Management of multi-modal data using the Fuzzy Hough Transform: Application to archaeological simulation

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***Abstract*— Management of multi-modal data is a classical problem in data mining and exploration. Geographic Information Systems usually store multi-modal data and employ them in spatial and image analysis. This paper proposes a fusion of multi-modal data in the context of line detection with Fuzzy Hough Transform (FHT). The goal of this work is to simulate the Roman streets according to periods from partial and uncertain excavation information. These simulations are based on three modalities : coordinates, orientations and dates. Data are stored into a geodatabase. As Roman streets form usually segments of lines, they are detected using three FHTs. The final visualization is obtained after merging the three FHTs. The proposed method gives a new tool helping archaeologists into their expertise and diagnostic processes. We validate it with Reims Roman streets excavations (France).**

***Index Terms*— Fuzzy Hough Transform, Simulation process, Archaeological data, GIS, fuzzy logic, multi-modal data.**

I. Introduction

Management of multi-modal data is a classical problem in data mining and exploration. Geographic Information Systems (GIS) usually store multi-modal data and employ them in spatial and image analysis. Our method of line detection aggregates multi-modal information by fusion. The fusion is implemented during the pattern recognition process itself. Our contribution improves the Fuzzy Hough Transform taking into account both the multi-modality and the inaccuracy and uncertainty of data.

In the Roman period, streets are usually linear. During archaeologists excavations, only passages of Roman streets are found. These passages are in the following defined as streets excavations. Data stemmed from them represent partial information and are stored in a geodatabase. They regroup dates, orientations, and coordinates of street excavations compounding multi-modal data. Archaeological information like dates, localization or orientation are uncertain. The Fuzzy Sets theory, introduced by Zadeh [20], proposes a formalism to represent data with their uncertainty. The use of Fuzzy Logic tends to become classical in GIS [1], [6], [7], [8], [17]. Dates, localizations and orientations are fuzzyfied to take care about their uncertain aspect. So stored multi-modal data become after the fuzzyfication process fuzzy multi-modal data. The goal of this paper is to estimate the potential presence of streets at a given period.

Roman streets usually form segments of lines. One of the most powerful methods for the detection and recognition of patterns with known simple geometrical shapes (as lines) in images is the Hough transform (HT) [10], [13], [15]. HT could be generalized and unsupervised for detecting natural shapes [2]. The Hough transform is a statistical method. Despite the abundance of papers dealing with HT, only a few of them pay attention to the uncertainty. The binary aspect of the vote in the classical HT seems to be one of the causes of this. Han et al. [12] propose a fuzzy Hough transform (FHT) which presents a method to detect lines in image with noise, or with quantization error. Han et al. define a fuzzy neighbourhood to each point, thus the counter function works with a fuzzy neighbourhood matrix. So FHT permits to select lines even if the positions of points are uncertain.

Our application has to work with fuzzy multi-modal data. This constraint implies to use three FHT counter functions: one for the localization, one for the orientation and the last one for the correspondence of dates with the given period. Only one valuation is wanted by experts. This imply that a fusion function is needed to build the final estimation. The application estimates Roman streets according to a given period and permits us to visualize them into a GIS.

In this paper, we present the interest of using fuzzy logic and possibility theory to approach uncertainty within archaeological environment. After an introduction of HT and FHT methods to detect lines, we propose to use three FHT and a merging function to respond to our goals. To finish, and before the conclusion, we present results given by our application.

II. Uncertainly, GIS, and Archaeological data

In this section, a part of a street found during excavation constitutes an excavation point. Let ep be an excavation point containing the following information:

- x, y : the coordinates,
- α : the orientation of the street (if $\alpha = 90$ then the orientation is North, if $\alpha = 0$ then the orientation is East),
- $date$: the interval $[bd, ed]$ (bd : date of the beginning; ed : date of the end).

Data contain part of uncertainty. Coordinates and orientations are stored with a margin of error. Dates are generally stemmed from experts interpretations or estimations, depending on the excavation context. Furthermore, numerical representations of linguistic periods codification vary in accordance with experts.

