# A QUANTITATIVE MEASURE FOR THE SIMILARITY BETWEEN FEATURES EXTRACTED FROM AERIAL IMAGES AND ROAD OBJECTS IN GIS

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**ABSTRACT**

Automated approaches for extracting roads form aerial images, and for verifying the correctness of extracted roads, usually involve matching of graphic entities from different sources. Of particular interest is the matching of GIS data to information extracted from images. This paper presents an approach for matching road segments extracted from aerial images to road objects in an existing GIS. In order to match different entities with a minimum number of errors a model to quantify the similarity of road segments has been developed. The method presented here is based on *fuzzy logic* and conceived as a better way for sorting and handling vague, imprecise, or incomplete information. The paper describes the motivations, outlines the method and presents preliminary results.

## 1 INTRODUCTION

Updating is a very important task required for improving and preserving the quality of the data in Geographical Information Systems (GIS). Updating is usually done by verifying new information with respect to existing data and by extracting new objects. Common sources of new information are aerial and satellite images, while the actual extraction is usually performed by a human operator. Such a procedure obviously requires extensive and tedious work. Performing this task automatically with a high level of detail requires comprehensive prior knowledge. Many studies have been carried out in the past two decades concerning extracting man-made features in general, and roads in particular (see Heipke *et al.*, 1997 for review). However, automatic extraction of man-made features is still in its research stage.

One way of introducing knowledge into automatic extraction of man-made objects is to exploit existing data. In particular, existing GIS data are shown valuable. These data provide knowledge about the cartographic objects in the scene and a description of their properties. A general framework for considering existing GIS data in the updating process consists of three steps:

1. Extracting image features that may be hypothesized as road segments. The basic assumption is that a road appears in the image as a set of parallel edges. Additional properties are also used to perceptually group raw features into objects that are then hypothesized as roads. Roads are also extracted from the GIS data, and each segment is assigned a set of properties. Some of these properties appear in the database, while others are derived from the geometry.
2. Comparing objects from the database to the hypothesized road segments from the image. The problem is to match graphic entities that appear differently in two overlapping sources. Such differences can be observed in the geometrical and topological descriptions. At the end of this step, there exist three groups of results: (i) matched objects; (ii) objects that appear in the database but do not appear in the image; and (iii) features in the image hypothesized as roads but do not exist in the database. Features of the latter group are either non-roads or new roads that should be verified carefully in the third step.
3. Classifying image features that were hypothesized as roads segments, and were not matched in the second step. This process is based on a learning procedure in which properties of matched roads are used to verify road hypotheses. At the end of this step new road segments are determined and linked to existing roads.

This paper deals with the second step mentioned above. It defines a method for quantifying the similarity between a road entity from a GIS, and a hypothesized road feature extracted from an image. The method presented here is based on a *fuzzy logic* concept. The use of fuzzy logic is useful for structuring the knowledge about geometrical, radiometrical and contextual properties of roads at different sources. It enables the representation of non determined properties, such as "width," as a fuzzy input, rather than a strict "wide" or "narrow" values.

Examples for the use of the fuzzy theory in the context of road extraction can be found in Agouris *at el.* (1998). In that work, the algorithms are designed to function within an integrated geospatial environment. Fuzzy logic is used in the first stage for detecting road pixels, i.e., pixels that have high probability to belong to a road. In a second stage, road tracking is performed, based on the selected pixels from the first stage, and some geometric properties.

In the work described in this paper, the idea of using fuzzy logic for matching road information from GIS to features extracted from an aerial image is presented. The paper describes the matching problem, details the proposed approach and shows some preliminary results.

## 2 MATCHING GIS ROAD ENTITIES WITH IMAGE ROAD SEGMENTS

Given two sets of features, one from a GIS (reference data) and one extracted from a digital image (extracted data), the matching task in this work is to conjugate as many road features from the two sets as possible. A road entity in the reference data may have a match in the extracted data, or may not have one. The matching step should generate these pairs with a minimum number of errors.

