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Bike Trail Difficulty Rating
in the South Moravian Region
Modelled Using Fuzzy Sets

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Abstract

The fuzzy sets are more suitable for modelling of the vagueness than the classical crisp sets. They present vague phenomenon and relations which are not exactly bounded but they are associated with their verbal expression. Inaccuracies of characteristics of the bike trail difficulty are connected to the area changes and it is necessary to evaluate and update them regularly. The analysis is solved by the compositional rule of inference methods especially by Mamdani’s and Larsen’s method. The difficulty is the result of rules processing with verbal variables for the type of road and slope. The suitability of methods is tested by certified and categorized parts of the bike trails. The modelling has been performed by rasters using software ArcGIS 10.1 and its geoprocessing tools.

Keywords: GIS, fuzzy set, fuzzy logic, fuzzy inference, modus ponens, compositional rule of inference, defuzzification, centroid, center of gravity, center of sums

1. Introduction

The term “fuzzy“ is used in meaning of wispy, unclear, misty, vague, uncertain [1]. Although we can describe the phenomenon exactly and clearly, we often utilize unclear, unconfined terms in usual life. We apply terms as moderate slope, near the road. We speak about “linguistic variables” (slope, road) which assume linguistic values (moderate, near) [2]. We sometimes modify linguistic terms by adding expressions called hedges, for example very moderate slope, slightly near the road.

We are able to model real situations better using fuzzy sets, sets with unclear boundary. Each element is in the set more or less. It is indicated by a degree of membership to a fuzzy set expressed by value between zero and one.

Fuzzy sets are perceived as generalization of classical crisp sets which are their special case. Quality “to be fuzzy“ is often expressed as ambiguity, not as inaccuracy or uncertainty, it is relative and subjective.

Look at the definition of fuzzy set using the characteristic function.

Let \( X \) be a universe set (crisp set). A fuzzy set \( A \) of the universe \( X \) is defined by a characteristic function called membership function \( \mu_A \) such that \( \mu_A : X \rightarrow [0, 1] \) where \( \mu_A(x) \) is the
membership value of \( x \) in \( A \).

The membership value assigns a degree of membership to a fuzzy set to any element.

\[
\mu_A(x) = \begin{cases} 
0 & \text{element } x \text{ doesn’t belong to a fuzzy set for sure} \\
< 1 & \text{we aren’t sure if element } x \text{ belongs to a fuzzy set.} \\
1 & \text{element } x \text{ belongs to a fuzzy set for sure}
\end{cases}
\]

Each function \( X \rightarrow \langle 0, 1 \rangle \) determines any fuzzy set definitely.

We can understand the fuzzy set as the complete universe, but only some elements are not definitely in it. The membership degree to the fuzzy set is specified by mathematical function \( [3] \).

We usually compose the membership functions of elementary linear functions. These are trapezoidal, triangular, S-shaped and L-shaped membership functions. We often use more complicated rounded functions, too – Gaussian function, bell-shaped function, sinusoidal function etc.

2. Operations on fuzzy sets and fuzzy logic

We can define operations complement, union and intersection on fuzzy sets in similar way as on crisp sets.

The standard intersection of two fuzzy sets \( A \) and \( B \) is a fuzzy set with the membership function defined by

\[
\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)). \quad \text{Zadeh’s intersection}
\]

The standard union of two fuzzy sets \( A \) and \( B \) is a fuzzy set with the membership function defined by

\[
\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) \quad \text{Zadeh’s union}
\]

The standard complement of fuzzy set \( A \) is a fuzzy set with the membership function defined by

\[
\mu_A^c(x) = 1 - \mu_A(x) \quad \text{Zadeh’s complement}
\]

Functions for modelling fuzzy conjunction are called triangular norms (t-norms), for fuzzy disjunction triangular conorms (t-conorms). They are assumed as functions of two variables defined on a unit square \([4]\).

**Fundamental t-norms**

\[
\begin{align*}
T_M(x, y) &= \min(x, y) & \text{minimum t-norm} \\
T_P(x, y) &= xy & \text{product t-norm} \\
T_L(x, y) &= \max(0, x + y - 1) & \text{Łukasiewicz t-norm} \\
T_D(x, y) &= \begin{cases} 
\min(x, y) & \text{if } \max(x, y) = 1 \\
0 & \text{else}
\end{cases} & \text{drastic t-norm}
\end{align*}
\]

The drastic t-norm is the smallest t-norm and the minimum t-norm is the largest t-norm, because we have \( T_D(x, y) \leq T_L(x, y) \leq T_P(x, y) \leq T_M(x, y) \).
Fundamental t-conorms

\[ S_M(x, y) = \max(x, y) \]  
maximum t-conorm

\[ S_P(x, y) = x + y - xy \]  
probabilistic t-conorm

\[ S_L(x, y) = \min(1, x + y) \]  
Łukasiewicz t-conorm

\[ S_D(x, y) = \begin{cases} 
\max(x, y) & \text{if } \min(x, y) = 0 \\
1 & \text{else}
\end{cases} \]  
drastic t-conorm

The maximum t-conorm \( S_M \) is the smallest t-conorm, drastic t-conorm is the largest t-conorm, because we have \( S_D(x, y) \geq S_L(x, y) \geq S_P(x, y) \geq S_M(x, y) \).

Now we can generalize expression of fuzzy sets union and intersection.

The intersection of fuzzy sets based on t-norm \( T \) is the fuzzy set with the membership function defined by

\[ \mu_{A \cap_T B}(x, y) = T(\mu_A(x, y), \mu_B(x, y)). \]

The union of fuzzy sets based on t-conorm \( S \) is the fuzzy set with the membership function defined by

\[ \mu_{A \cup_S B}(x, y) = S(\mu_A(x, y), \mu_B(x, y)). \]

Therefore, the standard intersection and union are special cases \( A \cap B = A \cap_{T_M} B \) and \( A \cup B = A \cup_{S_M} B \).

Similarly, the fuzzy negation, the complement of the fuzzy set and various implications are defined. [5].

Fuzzy relations

Let \( X, Y \) be crisp sets. A binary fuzzy relation \( R \) from \( X \) to \( Y \) is any fuzzy subset \( R \) of the set \( X \times Y \). Fuzzy relation \( R \) is described by the membership function \( \mu_R : X \times Y \rightarrow [0, 1] \).

We can define intersection on t-norm \( T \) and union on t-conorm \( S \).

\[ \mu_{A \cap_T B}(x, y) = T(\mu_A(x, y), \mu_B(x, y)) \]
\[ \mu_{A \cup_S B}(x, y) = S(\mu_A(x, y), \mu_B(x, y)) \]

Definition of composition of fuzzy relations

Let \( X, Y, Z \) be crisp sets, \( A, B \) binary fuzzy relations and \( T \) t-norm. Then \( \sup-T \) composition of fuzzy relations \( A \) and \( B \) is fuzzy relation \( C = A \circ_T B \) with the membership function \( \mu_C(x, z) = \sup_{y \in Y} T(\mu_A(x, y), \mu_B(y, z)) \).