Many papers as [5] deal with the quality of information in GIS. The literature discusses imprecise reasoning [11]. Altman proposes to use Fuzzy Set theoretic approaches for handling imprecision in spatial analysis [1]. This approach is applied to understand phenomena as road traffic, dynamic processes, or contamination of soil [6], [7], [8], [17]. In this paper, we propose to fuzzyfy archaeological data.

In the next $fLocalization_{ep}$ is the membership function associated to the fuzzyfication of ep localization. $fOrientation_{ep}$ is the membership function associated to the fuzzyfication of ep orientation. $fDate_{ep}$ is the membership function associated to the fuzzyfication of ep date.

In this work, some models of fuzzyfication are used. Three of them are described in Figures 1 to 3. Figure 1 proposes a representation of $fLocalization_{ep}$. Near the excavation point coordinates, the fuzzy membership function is equal to one and decreases when distance to ep grows up. Figure 2 presents a model for $fOrientation_{ep}$, where λ is equal to $\pi/180$ For the excavation point orientation, the fuzzy membership function is equal to one and decreases when the angle difference grows up. Figure 3 illustrated $fDate_{ep}$. In this figure, a is equal to $0.1 * |ed - bd|$ (10% of date duration) .

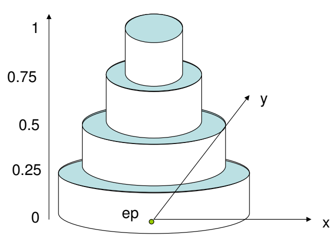

Fig. 1. Fuzzy membership function $fLocalization_{ep}$

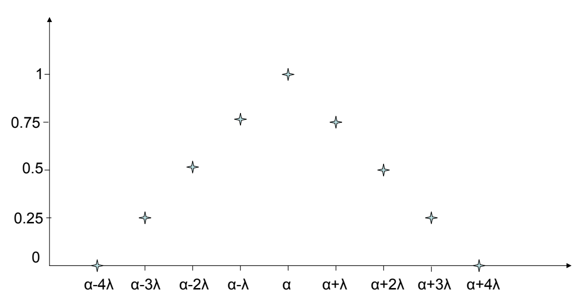

Fig. 2. Fuzzy membership function $fOrientation_{ep}$

The information fuzzyfication permits us to use data and their uncertainty into simulation processes. Because Roman streets have the particularity to be close to lines, this work

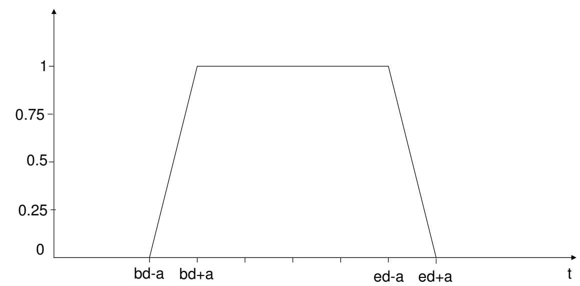

Fig. 3. Fuzzy membership function $fDate_{ep}$

proposes to use the Hough transform concept to simulate city maps according to Roman periods.

III. The Hough Transform

A. Hough transform

A brief introduction of HT [13] is presented, but we only consider a context in which the domain is a bounded box of R^2 points, i.e., a conventional image I. Surveys of HT are proposed [15], [16].

Since the studies of Duda and Hart [10], it is a common practice to define the membership of a point (x, y) in the plane to a straight line by the following relation: $f(x, y, \rho, \theta) = xcos\theta + ysin\theta$ with $(\rho, \theta) \in ([0, p], [0, \pi[)$, where θ represents the orientation of the vector normal to the line, and ρ denotes the distance from the straight line to the origin. Notes that $p = length(diagonalofI)$.

The Hough transform is used to analyse as follows: for each point (x, y) not in the background of I, and for each θ, the distance ρ from the straight line to the origin is simply determined by $xcos\theta + ysin\theta$. The accumulator $HAcc(\rho, \theta)$ is then incremented. The algorithm is Alg 1.

Alg. 1 HT

for all pixel(i,j) which is not in the background **do**
  for all angle(θ) **do**
    $\rho = icos\theta + jsin\theta$
    $HAcc(\rho, \theta) += 1$
  end for
end for

The goal of HT is to detect lines. Therefore they will be lines with the biggest scores in the counter function.