In order not to miss important information, it is possible that at the initial state a road segment in the reference data will have several potential matches in the extracted data. Avoiding combinatorial explosion is possible by limiting the search space to a predefined buffer along the road segment. The final purpose of the matching is to find the hypothesized road segment that has a best fit to the reference segment. However, once one of the features is selected as "best," the question that remains is "is this the correct match?"

The matching process might entail two types of errors in the context of roads. The first is a false negative result, meaning that entity in the reference data was not matched to a hypothesized road in the extracted data, while the latter is in fact a road. The second type of error occurs if an entity in the reference data is matched to a hypothesized road, when the latter is not a road. This type of error is denoted as false positive. The goal of the method described in this paper is to reduce the possibility of making such errors. The idea is to analyze the road model and structure the matching process in a way that the similarity between two features extracted from different sources is quantified. This provides a better estimation of the success of the matching process. Quantifying the similarity is based on a comparison of geometric (and possibly other) properties, and by weighting these properties according to a prior knowledge about roads.

In the first stage, a generic road model is defined which is mainly linked to the geometric and radiometric properties of the road. For example, (i) roads have parallel edges; (ii) there are no sharp radiometric changes along the road; (iii) a road profile changes gradually; (iv) road width is constant, or changes gradually; (v) roads have a maximum curvature; and (vi) road height varies in a rather gradual manner. Baumgartner *at el.* (1997), for example, took the two first fundamental assumptions for their road model. Each property is assigned a weight value that denotes its significance. A major idea in this research is that both hypothesized roads in the image and road entities from the GIS share some common attributes. Therefore, the matching tool is based in part on comparing these attributes from the two sources.

The entire matching process is formulated as a *fuzzy* problem. A description of the idea is given in the following section.

## 3 THE PROPOSED ALGORITHM

The proposed algorithm for quantifying the similarity between a road segment from a GIS and a hypothesized road segment extracted from an image is based on *fuzzy logic*. Zadeh (1973) conceived the concept of fuzzy logic as a way of processing data by allowing a partial set membership rather than a crisp set membership or non-membership. Fuzzy logic provides a simple way to achieve a quantitative conclusion based upon vague, ambiguous, imprecise, noisy or incomplete input information.

The primary mechanism in fuzzy logic is a list of statements in the form *IF input1 [AND input2 ...] THAN output*, which are called rules. The rules, in this form, are used for describing the desired system response in terms of linguistic variables rather than mathematical formulas. All rules are evaluated in parallel, meaning that the order of the rules is not important.

Each clause of the rules (i.e., input and output) is a declaration about a certain parameter of the data. Unlike usual rule-based systems, the correctness of the declaration is not necessarily a clear correct/wrong response, but a value of a *membership function* that ranges between 0 and 1. Thus, the response to an input declaration such as "the road segment is long" may be 0, which means "wrong," 1, which means "right," or any value in between. The value is determined by the membership function. In a similar way, another declaration may be "the road segment is short." The output declaration in the case described here may be "segments are similar." Figure 1 shows the membership functions for these three examples. Additional examples are shown later in the paper.

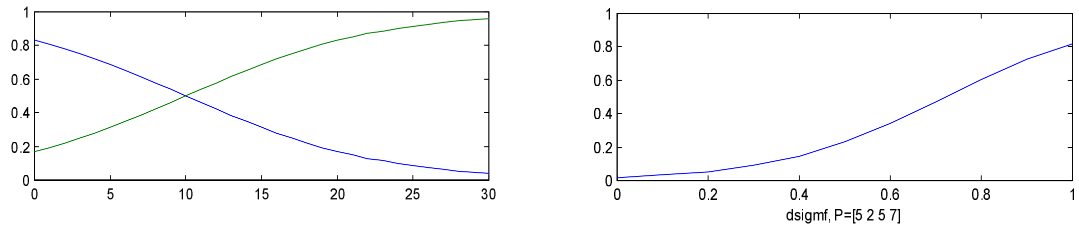


**Figure 1: Examples of membership functions – "road segment is long" (increasing function, left); "road segment is short" (decreasing function, left); "segments are similar" (right).**

The calculation of the resulted value is performed in three stages:

1. For each rule, evaluating the fuzzy result of the left hand side.
2. For each rule, selecting the area of the membership function of the right hand side underneath the value obtained in the first stage.
3. Combining the selected areas of the graphs for all the rules to one result. This part is considered the defuzzication stage.