3. Fuzzy inference and generalized modus ponens

The fuzzy inference is a process which is applied to reasoning based on vague concept. The inductive method \textit{modus tollens} and the deductive method \textit{modus ponens} are the basic rules of inference in binary logic. In modus ponens we infer validity of a propositional formula \( q \) from validity of implication \( p \Rightarrow q \) and validity of premise of a propositional formula \( p \).
3.1. Generalized modus ponens

In fuzzy reasoning we use a *generalized modus ponens* (Tab. 1) according to following statement, where $A$, $B$, $A'$, $B'$ are fuzzy sets, $X$, $Y$ linguistic variables. The scheme consists of a rule or a premise (prerequisite), an observing and a conclusion (consequence). The table (Tab. 1) compare generalized modus ponens to the basic deduction modus ponens.

<table>
<thead>
<tr>
<th>Rule</th>
<th>if $X$ is $A$, then $Y$ is $B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observing</td>
<td>$X$ is $A'$</td>
</tr>
<tr>
<td>Conclusion</td>
<td>$Y$ is $B'$</td>
</tr>
</tbody>
</table>

Table 1: Comparison of modus ponens method against generalized modus ponens

<table>
<thead>
<tr>
<th>$p$</th>
<th>$q$</th>
<th>$p \Rightarrow q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

The observing does not have to correspond to the premise in the rule. According to finding degree of comparison between premise $X$ is $A$ in the rule and current observing $X$ is $A'$ it happens modification conclusion $Y$ is $B$ in the rule and getting value $B'$ of variable $Y$. If it is $A' = A$ in observing, it have to be valid $B' = B$. The fact is, we operate more rules, input and output variables.

*Example:*

<table>
<thead>
<tr>
<th>Rule</th>
<th>if the slope is moderate, the bike trail difficulty is easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observing</td>
<td>slope is steeper</td>
</tr>
<tr>
<td>Conclusion</td>
<td>bike trail difficulty is harder</td>
</tr>
</tbody>
</table>

3.2. Compositional Rule of Inference

Practically we need to interpret verbal values of sets $A$, $B$ mathematically and define the rule of fuzzy relation $R$ between variables $X$, $Y$. We use the compositional rule of inference for assignment value $B'$ of variable $Y$, which corresponds with value $A'$ of variable $X$.

We can get term, where the set $B'$ is the sup-min composition of the fuzzy set $A'$ and the fuzzy relation $R$, written as $B' = A' \circ R$ with the membership [6]

\[
\mu_{B'}(y) = \sup_{x \in X} \min (\mu_{A'}(x), \mu_R(x, y)) \quad \text{standard intersection}
\]

or generally

\[
\mu_{B'}(y) = \sup_{x \in X} T(\mu_{A'}(x), \mu_R(x, y)) \quad \text{union based on t-norm} T
\]

\[
(X, Y) \quad \text{is} \quad R(A, B)
\]

\[
X \quad \text{is} \quad A'
\]

\[
Y \quad \text{is} \quad B', \quad B' = A' \circ_T R(A, B)
\]

compositional rule of inference on t-norm $T$
We have to keep generalized modus ponens during relational reasoning, too, i.e.

\[ A \circ_T R (A, B) = B. \]

The fuzzy relations can be modelled by a logical implication or by a cartesian product \( T^* \) based on t-norm. We confine to the second possibility and we get

\[ \mu_{R(A,B)}(x, y) = T^*(\mu_A(x), \mu_B(y)) \]

\[ \mu_{B'}(y) = \sup_{x \in X} \min (\mu_{A'}(x), T^*(\mu_A(x), \mu_B(y))) \]

We can generalize the properties to t-norm \( T \).

\[ \mu_{B'}(y) = \sup_{x \in X} T(\mu_{A'}(x), T^*(\mu_A(x), \mu_B(y))) \]

If we choose \( T = T^* = T_M \) we get Mamdani’s method.

\[ \mu_{B'}(y) = \sup_{x \in X} \min (\mu_{A'}(x), \min (\mu_A(x), \mu_B(y))) \]

For \( T = T_M \) and \( T^* = T_P \), it is Larsen’s method [7].

\[ \mu_{B'}(y) = \sup_{x \in X} \min (\mu_{A'}(x), \mu_A(x) : \mu_B(y)) \]

4. Mamdani’s method

Let’s have a look at Mamdani’s method in detail [8].

Let \( B = \{P_1, P_2, \ldots, P_k\} \) be a knowledge base with \( k \) rules for \( n \) input variables \( X_1, X_2, \ldots, X_n \) and one output variable \( Y \). Each of the variables \( X_i \) have the verbal value \( A_{i,j} \) in \( j \)-th rule, variable \( Y \) has the verbal value \( B_j \), where \( i = 1, 2, \ldots, n, j = 1, 2, \ldots, k \). For Mamdani’s regulator are defined:

Rules

\[ P_1 : \quad \text{if } X_1 \text{ is } A_{11} \text{ and } X_2 \text{ is } A_{21} \text{ and } \ldots \text{and } X_n \text{ is } A_{n1}, \text{ then } Y \text{ is } B_1 \]
\[ P_2 : \quad \text{if } X_1 \text{ is } A_{12} \text{ and } X_2 \text{ is } A_{22} \text{ and } \ldots \text{and } X_n \text{ is } A_{n2}, \text{ then } Y \text{ is } B_2 \]
\[ \ldots \]
\[ P_k : \quad \text{if } X_1 \text{ is } A_{1k} \text{ and } X_2 \text{ is } A_{2k} \text{ and } \ldots \text{and } X_n \text{ is } A_{nk}, \text{ then } Y \text{ is } B_k \]

Observing \( X_1 \text{ is } A'_1 \text{ and } X_2 \text{ is } A'_2 \text{ and } \ldots \text{and } X_n \text{ is } A'_n \)

Conclusion \( Y \text{ is } B \)

Because the effort with the whole of the relation is numerically arduous, it is preferable to use the approach FITA (first inference then aggregation), which means reasoning of conclusion rule-by-rule, where the final aggregate conclusion is \( B' = \cup_{j=1}^{k} B'_j \). Therefore \( \mu_{B'}(y) \) can be presented as

\[ \mu_{B'}(y) = \max_{j=1}^{k} \mu_{B'_j}(y) = \max_{j=1}^{k} \min (w_j, \mu_{B_j}(y)), \text{ where } w_j = \min (w_{1j}, w_{2j}, \ldots, w_{nj}) \]

is the total weight of \( j \)-th rule, numbers \( w_{1j}, w_{2j}, \ldots, w_{nj} \) are particular degrees of fulfilment of the premises in \( j \)-th rule \( X_1 \text{ is } A_{1j}, X_2 \text{ is } A_{2j}, \ldots, X_n \text{ is } A_{nj} \).

