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Fuzzy Sets in the GIS Environment in the Location of Objects on the Surface of Water Bodies

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Abstract

The issue presented here focuses on concerns about the localization of the object on water surface. The article shows how to facilitate localization process by applying mathematical solutions characterized by simplicity, rapid action and delivering credible results. The paper shows the results of background experiments, which enabled to collect technical parameters needed for conducting simulation testing. The research has been carried by employing network-centric maps of Zatoka Gdańska (Gdansk Bay) prepared in the ArcGIS environment. This allows to place scenarios in a real-life seacoast. Thanks to this solution, the simulation testing has remained very close to a real-life environmental condition. A particular attention has been devoted to the accuracy of observers' localization and its influence on operation effectiveness. Some new tools have been introduced, with an aim to support the usage of fuzzy sets in the GIS environment.

***Keywords*— fuzzy logic, geographic information systems, marine safety.**

I. Introduction

The support of making decisions through computational intelligence has become particularly common in the past few years [11], [3]. The main aim of the presented research outcome is to show the potential of fuzzy sets (as one of the computational intelligence methods) embedded in the ArcGIS environment.

Carrying out search and rescue activities in different water regions depends strongly on the localization accuracy of observers informing about accidents. The solution to this problem might be sought for in the most accurate depicting of the current situation in the region [17]. At present, one of the sources of the up-to-date area map is orthophotomap. Such maps, extended with redundant data (bathymetric, meteorological, hydrological), are called network-centric [7], [16]. The presented method, whose integrating platform is GIS, guarantees the fulfillment of this condition. This type of system is fully scalable and possible to superbly adjust to growing requirements [13], [14]. Enriching the system by employing fuzzy sets to describe information about object localization enables outworking a decision useful in water rescue services.

Studies has shown the lack of tool choice in the ArcGIS environment. There is a commonly known tool called Fuzzy Membership, which is used in decision-making analyses [1]. However, functions available in this tool do not provide for the spreading of a phenomenon from its source along a given direction. Such solutions are vital during visual observations on the surface of water basins. What is more, connecting the existing tools with the ones designed by the authors contributes to the development of GIS solutions in the field of water rescue services. A special emphasis has been put on the accuracy of observers' localization and its influence on the actions efficiency.

During the visual observation, when an observer's position is known and (s)he has given distance and direction for the object being localized, it is possible to establish unequivocally the position of an object [15]. The method in question assumes

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that the information about the direction is described via fuzzy sets based on Laplace's membership function. Thanks to the calculations on sets, it is possible to point out the area with the highest membership function value. GIS environment is a key tool which allows to visualize, analyze and verify our designated area [6]. A main advantage is the possibility to visualize against the background of available spatial data derived from detail-varied and multiresolution databases as well as orthophotomaps [8], [10].

The presented issue concentrates on the question of water area description made with sets of points [4]. The number of the points is constrained via area description through a membership function and calculations. Conducting environmental experiments has enabled to collect technical parameters required to a simulation testing. Experiments in real-word conditions has applied to collecting data pertaining to the way of localizing objects in water areas done by random observers [17]. The experiments involved setting up objects of the known position, and attempt to localize them by observers standing on the shore.

Simulation experiments have been carried out by involving GIS programs, which enabled to test different scenarios of incidents. Moreover, it allows to place scenarios in a real-life coast as well as make real-time analyses [19]. Due to this solution, simulation testing was very close to real-life environmental conditions. Connection fuzzy sets theory in the GIS environment gives the opportunity to prepare planning tactics and carry surface search at night. So far, water rescue services have been suspended during night time, so the solution presented here is of a great value for safety improvement [18].

II. ArcGIS as a Integrating Tool

Visual navigational observation might be seen as a carrier of the data about the incident. It means that parameters assigned to a particular observation are connected to the place where it has been done. For instance, in the information about coordinates it is taken into account in the first place, and then the coordinate is matched to the localization.

Coordinates and distance are the basic data possible to establish during a visual observation. A set which interprets graphically a simple piece of information is described by a line with a designated data (bearing and distance) and a function characterizing the layout of the information error. If an observer's position is known, they establish a comprehensive interpretation on a map without any interactions between themselves and other visual observations. It should be pointed out that these observations are components in the process of their interpretation on the map.