When applying HT to noisy data, a shape could appear locally maximal for the counter function but could be different from the true one. Han et al [12] propose the fuzzy Hough Transform to solve this problem.

B. Fuzzy Hough transform

Han et al. propose with the Fuzzy Hough transform to detect lines in images with noise, or quantization error. The FHT takes into consideration points and their neighbourhood. Han et al. use a fuzzy set to build a neighbourhood (m x n) matrix W of the studied point. This matrix determines the value of the incrementation of the counter function FHAcc. The algorithm is Alg 2.

Alg. 2 FHT

for all pixel(i,j) not in the background **do**
  for all $x \in [-m/2, m/2]$ **do**
    for all $y \in [-n/2, n/2]$ **do**
      for all angle(θ) **do**
        $\rho = (i + x) * cos\theta + (j + y) * sin\theta$
        $FHAcc(\rho, \theta) += W(x, y)$
      end for
    end for
  end for
end for

Since 1994, a lot of papers propose to optimize FHT [3] or to use it with different types of image [19]. In our application, FHT is not used with images but with multi-modal data stored in a geodatabase. In the next section, a method to determinate Roman streets according to a given period is proposed, and this method uses FHT with fuzzy multi-modal data.

IV. Presentation of the method

A. The three FHT

The goal is to obtain streets of antique Reims according to a given period. Roman streets have the particularity to be most of time linear. The geodatabase of Roman streets excavation is as in section 2. The idea is to apply three Fuzzy Hough transform on this database to obtain spatial configuration of Roman streets.

To use FHT, a neighbourhood must be defined. For each excavation point ep, for each $(x, y) \in R^2$ then $(x, y) \in neighbourhood_{ep}$ iff $fLocalization_{ep}(x, y) > 0$. This definition of neighbourhood of ep is used for the three FHT: $FHTLoc, FHTOrien, FHTDate$. $FHTLoc$ corresponds to the FHT for the orientation (see in Alg. 3). We propose to add in the counter function FHAccLoc the value of the $fLocalization_{ep}$ of each point in the neighbourhood. $FHTOrien$ corresponds to the FHT for the orientation (see in Alg. 4). We propose to add in the counter function FHAccOrien the value of $fOrientation_{ep}(\theta)$ for each lines (ρ, θ) based on the neighbourhood. The goal of this paper is to estimate the potential presence of a street according to a given period. Let be $refDate$ the date given by users. We propose to add in the counter function FHAccDate of FHTDate (see in Alg. 5), the maximum of the intersection between $refDate$ and $fDate_{ep}$.

Each counter cell is normalized by the maximum of the associated counter function results.

To simulate map based on fuzzy multi-modal data, we need to merge those three FHT. The next section deals with the choice of the merging function.

Alg. 3 FHTLoc

for all excavation point ep stored with $(x, y, date, \alpha)$ **do**
  for all $(x, y) \in neighbourhood_{ep}$ **do**
    for all angle(θ) **do**
      $\rho = icos\theta + jsin\theta$;
      $FHAccLoc(\rho, \theta) += fLocalization_{ep}(x, y)$;
    end for
  end for
end for

Alg. 4 FHTOrien

for all excavation point ep stored with $(x, y, date, \alpha)$ **do**
  for all $(x, y) \in neighbourhood_{ep}$ **do**
    for all angle(θ) **do**
      $\rho = icos\theta + jsin\theta$;
      $FHAccOrien(\rho, \theta) += fOrientation_{ep}(\theta)$;
    end for
  end for
end for

B. The merging function choice

Merging uncertain data is a classical problem in the field of fusion information. According to Dubois and Prade [9] the choice of a fusion mode is not unique and depends on:

- the nature of the items to be merged: knowledge fusion and preference fusion may require different specific families of aggregation functions;
- the representation framework: qualitative information fusion cannot use the same mathematical tools as quantitative information fusion.

Some rules of merging information from independent and conflicting sources about the same event are proposed in [14]. Detyniecky [4] proposes a review of traditional aggregation operators.