We can generalize the properties to t-norm \( T \).
Consider the generalisation of t-norm $T$ for an intersection and t-norm $T^*$ for an assignment of the relation (Fig. 1). The membership function for degrees $w_j = T(w_{1j}, w_{2j}, \ldots, w_{nj})$ is defined as $\mu_{B_i}(y) = \max_{j=1}^k \mu_{B_{ij}}(w_j) = \max_{j=1}^k T^*(w_j, \mu_{B_i}(y))$.

For Larsen’s method is written $T = T_M$ and $T^* = T_P$.

\[
\begin{align*}
  w_1 &= T(w_{11}, w_{21}) \\
  w_2 &= T(w_{12}, w_{22}) \\
  \mu_{B_{11}}(y) &= T^*(w_1, \mu_{B_{11}}(y)) \\
  \mu_{B_{12}}(y) &= T^*(w_2, \mu_{B_{12}}(y)) \\
  \mu_{B_{1}}(y) &= \max \left( \mu_{B_{11}}(y), \mu_{B_{12}}(y) \right) \\
  \mu_{B_{1}}(y) &= \max_{j=1}^2 T^*(T(w_{1j}, w_{2j}), \mu_{B_{1j}}(y))
\end{align*}
\]

Figure 1: Illustrative scheme of the universal regulator with two rules, two input variables and one output variable

5. Defuzzification

If we apply crisp inputs, the results of inference are fuzzy outputs. We often need to find the particular real value of output by defuzzification. There are several methods to defuzzify for miscellaneous usage (Fig. 2). We can distribute them to methods searching the most acceptable solution and methods of the best compromise [9].

The methods of the most acceptable solution are presented by the methods of the most important maximum with selection of the biggest value of the membership functions placed leftmost, middlemost or rightmost - Left of Maximum (LoM), Mean of Maximum (MoM), Right of Maximum (RoM). Methods of the best compromise include:

- Center of Gravity (CoG) – the centroid of area (the centroid of the plane figure given by union of the part areas bounded by particular membership functions).
Center of Sums (CoS) – the centroid of sums (the centroid of the plane figure given by function, which is equal to the sum of the particular membership functions in the rules).

Center of Maximum (CoM) – the centroid of singletons (the centroid of the typical values, e.g. MoM, for the particular membership functions of the rules).

Method Bisector of Area (BoA) divides the area of the plane figure into two sub-regions of the equal area.

CoG

It makes for finding the first coordinate of the centroid of area bounded by the membership function \( \mu'_{B_j} \). The method is mathematically difficult because we need to know the membership function and calculate the Riemann integrals. In the reasoning of conclusion rule-by-rule \( B = \bigcup_{j=1}^{k} B'_j \) is \( \mu'_B(y) = \max_{1 \leq j \leq k} \mu'_{B_j}(y) \). The situation is simpler, if the universe of the output variable is discrete subset of real numbers \( Y = \{y_1, y_2, \ldots, y_r\} \).

\[
\begin{align*}
    y_{\text{BoA}}^{\text{CoG}} &= \frac{\int y \mu'_B(y) \, dy}{\int \mu'_B(y) \, dy} = \frac{\int y \left(\max_{1 \leq j \leq k} \mu'_{B_j}(y)\right) \, dy}{\int \left(\max_{1 \leq j \leq k} \mu'_{B_j}(y)\right) \, dy} \quad \text{continuous membership function} \\
    y_{\text{BoA}}^{\text{CoS}} &= \frac{\sum_{i=1}^{r} \mu'_{B_i}(y_i) y_i}{\sum_{i=1}^{r} \mu'_{B_i}(y_i)} \quad \text{discrete membership function}
\end{align*}
\]

CoS [3]

It serves to find the first coordinate of the centroid of area which is bounded by the function defined as sum of the membership functions \( \mu'_{B_j} \). The method is easy-to-use because it does
not need to determine the conclusion \( B' \). If the particular conclusions of rules do not overlap, the result of the method CoS is the same as for the method CoG.

\[
y_{B'_j}^{CoS} = \frac{\int_{y} \left( \sum_{1 \leq j \leq k} \mu_{B'_j}(y) \right) y \, dy}{\int_{y} \left( \sum_{1 \leq j \leq k} \mu_{B'_j}(y) \right) \, dy} = \frac{\sum_{1 \leq j \leq k} \left( \int_{y} \mu_{B'_j}(y) \, dy \right)}{\sum_{1 \leq j \leq k} \left( \int_{y} \mu_{B'_j}(y) \, dy \right)}
\]

continuous membership function

\[
y_{B'_j}^{CoS} = \frac{\sum_{i=1}^{r} \sum_{j=1}^{k} \mu_{B'_j}(y_i) \cdot y_i}{\sum_{i=1}^{r} \sum_{j=1}^{k} \mu_{B'_j}(y_i)}
\]

discrete membership function

CoM

The first coordinate of the membership function is written for each conclusion of rule by the method of the most important maximum (Mean of Maximum) and the result is the centroid of singletons.

\[
y_{B'_j}^{CoM} = \frac{\sum_{j=1}^{k} y_j \cdot \mu_{B'_j}(y_j)}{\sum_{j=1}^{k} \mu_{B'_j}(y_j)}
\]

6. The application of fuzzy methods in solution of bike trail difficulty rating

Bike trail difficulty is the basic characteristic to recognize during the cycle route planning. It gives us to qualify whether the route is suitable for families with children, for recreational sportsmen, maybe for athletes. In 2003 and 2005 projects were made with intent to collect information about cycle routes and their facilities. In 2007 the data were updated by terrain research - especially the status of surface and difficulty (demandingness) of bike trail.

The data are published on the web cycling portal of the South Moravian Region http://www.cyklo-jizni-morava.cz, including the interactive bike trail map with choosing routes and view points of interest.

During actual checking well-known routes it was verified that the characteristic of bike trail difficulty has already completely disagreed with the reality. Each rating depends on time, it is affected by the subjective view and data collection is a hard task in terrain.

Therefore, we need to utilize another approach for instance by fuzzy reasoning. The slope and the quality or type of the road surface, which were chosen as analytical inputs, impact on the difficulty.

The modelling is accomplished over rasters in ArcGIS 10.1 using ModelBuilder and geoprocessing tools, especially Spatial Analyst Tools – Fuzzy Membership, Fuzzy Overlay, Raster Calculator, Cell Statistics.
6.1. Methods

We use two input variables, $X_1$ for the type of the road surface and $X_2$ for the angle of the slope (both defined by crisp values) and output variable $Y$ for the bike trail difficulty.

Assume the following input and output fuzzy subsets which are given by verbal values and rules representing their relationship.