One of the greatest problems is the observer's localization. The solution is to gather information about his or her surroundings. When we have a precise orthophotomap (e.g. 0.03 spatial resolution) at our disposal, such information enables to place him or her precisely [12]. The ArcGIS environment enables to visualize an orthophotomap together with other spatial data, e.g. navigational charts [5]. This environment integrates mathematical tools (in our case – fuzzy sets) with other data included in geodatabase very well [9].

The integration of all abovementioned elements enables to localize the observer's location and determine the localization of the event. When we have the observer's position, if we set an azimuth or an orientation angle between a distinct field detail and an event, we determine a bearing, by designating distance we localize the position of an incident.

III. Observation with Distance Giving

People who notice a distress signal or witness an accident at sea, most often try to establish distance. They assume that determining the distance is easier than determining a bearing. It has been manifested during experiments conducted as a part of a research project. We shall then have a closer look at the interpretation of such information first. Our assumption is that something is being noticed in distance R from an observer standing in a point $P - P(x_0, y_0)$. Such information in a classical understanding might be interpreted as a position line depicted by a circle with a radius r and center P. Adopting this task as our assumption requires some simplification - we should assume that a given observation has been made in a carefully delineated point. To determine this point we use the aforementioned orthophotomap embedded in the ArcGIS environment.

We assume that a distance is usually given with some error. The distance can be described with a function ω, whose form depends on a lot of attributes, inter alia surroundings of the observer and meteorological conditions in which the observation has been conducted. The information about noticing the object in distance by the observer from point $P - P(x_0, y_0)$ - is noted as $O_{P,\omega}$, and the area assigned by it can be interpreted as a fuzzy set $\|O_{P,\omega}\|$. Fuzzy sets can be graphically represented as tridimensional graph. Fig. 1 presents such graph for an error function made while establishing the distance. In order to present fuzzy sets as geoinformation on a map in the GIS environment, we will employ a raster data structure since they present constant data in this environment.

An error value function was projected on a plane XY. Through an appropriate color gradation a map of the error value function was created. The layout of a distance error of a point $Q = Q(x, y)$ to a point $P = P(x_0, y_0)$ is described via the following function:

$$\|O_{P,\omega}\|(Q) = \mu_{\omega,P,r}(Q) = \frac{1}{2b\beta} \quad e^{\frac{\|\sqrt{(x_0-x)^2+(x_0-x)^2}-ra\|}{rb}} \qquad (1)$$

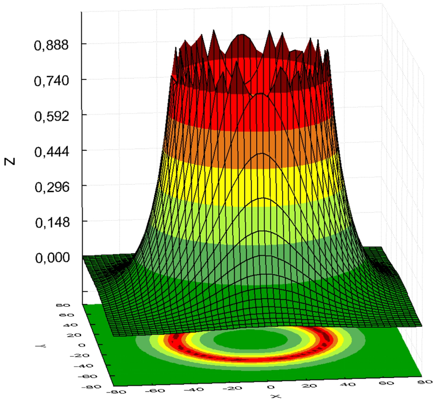

Fig. 1: *A spatial function of interpreting the observation "in a distance".*

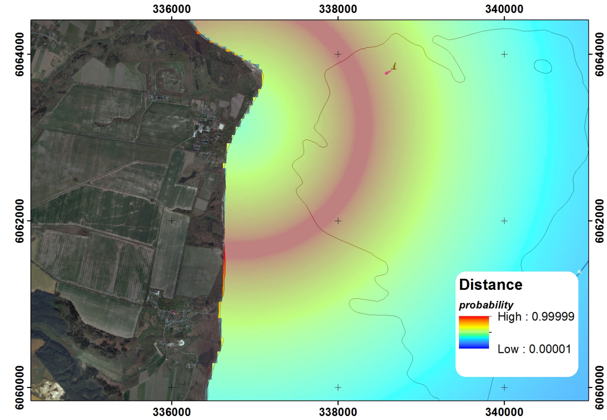

Fig. 3: *A spatial function of interpreting "in a distance" observations applied to a map in the GIS environment.*

where:

r — stands for the distance given by the observer;
$\mu_{\omega,P,r}(Q)$ — a normalized membership function of interpreting observation "in a distance";
$P - P(x_0, y_0)$ — stands for the observer's localization;
Q — is an argument, a point with coordinated x and y;
a — stands for an average distribution value;
b — stands for a sale parameter;
β_0 — modification rate;