The rules for defining the similarity measure are based on the following parameters (Figure 2):

1. The difference between the direction of the GIS road entity and the direction of the hypothesized segment ( $d\alpha$ ).
2. The length of the hypothesized road segment extracted from the image ( $\ell$ ).
3. The difference between the width of the road defined in the GIS and the average distance between the two potential road margins extracted from the image ( $dw$ ).
4. The distance between the GIS road entity and the hypothesized road segments, with respect to a common coordinate system ( $d$ ).

Table 1 details the rules that are currently used for matching the features. These rules are based on common knowledge about how roads are represented in the image and in a database. When more knowledge is available, it can be easily incorporated to the system. It should be noted that the evaluation process requires that each rule should have its opposite, which calls for pairs of rules.

**Table 1: Rules for evaluating the similarity between road entities from a GIS and hypothesized road segments in an image.**

| IF | THEN |
|---|---|
| $d\alpha$ is small AND $\ell$ is large | Similarity is good |
| $d\alpha$ is large | Similarity is bad |
| $dw$ is small AND $\ell$ is large | Similarity is good |
| $dw$ is large | Similarity is bad |
| $d$ is small | Similarity is good |
| $d$ is large | Similarity is bad |

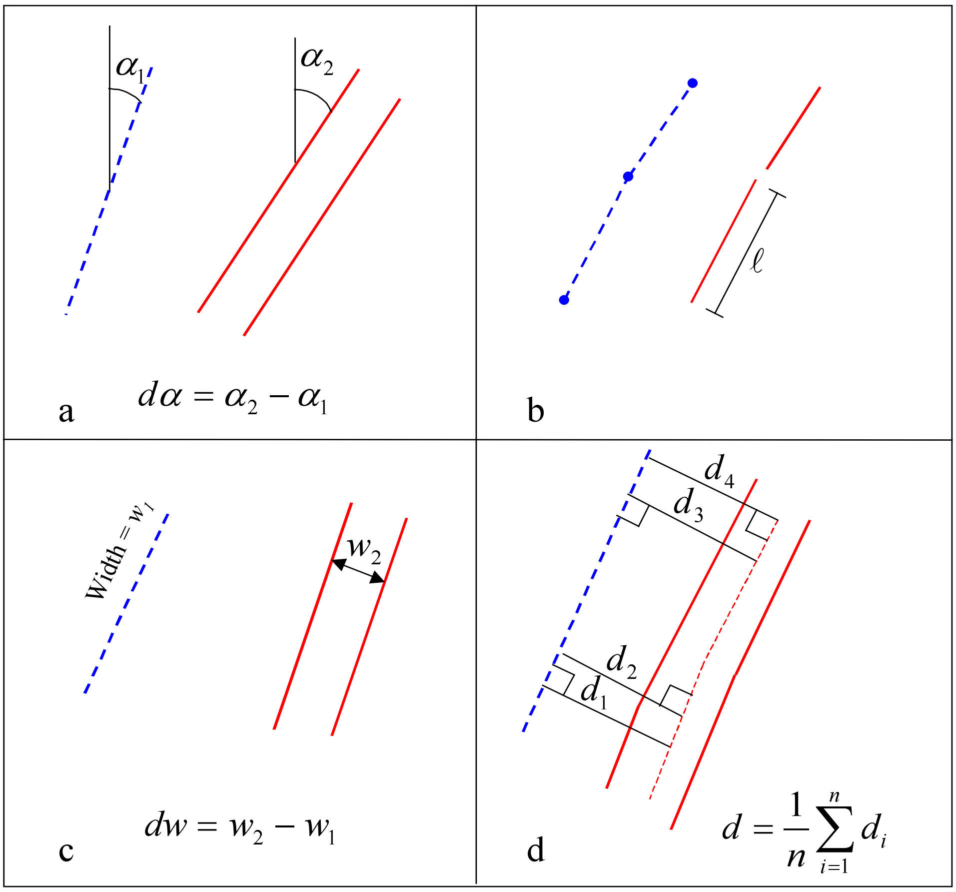


**Figure 2: Definitions of geometric properties that affect the similarity evaluation – (a) direction difference ($d\alpha$); (b) segment length ($\ell$); (c) difference of road width ($dw$); and (d) distance between the features with respect to a common coordinate system ($d$).**