**Type of road surface** (data StreetNet 2012)
- $K_1$ - paved roads (asphalt, pavement, concrete)
- $K_2$ - maintained roads (unpaved, gravel)
- $K_3$ - other unpaved roads (forest and cart roads)

**Angle of slope** (DMT, in degrees)
- $S_1$ - moderate slope
- $S_2$ - steep slope

**Bike trail difficulty**
- $D_1$ - small difficulty – easy difficult roads (suitable for families with children)
- $D_2$ - intermediate difficulty – more difficult roads (suitable for recreational sportsmen)
- $D_3$ - hard difficulty - very difficult roads (suitable for athletes)

Rules
- $P_1$: if $X_1$ is $K_1$ and $X_2$ is $S_1$, then $Y$ is $D_1$
- $P_2$: if $X_1$ is $K_2$ and $X_2$ is $S_1$, then $Y$ is $D_1$
- $P_3$: if $X_1$ is $K_3$ and $X_2$ is $S_1$, then $Y$ is $D_2$
- $P_4$: if $X_1$ is $K_1$ and $X_2$ is $S_2$, then $Y$ is $D_2$
- $P_5$: if $X_1$ is $K_2$ and $X_2$ is $S_2$, then $Y$ is $D_3$
- $P_6$: if $X_1$ is $K_3$ and $X_2$ is $S_2$, then $Y$ is $D_3$

Observing $X_1$ is $K'$ and $X_2$ is $S'$

**Conclusion**

The fuzzy sets $K_1$, $K_2$, $K_3$ were given by the bell-shaped membership function Near (Midpoint 0, Spread 0.0001) available in the geoprocessing tools of ArcMap in the category Fuzzy Membership (Fig. 3). The function expresses the close localization of the road as a fuzzy line [10] in network of roads. The tool Kernel Density was selected at first. But the results were not satisfactory because they characterised roads inaccurately as fuzzy lines in regions with small density of roads.

Next figures show settings that define $S_1$, $S_2$ and $D_1$, $D_2$, $D_3$ (Fig. 4 and Fig. 5).

We will use and compare several regulators and defuzzification methods. We will do the interpretation rule-by-rule. We declare $w_j$ as the total weight of the $j$-th rule worked from particular weights of premises (roads, slope) $w_{1j}, w_{2j}$. The membership function of conclusion of the $j$-th rule is written $\mu_{D_j}(y)$. This is summary and specification of applied methods.

**Mamdani’s method** (COS-TM-TM, COM-TM-TM)

$$\mu_{D_j}(y) = \max_{j=1}^k T_M \left( T_M \left( w_{1j}, w_{2j} \right), \mu_{D_j}(y) \right) = \max_{j=1}^k \min \left( \min \left( w_{1j}, w_{2j} \right), \mu_{D_j}(y) \right)$$
\[
\mu(x_1) = \frac{1}{1 + 0.0001x_{12}}
\]

Figure 3: Membership function for road surface

Figure 4: Membership function for slope

Figure 5: Membership function for difficulty of road
Larsen’s method (COS-TP-TM)
\[
\mu_{D_j}’(y) = \max_{j=1}^k T_P \left( T_M \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right) = \max_{j=1}^k \left( \min \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right)
\]

Product t-norm and product t-norm (COS-TP-TP)
\[
\mu_{D_j}’(y) = \max_{j=1}^k T_P \left( T_P \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right) = \max_{j=1}^k \left( w_{1j} \cdot w_{2j}, \mu_{D_j} (y) \right)
\]

Łukasiewicz t-norm and minimum t-norm (COS-TL-TM)
\[
\mu_{D_j}’(y) = \max_{j=1}^k T_L \left( T_M \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right) = \max_{j=1}^k \left( 0, \min \left( w_{1j}, w_{2j} \right) + \mu_{D_j} (y) - 1 \right)
\]

Łukasiewicz t-norm and product t-norm (COS-TL-TP)
\[
\mu_{D_j}’(y) = \max_{j=1}^k T_L \left( T_P \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right) = \max_{j=1}^k \left( 0, w_{1j} \cdot w_{2j} + \mu_{D_j} (y) - 1 \right)
\]

Łukasiewicz t-norm and Łukasiewicz t-norm (COS-TL-TL)
\[
\mu_{D_j}’(y) = \max_{j=1}^k T_L \left( T_L \left( w_{1j}, w_{2j} \right), \mu_{D_j} (y) \right) = \max_{j=1}^k \left( 0, \max \left( 0, w_{1j} + w_{2j} - 1 \right) + \mu_{D_j} (y) - 1 \right)
\]

### 6.2. Mamdani’s method (COS-TM-TM)

Considering evaluation of the road surface and reasoning of conclusion rule-by-rule, we will choose (COS-TM-TM) the centroid of sums which means calculation.

\[
y_{D_j}^{\text{CoS-TM}} = \int_{0}^{\mu_{D_j}’(y)} \frac{\int \mu_{D_1}(y) \, dy + \int \mu_{D_2}(y) \, dy + \int \mu_{D_3}(y) \, dy + \int \mu_{D_4}(y) \, dy + \int \mu_{D_5}(y) \, dy + \int \mu_{D_6}(y) \, dy}{\int \mu_{D_1}(y) \, dy + \int \mu_{D_2}(y) \, dy + \int \mu_{D_3}(y) \, dy + \int \mu_{D_4}(y) \, dy + \int \mu_{D_5}(y) \, dy + \int \mu_{D_6}(y) \, dy} \, dy
\]

The total weight of the \( j \)-th rule \( w_j \) is the minimum of the particular weights of the premises (roads, slope) \( w_{1j}, w_{2j} \) in this rule (simply signed \( w \)). The membership function of the conclusion of the \( j \)-th rule is presented as \( \mu_{D_j}’(y) = \min \left( w_j, \mu_{D_j} (y) \right) \). The membership \( \mu_{D_j} (y) \) is simply denoted \( \mu (y) \).

The model in ArcGIS ModelBuilder is shown in Fig. 9.