The placement of the above mentioned analysis in the GIS environment forces unambiguity in providing information about the observer's localization - that is, by geographic coordinates. From this coordinates, based on the Euclidean distance, a distance raster is created. Raster cells adopt values equal to 0 or close to 0 in the distance provided by the observer. Cells with the lowest values create a ring of a diameter amounting to the distance from the observer's coordinates, which can be observed in the Fig. 2

Due to the raster created in such a way, we recalculate distance values employing formula 2

$$\mu_{r,ij} = \frac{b\beta}{2} \quad e^{\frac{\|d_{ij}-a\|}{b}} \tag{2}$$

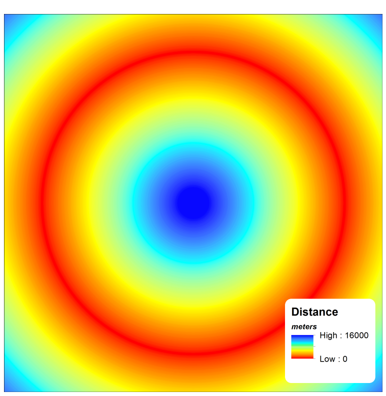

Fig. 2: *A membership function raster of interpreting "in a distance" observation in the GIS environment.*

where:

$\mu_{r,ij}$ — a membership function raster of interpreting "in a distance" of a given raster cell;
d_{ij} — stands for a distance raster value;
a — stands for an average distance value;
b — stands for a scale parameter;
β_0 — modification rate;

The result of the membership function operation is depicted in Fig. 3. There is a coherent change of the value in the direction from the observer. The highest value of the event probability membership function is depicted by a red color. In the systems of fuzzy sets logic, the shape of the function has a big impact on the accuracy of a modelling [2]. Visual observations of events on water areas are strongly influenced by accompanying errors. Taking these aspect into account, the function has a mild value gradation from an expected value.

The above general function describes the membership function value for a point Q depending on its distance from a point of conducting observations P, assuming that the distance given by the observer equals r. Values of the attributes β_0, a, a and b will be changing, depending on the observation conditions. For example, for the majority of observation parameters the values equal β_0=0.09766, a=0.0900874 and b =10.48005.

IV. Observation with Bearing Provision

The second commonly given information is an observation with bearing provision. When it comes to short distances (ca. 10 nautical miles), it can be assumed that an orthodrome as well as iso-azimuth and loxodrome overlap, creating a straight line.

Information about the accident with bearing provision - made from a point $P - P(x_0, y_0)$, with an error described with a function γ dependent on the observer's surroundings and meteorological conditions in which it has been conducted - will be defined as a fuzzy set $N_{P,\psi}$

A layout of a bearing error (Fig. 4) in an observation from a point $P - P(x_0, y_0)$, is described via a following function:

$$\|N_{P,\psi}\|(Q) = \mu_{\gamma,P,\psi}(Q) = \frac{1}{2b\beta} \quad e^{-|\frac{\psi\pi}{180} \quad -arctg\frac{y-y_0}{x-x_0} \quad +a|b} \tag{3}$$

where:

ψ — stands for a bearing given by the observer;
$\mu_{\gamma,P,\psi}(Q)$ — a standardized membership function of interpreting "in bearing" observation;
$P - P(x_0, y_0)$ — stands for the observer's localization;
Q — is an argument, a point with coordinated x and y;
a — stands for an average distribution value;
b — stands for a scale parameter;
β_0 — modification rate;

The above general function describes the membership function value for a point Q, depending on its bearing for Q from a point of conducting observations P, assuming that the distance given by the observer equals ψ. Values of the attributes β_0, a and b will be changed, depending on the observation conditions. For example, for the majority of observation parameters such values equal β_0 = 0.19533, a = 0.0900874 and b = 10.48005.

