided by the experts and to reach a consensus if the experts provide different values. The operations include the ranking index manipulation and fuzzy arithmetic for integrating multiple assessments into a single measure. The method developed herein is relatively simple to use, and the results can be represented graphically making them easy to understand.

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