In the first and the second rule we evaluate small difficulty \( D_1 \) (Fig. 6).

\[
A = w \left[ \frac{y^3}{2} \right]_{0}^{2w+3} + \left[ \frac{y^3}{6} + \frac{3y^2}{4} \right]_{2w+3}^{3} = \frac{2}{3}w^3 - 3w^2 + \frac{9}{2}w
\]
\[ \int_{-2w+3}^{0} \frac{3}{w} y \, dy + \int_{-2w+3}^{3} \left( -\frac{y}{2} + \frac{3}{2} \right) y \, dy \quad (A) \]

and

\[ \int_{0}^{2w+3} \frac{3}{w} y \, dy + \int_{-2w+3}^{3} \left( -\frac{y}{2} + \frac{3}{2} \right) y \, dy \quad (B) \]

In the third and the fourth rule we evaluate intermediate difficulty \( D_2 \) (Fig. 7).

\[ B = w \left[ y \right]_{0}^{2w+3} - \left[ \frac{-y^2}{4} + \frac{3y}{2} \right]_{-2w+3}^{3} = -w^2 + 3w \]

In the fifth and the sixth rule we evaluate hard difficulty \( D_3 \) (Fig. 8).

\[ C = \left[ \frac{y^3}{6} - \frac{y^2}{4} \right]^{2w+1} + w \left[ \frac{y^2}{2} \right]_{2w+1}^{2w+5} + \left[ -\frac{y^3}{6} + \frac{5y^2}{4} \right]_{-2w+5}^{5} = -6w^2 + 12w \]

\[ D = \left[ \frac{y^2}{4} - \frac{y}{2} \right]_{1}^{2w+1} + w \left[ y \right]_{-2w+5}^{2w+5} + \left[ -\frac{y^2}{4} + \frac{5y}{2} \right]_{-2w+5}^{5} = -2w^2 + 4w \]
\[
\int_3^{2w+3} \left( \frac{y}{2} - \frac{3}{2} \right) y \, dy + \int_2^{w+3} w \, y \, dy \quad (E)
\]
and
\[
\int_3^{2w+3} \left( \frac{y}{2} - \frac{3}{2} \right) \, dy + \int_2^{w+3} w \, dy \quad (F)
\]

\[
E = \left[ \frac{y^3}{6} - \frac{3y^2}{4} \right]^{2w+3}_3 + w \left[ \frac{y^6}{2} \right]^{2w+3} = -\frac{2}{3} w^3 - 3w^2 + \frac{27}{2}
\]

\[
F = \left[ \frac{y^2}{4} - \frac{3y^2}{2} \right]^{2w+3}_3 + w [y]^{6}_2 w+3 = -w^2 + 3w
\]
6.3. Mamdani’s method (COM-TM-TM)

We evaluate by the centroid of singletons Center of Maximum (COM-TM-TM) using the mean of the maximum.

\[
\frac{y_{CoM}}{w_{D_j}} = \frac{y_1 \cdot \mu_{D'_1}(y_1) + y_2 \cdot \mu_{D'_2}(y_2) + y_3 \cdot \mu_{D'_3}(y_3) + y_4 \cdot \mu_{D'_4}(y_4) + y_5 \cdot \mu_{D'_5}(y_5) + y_6 \cdot \mu_{D'_6}(y_6)}{\mu_{D'_1}(y_1) + \mu_{D'_2}(y_2) + \mu_{D'_3}(y_3) + \mu_{D'_4}(y_4) + \mu_{D'_5}(y_5) + \mu_{D'_6}(y_6)}
\]

By substituting values:

\[
\frac{y_{CoM}}{w_{D_j}} = \frac{0 - 2w_1 + 3}{2} \cdot w_1 + \frac{0 - 2w_2 + 3}{2} \cdot w_2 + \frac{2w_3 + 1 - 2w_3 + 5}{2} \cdot w_3 + \frac{2w_4 + 1 - 2w_4 + 5}{2} \cdot w_4 + \frac{2w_5 + 3 + 6}{2} \cdot w_5 + \frac{2w_6 + 3 + 6}{2} \cdot w_6
\]

6.4. Comparison of defuzzification methods CoS and CoM

The raster analysis result is in range between 1,085 and 4,916 for CoS method, between 0,501 and 5,500 for CoM method. In ArcMap we see that the results are comparable. The value difference of both processes CoM-CoS gives results from -0,564 to 0,626.

Negative values of the difference are related to the flat land and the closeness to the paved and maintained roads (CoS>CoM), CoM gives the less difficulty of the roads. Positive values are related to the steep slope and the closeness to the forest and the cart roads (CoS<CoM), CoM gives the bigger difficulty of the roads. The numerically simpler and less accurate method CoM without the integral calculus gives similar view to data but with bigger interval range depending on the relief and the road.

Analogous to Mamdani’s method we will process other methods where we will choose CoS defuzzification, too.

6.5. Comparison of all used methods

The data of well-known parts of the bike trails which were possible to classify in predominant distance were selected to choose the best method.

Following tables (Tab. 2, Tab. 3 and Tab. 4) show the comparison of the maximum, minimum, arithmetic mean and standard deviation according to the difficulty of the bike trails. Then we monitored frequency histograms.

From these fundamental characteristics and also matching histograms (they are not in this paper) we can see that Mamdani’s method is well representative with defuzzification CoS but also with defuzzification CoM, where there is the bigger value range and the higher frequency on the intervals of the maximum occurrence.

Larsen’s method and its modifications with the product t-norm of the degrees of the premises have similar characteristics. However, they are not suitable for the bike trails with the intermediate difficulty because they have the maximum frequency for the maximum and the
Table 2: Bike trails classified as small difficulty roads

<table>
<thead>
<tr>
<th></th>
<th>maximum</th>
<th>minimum</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>COS-TM-TM</td>
<td>4,070</td>
<td>1,100</td>
<td>1,571</td>
<td>0,411</td>
</tr>
<tr>
<td>COM-TM-TM</td>
<td>4,319</td>
<td>0,511</td>
<td>1,049</td>
<td>0,528</td>
</tr>
<tr>
<td>COS-TP-TM</td>
<td>4,154</td>
<td>1,091</td>
<td>1,440</td>
<td>0,423</td>
</tr>
<tr>
<td>COS-TP-TP</td>
<td>4,080</td>
<td>1,091</td>
<td>1,422</td>
<td>0,395</td>
</tr>
<tr>
<td>COS-TL-TM</td>
<td>4,486</td>
<td>0,792</td>
<td>1,262</td>
<td>0,445</td>
</tr>
<tr>
<td>COS-TL-TP</td>
<td>4,396</td>
<td>0,791</td>
<td>1,238</td>
<td>0,413</td>
</tr>
<tr>
<td>COS-TL-TL</td>
<td>4,265</td>
<td>0,766</td>
<td>1,219</td>
<td>0,380</td>
</tr>
</tbody>
</table>

Table 3: Bike trails classified as intermediate difficulty roads

<table>
<thead>
<tr>
<th></th>
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<th>minimum</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>COS-TM-TM</td>
<td>4,901</td>
<td>1,090</td>
<td>2,871</td>
<td>0,992</td>
</tr>
<tr>
<td>COM-TM-TM</td>
<td>5,493</td>
<td>0,504</td>
<td>2,849</td>
<td>1,194</td>
</tr>
<tr>
<td>COS-TP-TM</td>
<td>4,913</td>
<td>1,086</td>
<td>2,830</td>
<td>1,186</td>
</tr>
<tr>
<td>COS-TP-TP</td>
<td>4,913</td>
<td>1,086</td>
<td>2,817</td>
<td>1,207</td>
</tr>
<tr>
<td>COS-TL-TM</td>
<td>5,493</td>
<td>0,505</td>
<td>2,687</td>
<td>1,727</td>
</tr>
<tr>
<td>COS-TL-TP</td>
<td>5,496</td>
<td>0,504</td>
<td>2,657</td>
<td>1,782</td>
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<tr>
<td>COS-TL-TL</td>
<td>5,500</td>
<td>0,500</td>
<td>2,656</td>
<td>1,776</td>
</tr>
</tbody>
</table>