Some classical operators used to merge data are AND ($t-norm$) or OR ($t-conorm$) functions. In fuzzy logic, the main $t-norm$ and $t-conorm$ are those proposed by Zadeh (Min and Max) or those used in the probabilistic theory ($f * g$ and $f+g-f*g$). With these merging function, data are considered with the same weight.

In our simulation context, the problem is to consider that all modalities have not the same importance. For example, the information about dates could be more important than the information about orientations. Taking for merging function an extension of the arithmetic mean, the weighted mean, gives an

Alg. 5 FHTDate

for all excavation point ep stored with $(x, y, date, \alpha)$ **do**
  for all $(x, y) \in neighbourhood_{ep}$ **do**
    for all angle(θ) **do**
      $\rho = icos\theta + jsin\theta$;
      $FHAccDate(\rho, \theta) += max(fDate_{ep} \cap refDate)$;
    end for
  end for
end for

answer to this problem. Thus, we propose to use a weighted average on the three $FHAcc$.

In this work, the chosen merging function is as follows:

$$\begin{aligned} FHAccFinal(\rho, \theta) =& \lambda * FHAccLoc(\rho, \theta) \\ &+ \mu * FHAccOrien(\rho, \theta) \\ &+ \nu * FHAccDate(\rho, \theta), \end{aligned}$$

where the weights λ, ν and μ are non negative and $\lambda + \nu + \mu = 1$.

With this merging function, weights permit to affect, for example, more importance to the localization than to the orientation, or to the correspondence to the given date. The weights (λ, μ, ν) are defined by applications. Using this function, the three FHT could be reduced to only one (FHTFinal) as in Alg 6.

Alg. 6 FHTFinal

for all excavation point ep stored with $(x, y, date, \alpha)$ **do**
  for all $(x, y) \in neighbourhood_{ep}$ **do**
    for all angle(θ) **do**
      $\rho = icos\theta + jsin\theta$;
      $FHAccFinal(\rho, \theta) += $
        $\lambda * fLocalization_{ep}(x, y)$;
        $+\mu * fOrientation_{ep}(\theta)$;
        $+\nu * max(fDate_{ep} \cap refDate)$;
    end for
  end for
end for

The next section presents the finalization step which is needed to estimate presences of lines.

C. Visualization

In this section, an interactive graphical visualization of data exploration is proposed. To visualize streets, the application must choose lines corresponding to streets. A threshold s is applied to select lines in $FHTAccFinal$. The result is shown in Figure 4.

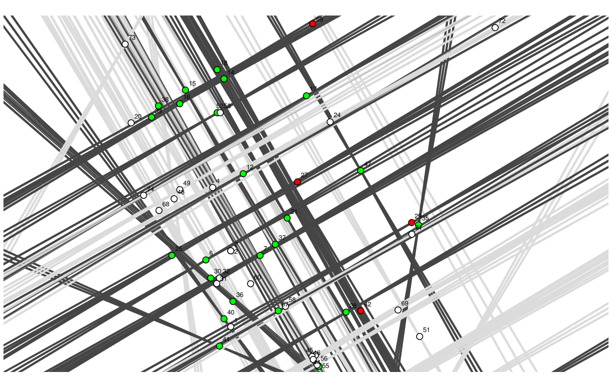

Fig. 4. Simulated map with streets as lines

Streets are not lines but only segments, and excavation data give us information on local positions. We use fuzzy set FSeg to determinate length and values of segments, and the membership function fSeg of FSeg decreased with distance to excavation points which valid the street. The value of a point (i, j) in a street (ρ, θ) going through excavation points $\{\text{ep}\}$ is defined by :

$$F(x, y, \rho, \theta, \{ep\}) = fSeg(i, j, ep) * FHAccFinal(\rho, \theta).$$

With regard to the above, results are illustrated in Figure 5. The method proposed in this paper was applied to simulate maps according to periods defined by users. The next section presents results obtained by the method, which are compared with maps given by experts according to the same periods.

V. Application

In this section, we apply our method to estimate the potential presence of streets at the Third Century, or the Fourth and the Fifth Centuries in Reims. The SIGRem project [18], an archaeological GIS dedicated to Roman periods of Reims, stores in the geodatabase BDRues information about Roman streets excavations.