Similarly to a distance determination membership function raster, an indirect raster was needed - a distance raster. Also in this case we create a raster whose cells adopt values of an angle contained held between an incident direction and a centre direction of an analysed cell. It has been showed in the Fig. 4. In this case, the raster adopts values from $-180°$ to $180°$.

During algorithm operation, cells values are recalculated for a probability level by employing the formula 4.

$$\mu_{\psi,ij} = \frac{b\beta_0}{2} \quad e^{\frac{\|\lambda_{ij}-a\|}{b}} \tag{4}$$

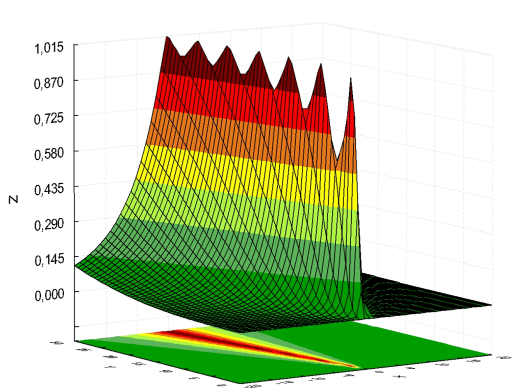

Fig. 4: *A spatial function of interpreting "in bearing" observation.*

where:

$\mu_{\psi,ij}$ — a membership function of interpreting "in a bearing" observation of a given raster cell;
λ_{ij} — stands for a direction raster value;
a — stands for an average distance value;
b — stands for a scale parameter;
β_0 — modification rate;

The distribution of values presented in Fig. 5 and 6 has a uniform character in relation to the distance from the observer, whilst value differences change in relation to the given direction. The highest membership function values are at closest proximity to the given direction (Fig. 6).

V. Observation Conjunction

Often the information given by an observer is an amalgamation of two observations - the observation "in a distance" and the observation "in a bearing". Such information, due to the fact that their graphic interpretation is created via establishing the common part, are treated as the observation conjunction. In the case of a fuzzy observation interpretation, there are many possible cases of generalization of the intersection phenomenon, known from a classical plurality theory. Studies has shown that the most adequate ones for the presented issue are as follows:

$$(\mu_{\omega,P,r} \cap \mu_{\omega,P,\psi})^{(Q)} = min(\mu_{\omega,P,r}, \mu_{\gamma,P,\psi}) \tag{5}$$

A formula (5) defines value $\mu_{\omega,P,r} \cap \mu_{\omega,P,\psi}$ as the minimum from values returned from $\mu_{\omega,P,r}$ and $\mu_{\omega,P,\psi}$, which means that it gives back the smaller of its arguments (Fig. 7).

Placing the above mentioned mathematical analysis in the GIS environment forces the creation of rasters for "in a distance" and "in a bearing" observations. Subsequently, multiplying values from both rasters, we are given a conjunction raster of both functions (Fig. 8).

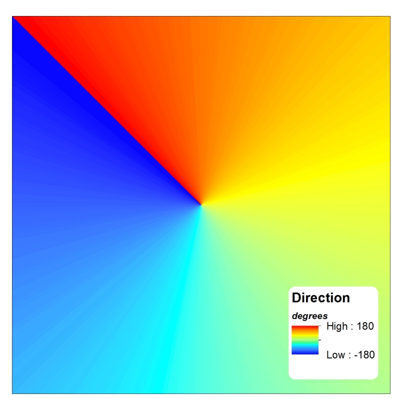

Fig. 5: *A membership function raster of interpreting observations "in bearing" in the GIS environment.*

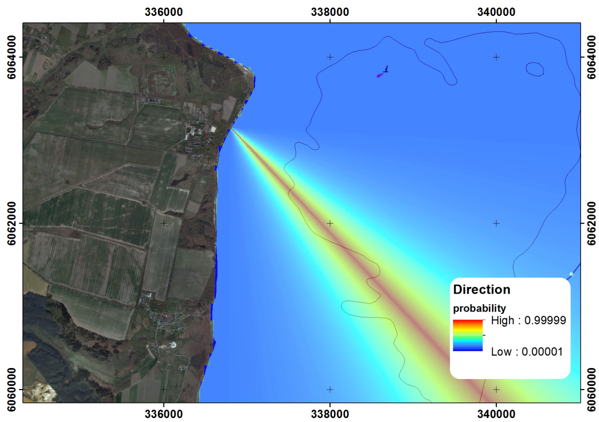

Fig. 6: *A spatial function of interpreting "in bearing" observation applied to a map in the GIS environment.*