Table 4: Bike trails classified as hard difficulty roads

<table>
<thead>
<tr>
<th></th>
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<th>minimum</th>
<th>mean</th>
<th>standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>COS-TM-TM</td>
<td>4,904</td>
<td>1,262</td>
<td>4,009</td>
<td>1,041</td>
</tr>
<tr>
<td>COM-TM-TM</td>
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<td>0,634</td>
<td>4,315</td>
<td>1,371</td>
</tr>
<tr>
<td>COS-TP-TM</td>
<td>4,910</td>
<td>1,176</td>
<td>4,085</td>
<td>1,135</td>
</tr>
<tr>
<td>COS-TP-TP</td>
<td>4,910</td>
<td>1,172</td>
<td>4,086</td>
<td>1,162</td>
</tr>
<tr>
<td>COS-TL-TM</td>
<td>5,252</td>
<td>0,848</td>
<td>4,193</td>
<td>1,301</td>
</tr>
<tr>
<td>COS-TL-TP</td>
<td>5,274</td>
<td>0,840</td>
<td>4,191</td>
<td>1,343</td>
</tr>
<tr>
<td>COS-TL-TL</td>
<td>5,270</td>
<td>0,780</td>
<td>4,185</td>
<td>1,370</td>
</tr>
</tbody>
</table>

minimum and highlight the bike trail with the small and hard difficulty. The methods going from Łukasiewicz t-norm with other t-norms still more emphasize these extremes. The result does not almost depend on the choice of these methods.

It still will be interesting to compare the percentage of the bike trails suitable for the membership in intervals \((0; 25; 1), (0; 5; 1)\) and \((0; 75; 1)\) according to the functions \(D_1, D_2, D_3\) (small, intermediate and hard difficulty) in regard of their whole choice for the individual difficulties and the methods (Tab. 5, Tab. 6 and Tab. 7).

In the first case we will take the domains of definition of these functions in intervals \((0; 2), (2; 4)\) and \((4; 6)\). In the second case the domains of definition are the connecting intervals \((0; 2), (2; 4)\) and \((4; 6)\). In the last “the most strict” case the domains of definition of \(D_1, D_2, D_3\) are \((0; 1; 5), (2; 5; 3; 5)\) and \((4; 5; 6)\).

The sum value of the percentages expresses the precision of the individual method. We can see that Mamdani’s method bluntly dominates, especially with defuzzification CoS respectively in the larger membership. The results of Larsen method are quite good. This method is
not much reliable in the evaluation of the intermediate difficult bike trails. It significantly competes with Mamdani’s method within the small and hard difficult bike trails. Other methods are not much satisfactory. The most important three methods are compared at the selected region (Fig. 10).

We choose the bike trail difficulty obtained by Mamdani’s method with the defuzzification CoS for another analytical processing. This method increases practical applicability for all roads. It will permit to reclassify the attribute of the current bike difficulty and to add the difficulty of the other roads for the routing as the finding optimal road according to the difficulty.

We also can get roads and transform them to the points by the extract from the fuzzy raster. The points provide the precise assessment of the behaviour of the road difficulty depending on the raster quality and they are classified by smaller or bigger value of the degree of the difficulty in the following figure (Fig. 11).
Figure 10: Comparison of the methods in the region detail
Figure 11: Comparison of the initial bike trail rating, the fuzzy point road rating and the fuzzy road section rating after reclassification
7. Conclusion

The bike trail difficulty is the important data for the planning the cycle trips. Mainly, it depends on the quality of the surface road and the slope. We can express the requests to the bike trail fairly verbally by rules that are processed using the fuzzy sets based on the compositional rule of inference and Mamdani’s method. This method has reached the best effect with the defuzzification the centroid of sums and using the integral calculus.

The main aim of this paper is the exploitation and map presentation of the results on the web cycling portal of the South Moravian Region http://www.cyklo-jizni-morava.cz/. The analysis extends the difficulty of the bike trails to all roads. Considering fuzzy approach we can imagine the region compactly as a whole of the seamless bike trail difficulty raster fuzzy map and as the bike trail difficulty point fuzzy map. The reclassification of the current difficulty and update of the road difficulty network for the routing is important to the improvement of routing depending on required target group (family with children, recreational sportsman or athlete).

References

Extension of mathematical background for Nearest Neighbour Analysis in three-dimensional space

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Abstract

Proceeding deals with development and testing of the module for GRASS GIS [1], based on Nearest Neighbour Analysis. This method can be useful for assessing whether points located in area of interest are distributed randomly, in clusters or separately. The main principle of the method consists of comparing observed average distance between the nearest neighbours $r_A$ to average distance between the nearest neighbours $r_E$ that is expected in case of randomly distributed points. The result should be statistically tested. The method for two- or three-dimensional space differs in way how to compute $r_E$. Proceeding also describes extension of mathematical background deriving standard deviation of $r_E$, needed in statistical test of analysis result. As disposition of phenomena (e.g. distribution of birds’ nests or plant species) and test results suggest, anisotropic function would represent relationships between points in three-dimensional space better than isotropic function that was used in this work.

Keywords: 3D GIS, spatial analysis, Nearest Neighbour Analysis

1. Introduction

The purpose of this work is to outline the way how to implement Nearest Neighbour Analysis (NNA) in three-dimensional space into the geographical information systems (GIS) environment. At first, the article summarizes derivation of mathematical background in case of isotropic phenomenon. In the next part, there is described the module of open source software GRASS GIS [1] that was developed on the base of these relationships. Finally, the results of modules tests are analysed.

NNA helps to assess whether points located in tested area are distributed randomly, in clusters or separately. It can be useful in biology to monitor behaviour of plant or animal populations [2], in stellar statistics, in chemistry to analyse atomic structures, etc. In GIS, NNA may be helpful in answering questions in biology (mentioned above) or in solving social problems (e.g. crime analysis). In case of analysing vertically divided phenomena (as artifacts in archaeological trench, birds’ nests, behaviour of plant or animal populations in 3D space), three-dimensional distance should be considered in NNA. This distance depends also on the difference of elevation between objects.

If we assume the phenomenon to be isotropic, it is possible to express NNA as function of distance $r$. It is more probable that natural phenomena are anisotropic - they behave
differently in horizontal and vertical direction. NNA then could be a function of horizontal
distance and vertical difference of elevation (or zenith angle). In another case, the phenomenon
may be anisotropic in three dimensions.