The weights (λ, μ, ν) of $FHAccFinal$ is empirically evaluated as $(3/14, 1/14, 5/7)$ in the application. This affectation permits to give more importance to date correspondence compared with localization, and more importance to localization in comparison to orientation.

The comparison between simulated maps (Figures 5 and 7) and maps from experts (Figures 6 and 8), validates the method. In these figures, simulated streets and streets from experts are most of time similar.

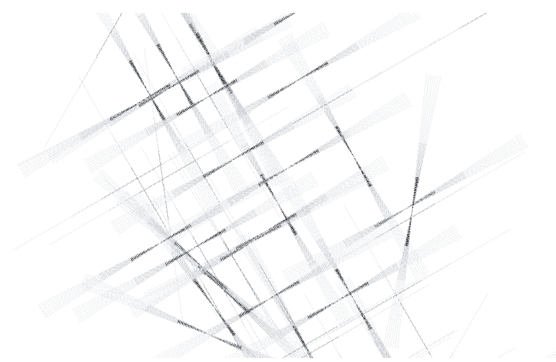

Fig. 5. Simulated map of Reims during the third century

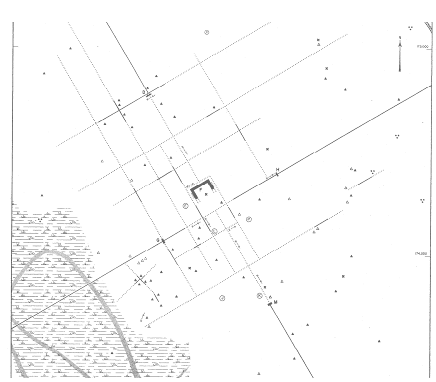

Fig. 6. Map given by experts of Reims during the third century

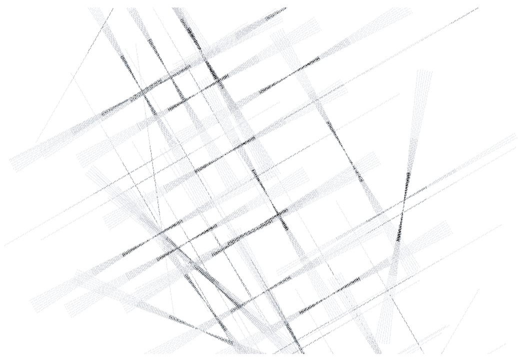

Fig. 7. Simulated map of Reims during the fourth and the fifth Centuries

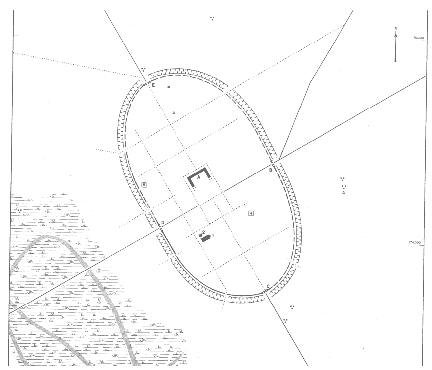

Fig. 8. Map given by experts of Reims during the fourth and the fifth Centuries

VI. Conclusion

Management of uncertainty is fundamental to simulation processes in archaeology. We propose to fuzzyfy multi-modal data and employ them in spatial and image analysis. Our method of lines detection, aggregates multi-modal information by fusion. The fusion is implemented during the pattern recognition process itself. Our contribution improves the Fuzzy Hough Transform taking into account both the multi-modality and the inaccuracy and uncertainty of data.

The method is decomposed into three steps. In the first one, this work proposes to apply FHT to each fuzzy modal data we dispose. Resulting accumulators are normalized. The second step talks about building a new accumulator using a merging function. In the last one, a threshold is chosen to select lines, and finally a fuzzy function is applied to selected lines. These steps produce the operational application, which is a new tool to help archaeologists in their expertises and diagnostics.

By using fuzzy set theory and adapting Fuzzy Hough Transform to archaeological data, this work gives the first results for the SIGRem project [18]. Comparison between simulated maps and maps from experts validates our method.

Some evolutions are possible. In our future work, maps from experts registration on excavation data process will be studied. An other perspective to this work could be a decision process to estimate dates of Reims Roman streets that have no affected dates.

Acknowledgment

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