## 4 EXPERIMENTATION AND RESULTS

The proposed approach has been tested by a prototype system, and some preliminary results are presented here. Figure 3 shows the set of rules, which were described in the previous section, as a matrix of graphs. The matrix demonstrates an operation of the rules on a set of parameters that apply to a pair of segments to be matched. Each row of the matrix represents one rule. The left-hand side of the row contains the membership functions of the inputs. The right-hand side shows the membership function of the output. The selected part of the latter (shown as the dark part under the graph) is considered in the process of combining all fuzzy rules to a clear response.

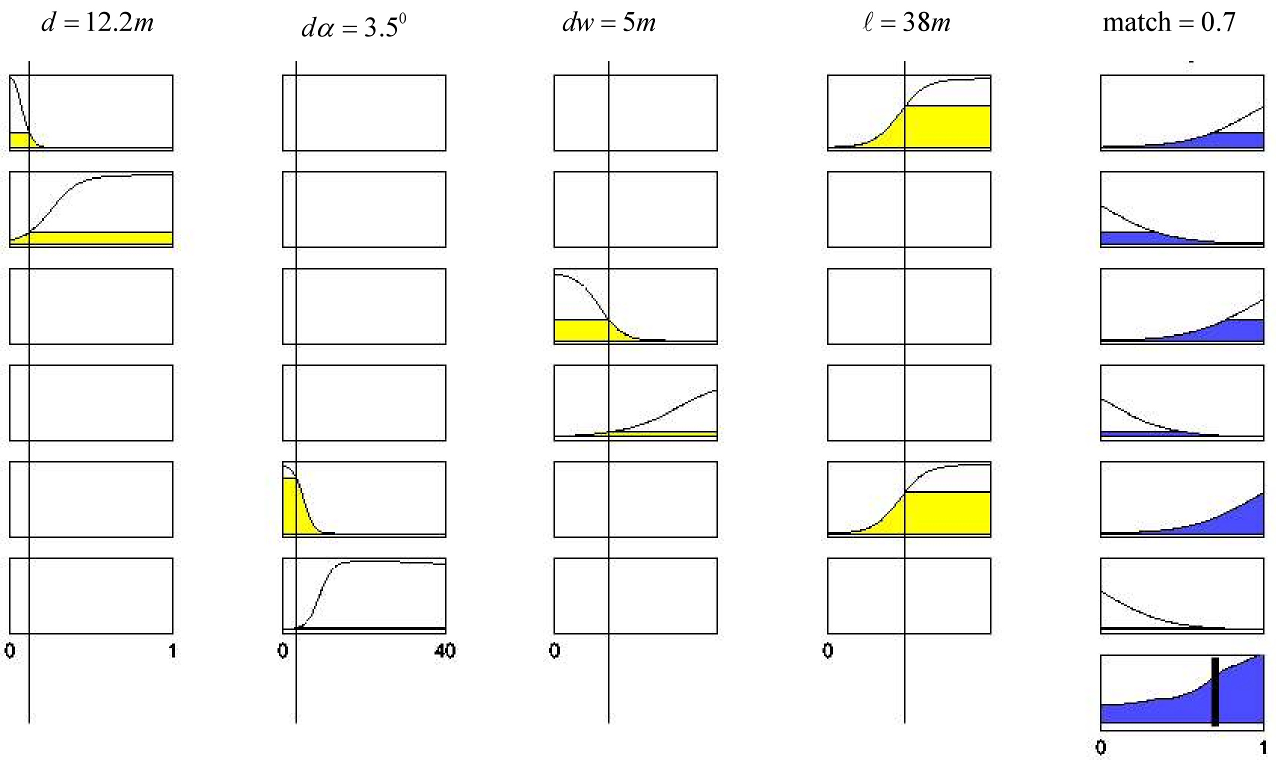


**Figure 3: An example for applying the fuzzy rules to a set of input parameters.**

Membership functions were selected based on common knowledge about roads. Thus, for example, the function for the declaration "*d* is small" (top left in Figure 3) drops sharply, since it is not reasonable that the road entity from the GIS will be far apart from the road hypothesized in the image. Another example is the statement "*dw* is small" (third row, third column). In this case, the function drops gradually as it is expected that the width attribute of the road in the GIS is not precise. Currently, a refinement of these functions was performed empirically, based on a relatively small number of experiments. Nevertheless, the experiments show that applying the rules to real data clearly point to the correct results.