2. Keynote

NNA in three-dimensional space was outlined in proceedings [3] and [4]. The main principle of
this work is based also on [2] that describes NNA for two-dimensional space. The goal of this
article on theoretical level is to complete the idea of statistical testing in three-dimensional
space.

There are $N$ points located in the area of interest. Their average isotropic distance between
the nearest neighbours $r_A$ is expressed using arithmetic mean. If these points are randomly
distributed, average isotropic distance of the nearest neighbours in three-dimensional space
is expected to be (according to [4], formulas (674), (675)):

$$r_E = \int_0^\infty 4\pi n \cdot r^3 \cdot e^{-\frac{4\pi n}{3} \cdot r^3} \, dr = \frac{1}{\sqrt[4]{4\pi n}} \int_0^\infty e^{-x} \cdot \sqrt[4]{3} \, dx = \frac{1}{\sqrt[4]{4\pi n}} \cdot \Gamma\left(\frac{4}{3}\right)$$

where $n$ is density of points in volume unit and $\Gamma\left(\frac{4}{3}\right)$ is the gamma function\(^1\). This formula is
based on the probability that the nearest neighbour of a point is located on the boundary of
its spherical surrounding with radius $r$. More detailed explanation of the topic can be found
in [4] or in [3].

The measure of degree to which observed points are randomly distributed $R$ is expressed as
the ratio of observed and expected distance [2]. It may acquire these values:

$R = 1 \rightarrow$ points are distributed randomly, because $r_A = r_E$

$R = 0 \rightarrow$ points are identical, because $r_A = 0$

$R = max \rightarrow$ it is necessary to derive maximal value of ratio $R$. According to [2], if points are
located on a hexagonal pattern, $R$ in two-dimensional space reaches maximal value

$$R_{2D_{max}} = \frac{2.1491}{\sqrt{k}}$$

where $k$ means the number of segments in circle of infinite radius with a center in the observed
point. The results of module testing (Chap. 6), as well as the results obtained using analytical
tool Average Nearest Neighbor [6], do not correspond with this value. Determining of $R$
maximum will be purpose of further work (Chap. 7).

3. Test of statistical significance

Derivation of standard deviation of the average distance expected in case of randomly dis-
tributed points $\sigma_{r_E}$ in three-dimensional space belonged in the purposes of this article. $\sigma_{r_E}$ is
needed to enumerate test statistic of Student’s t-test of significance of the mean [7] that helps
to assess the statistical significance of the deviation from a random distribution of points (clus-
tering or, on the other hand, separation). Method of derivation (Appendix A) is analogical
to method for two-dimensional space [2].

\(^1\)Gamma function $\Gamma(n)$ means extension of factorial for complex and real numbers [5].
Null hypothesis $H_0$: $r_A = r_E$ means that points are randomly distributed in the space (according to [8]). Alternative hypothesis $H_a$: $r_A < r_E \lor r_A > r_E$ and statistical tables (e.g. [9]) of the cumulative standard normal distribution are base for determination of critical values $W$:

$$W = (-\infty, u_{\alpha/2}) \cup (u_{1-\alpha/2}, \infty)$$

If null hypothesis about randomness of distribution in point dataset is rejected with positive values of the test statistic $c$, the points are assumed to be separated (patterned). If the values of the test statistic $c$ are negative and the null hypothesis is rejected, the points are assumed to be clustered.

4. Implementation of 3D Nearest Neighbour Analysis

The theoretical background described in the previous chapters was implemented in the module v.nn.spatial_stat developed in the environment of open-source software GRASS GIS [1]. The module contains functionality of NNA in two-dimensional space (implemented also in the analytical tool [6] of ArcGIS [10]) and solution for objects in three-dimensional space. The most significant complications during development were connected with determining of Minimum Bounding Box (MBB).

In two-dimensional space, the density of points depends on the area of surface where the points are located. According to [11], the area could be set up by user or it is possible to use area of Minimum Bounding Rectangle (MBR). Analogically, the density of points in three-dimensional space could be determined using volume of box set up by user or volume of MBB.

Methods how area (volume) of MBR (MBB) can be determined are principally quite similar:

- Coordinates of convex hull\(^3\) that covers the point set must be obtain. In 3D case it is necessary to know also reference of each vertex to the faces. Partially modified functions of the module v.hull [13] that enables to build convex hull in new vector layer were used. Output of modified functions is represented by the list of coordinates of vertices (or faces), not by new vector body.

- The coordinates of vertices must be transformed to coordinate systems
  - which $x$ axes are parallel to lines between neighbouring vertices in 2D case
    $$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = R_x(\sigma) \cdot \begin{pmatrix} x \\ y \end{pmatrix}$$
    where $\sigma$ is bearing of the line,
  - which $xy$ planes are parallel to planes of faces of the convex hull in 3D case
    $$\begin{pmatrix} x_t \\ y_t \\ z_t \end{pmatrix} = R_{xy}(\sigma_x, \sigma_y) \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}$$

\(^2\)Minimum Bounding Box encloses all features in vector dataset. Its faces are parallel to planes of 3D coordinate system in special case only.

\(^3\)Convex hull is a cycle graph (body) that encloses all features in dataset. Its vertices are located on the features in such way that all interior angles are less than $180^\circ$ (according to [12]).
where the angles $\sigma_x$, $\sigma_y$ may be expressed:

$$\tan(\sigma_x) = \frac{z_1 - z_0}{y_1 - y_0}$$

$$\tan(\sigma_y) = \frac{z_2 - z_0}{x_2 - x_0}$$

and $x$, $y$, $z$ are coordinates of vertices belonging to triangular face of convex hull. Transformation matrix is based on rotation of $x$ and $y$ axes:

$$R_{xy}(\sigma_x, \sigma_y) = R_x(\sigma_x) \cdot R_y(\sigma_y) =$$

$$= \begin{pmatrix}
\cos(\sigma_y) & 0 & \sin(\sigma_y) \\
\sin(\sigma_x) \cdot \sin(\sigma_y) & \cos(\sigma_x) & \sin(\sigma_x) \cdot \cos(\sigma_y) \\
\cos(\sigma_x) \cdot \sin(\sigma_y) & -\sin(\sigma_x) & \cos(\sigma_x) \cdot \cos(\sigma_y)
\end{pmatrix}$$

- Extent of transformed coordinates should be determined,
- Area / volume of the extent must be counted and the values should be compared to obtain the smallest one. This value becomes input in determining the density of points.

5. Testing of the module `v.nn_spatial_stat`

For points located in two-dimensional space, the module was tested comparing numerical results with outputs of the analytical tool `Average Nearest Neighbor` [6] that is part of the `Spatial Statistics` toolbox in the software `ArcGIS 10.1` [10]. 3D variant of NNA is not implemented in any of accessible softwares. That was the reason to verify numerical results by comparing them with values computed by scripts in the software `Mathematica` [14] and `Matlab` [15].