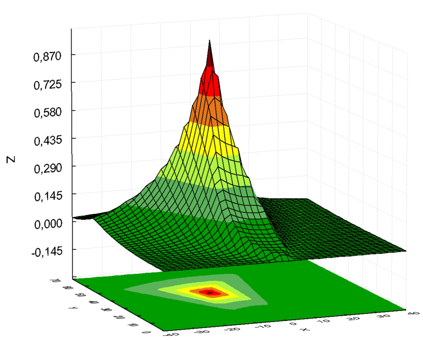

Fig. 7: *A spatial function presenting the conjunction interpretation of the "in a distance" and "in a bearing" observations.*

Noting down a few pieces of information from random

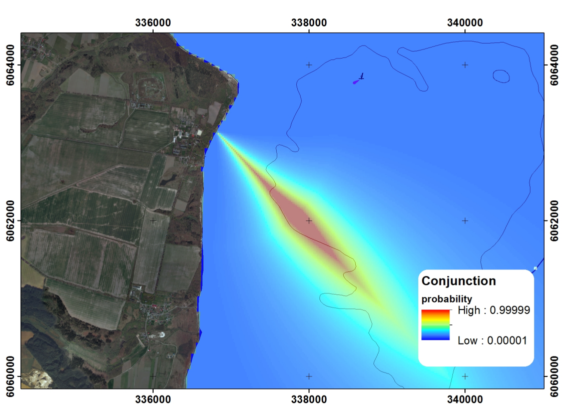

Fig. 8: *A spatial function presenting the conjunction interpretation of the "in a distance" and "in a bearing" observations applied to a map in GIS environment.*

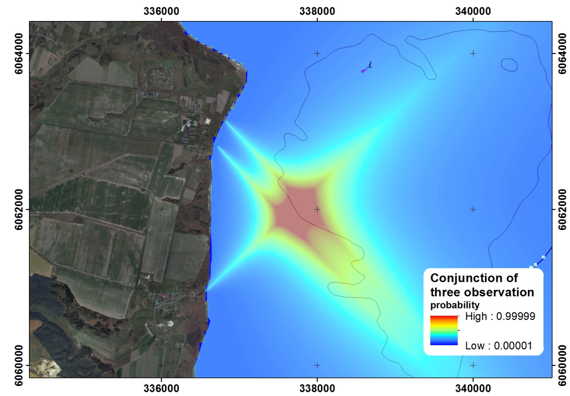

Fig. 9: *A spatial function presenting the conjunction interpretation of three observation "in a distance" and "in a bearing", applied to a map in GIS environment.*

observers with giving a distance and bearing for a localized object on a water surface can be easily interpreted in the GIS environment. Employing algebra map tools, we connect rasters of singular observations by rasters sum. As a result, we receive values from ~ 0 do $\sim n$ (n - a number of singular observations). The final raster can be normalized by the Fuzzy Membership tool with applying linear function (Fig. 9).

VI. Conclusion

The presented basis for localizing objects on water surface by employing visual observations as fuzzy sets guarantees complete objectivity during data interpretation. Referring to fuzzy sets has enabled to describe the whole are on which an object can be found with membership function values. It gives ground to the formulation of a geographic information system dedicated to water rescue for the areas where procedures described in a course books for marine rescue have a very limited application. The suggested notation for coding navigation observations is very elastic and allows to describe even complex situations. Consequently, information resources offered by the system are expanded, and, ultimately, the safety in water areas is being improved. The issues in this article have been solved in stages. The first phase presented the outcome of the research focusing on the layout of visual observations error. This was done in order to develop a function describing this layout. The second stage was to interpret information as a fuzzy set in a two-dimensional Euclidean space. It has been assumed that the interpretation of the information pertaining to object localization on water surface as the set of points on a plane enables to fully express information character. Interpretation of the data accounts for great analysis possibility, both for a singular piece of information as well as their relationships. Even though information was described by big sets, as a result of a section the scope of research has been narrowed.

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