The system was applied to real data, which contain an area in central Israel. The GIS data were taken from the Israeli National GIS. The image features were extracted automatically from an orthophoto of the area. Figure 4 shows two parts of the orthophoto, overlaid by the vector data. The particular features that are shown later in the results are annotated on the image.

The experiments were performed in the following way:

- Selecting a road entity in the GIS.
- Selecting all hypothesized road segments from the image that are within a certain buffer around the selected segment (based on the common coordinate system).
- Applying the set of rules to the GIS road entity and each of the hypothesized road segments, and calculating the resulted similarity value.
- Presenting the results of the segments that yielded the highest similarity values.

The results for two particular segments (as annotated on Figure 4) are shown in Figure 5.


**Figure 4: GIS data (blue) and hypothesized road features (red and green) overlaid on an orthophoto. Marked GIS segment is matched with red image segments.**

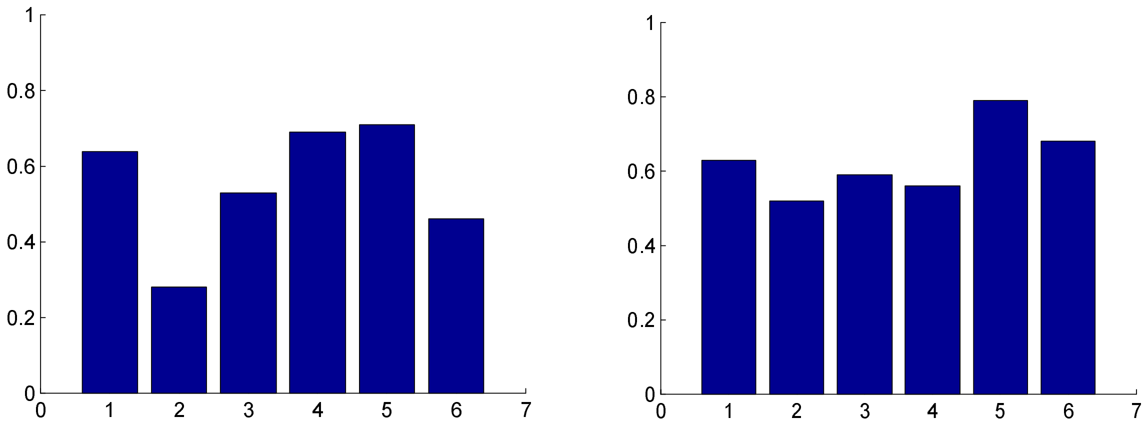


**Figure 5: Resulted similarity values for two road segments.**

## 5 SUMMARY

In this paper, a method for matching hypothesized road segments, extracted from an aerial image, and road entities in GIS, has been presented. The main idea is to quantify the similarity between these features. The matching is based on formulating the problem as a set of fuzzy rules. Using this methodology, a certain input does not have to "have" or "do not have" a certain property, but could "partially have" that property. This type of problem formulation is suitable for information extracted automatically from an aerial image.

Preliminary results show that it is possible to obtain a similarity value between a hypothesized road segment in the image, and a road entity from a GIS. A comparison of the values obtained for a true match and false matches shows a difference, however there are a few matches with high values.

One of the important factors of the method is the selection of the membership functions of the fuzzy rules. Future research should concentrate on testing the sensitivity of the output value to the selection of the membership functions. In addition, the incorporation of more rules, which are founded on prior knowledge about roads and on the possible available data in the GIS and in the extracted image information, should be examined. It is expected that the methodology presented here will be incorporated in a general automated GIS updating framework.

## ACKNOWLEDGMENTS

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