5.1. Testing in two-dimensional space

The module was tested on various sets of synthetic data. Configuration of observed points in the area of interest 20 km x 20 km was designed to represent all possible cases: randomly distributed points, separated points and clustered points.

The samples of randomly distributed points were generated in the software `GRASS GIS` [1] using the module `v.random` [16]. Except numerical accuracy, process speed was tested too.

The results are summarized in tables 1a and 1b.

<table>
<thead>
<tr>
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<td></td>
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<td>$c$</td>
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<td>1.008245</td>
<td>0.000006</td>
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<td>$A [m^2]$</td>
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<td>398645718.650315</td>
<td>-345 mm^2</td>
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<tr>
<td>$t [s]$</td>
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</table>

Table 1a: The results of testing of the module `v.nn_spatial_stat` in two-dimensional space using 2000 randomly distributed points.
Table 1b: The results of testing of the module v.nn.spatial_stat in two-dimensional space using 5000 randomly distributed points

According to the test statistic \( c \in (-1.96; 1.96) \), it can be assumed that in both cases the points were randomly distributed.

Differences in the values of MBR area may be caused by the different way of storing data in computer memory, as the results of next experiments show. Significantly shorter processing time (compared with the analytical tool Average Nearest Neighbor [6]) may be reached, because the module does not generate report with graphical outputs.

The condition of maximized separation in two-dimensional space is accomplished by points arranged in the pattern of equilateral triangles, i.e. the nearest neighbouring points are located around the observed point in the shape of regular hexagon (proofed in [2]). Two datasets were generated, seven points arranged in the hexagon with centre and many points arranged in the hexagonal pattern. Coordinates of the points were computed in the Matlab [15] environment. Tables 2a and 2b summarize the results of the tests.

Table 2a: The results of testing of the module v.nn.spatial_stat in two-dimensional space using maximally separated points (hexagon with centre)

Table 2b: The results of testing of the module v.nn.spatial_stat in two-dimensional space using maximally separated points (hexagonal pattern)
Because of the test statistic \( c < 2.58; \infty \), null hypothesis about random distribution of the points is rejected on the confidence level \( \alpha = 0.01 \). The points are separated.

Clusters of points were created locating points around each of sample of \( n_0 \) randomly generated points. Coordinates of new points were computed in Matlab [15] using bearings with step 36° and random distances (table 3a, table 3b).

<table>
<thead>
<tr>
<th>( n_0 = 100 )</th>
<th>( \sigma = [0°;36°;\ldots;324°] )</th>
<th>( r = \text{random('Normal',30,10)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v.nn_spatial_stat )</td>
<td>Average Nearest Neighbor [6]</td>
<td>difference</td>
</tr>
<tr>
<td>( r_A ) [m]</td>
<td>20.121996</td>
<td>20.121996</td>
</tr>
<tr>
<td>( r_E ) [m]</td>
<td>311.387518</td>
<td>311.387518</td>
</tr>
<tr>
<td>( R )</td>
<td>0.06462</td>
<td>0.06462</td>
</tr>
<tr>
<td>( c )</td>
<td>-56.586926</td>
<td>-56.587273</td>
</tr>
<tr>
<td>( A ) [m²]</td>
<td>387848745.955230</td>
<td>387848745.955141</td>
</tr>
</tbody>
</table>

Table 3a: The results of testing of the module \( v.nn\_spatial\_stat \) in two-dimensional space using clusters of points with shorter distances from local centres

<table>
<thead>
<tr>
<th>( n_0 = 100 )</th>
<th>( \sigma = [0°;36°;\ldots;324°] )</th>
<th>( r = \text{random('Normal',300,1000)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v.nn_spatial_stat )</td>
<td>Average Nearest Neighbor [6]</td>
<td>difference</td>
</tr>
<tr>
<td>( r_A ) [m]</td>
<td>301.259436</td>
<td>301.259436</td>
</tr>
<tr>
<td>( r_E ) [m]</td>
<td>351.460991</td>
<td>351.460991</td>
</tr>
<tr>
<td>( R )</td>
<td>0.857163</td>
<td>0.857163</td>
</tr>
<tr>
<td>( c )</td>
<td>-8.641085</td>
<td>-8.641138</td>
</tr>
<tr>
<td>( A ) [m²]</td>
<td>494099313.011801</td>
<td>494099313.011630</td>
</tr>
</tbody>
</table>

Table 3b: The results of testing of the module \( v.nn\_spatial\_stat \) in two-dimensional space using clusters of points with longer distances from local centres

Null hypothesis about randomly distributed points may be rejected on confidence interval \( \alpha = 0.01 \) because \( c \in (\infty; -2.58 \rangle \). Negative values of the test statistic \( c \) indicate that the samples are clustered. The sample in table 3a in which clusters were generated using random distances with normal distribution \( N(30,10) \) is characterized by significantly lower value of test statistic \( c \) as the sample in table 3b in which distances with normal distribution \( N(300,1000) \) were used.

5.2. Testing in three-dimensional space

Nowadays, there is no accessible tool for process NNA in three-dimensional space, so it is not possible to compare the results of the module with outputs of any verified software. That is the reason to control the results using parts of code scripted in mathematical software Mathematica [14] or Matlab [15]. This method helped to verify numerical accuracy and to repair few bugs.

The most complicated task was verification of volume of Minimum Bounding Box (MBB). This value is based on coordinates of vertices belonging to faces of convex hull.
convex hull are transformed to coordinate systems with plane of \(x\) and \(y\) axes parallel to plane of each face. Output is volume of the smallest box extending the transformed coordinates.

Functions of module \(v\.hull\) [13] have been used to obtain vertices belonging to faces of convex hull. These functions were modified to output not new vector layer with convex hull but matrices containing coordinates of vertices and faces. Numerical accuracy of transformations and determining of volume of MBB were verified comparing results of module to outputs computed by \textit{Matlab} [15]. This method enables also to verify coordinates exported of convex hull that we suppose to be created correctly.

Other functions of the module were tested while debugging or they were tested as part of 2D NNA functionality. For example, the function for computing average distance of the nearest neighbour \(r_A\) that is identical for 2D and 3D case (only input \(z\) coordinates differ, they are zeros for two-dimensional space). Numerical accuracy of formulas for determining expected average distance between the nearest neighbours in set of randomly distributed points \(r_E\), ratio \(R\) and test statistics \(c\) were tested comparing to results obtained by \textit{Mathematica} [14] while deriving of formulas and debugging.

The results of testing randomly distributed points are summarized in tables 4a and 4b. The same datasets as while testing in 2D space were used but \(z\) coordinates were considered.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textit{n = 2000} & \textit{v.nn\_spatial\_stat} & \textit{Matlab [15] script} & difference \\
\hline
\textit{\(r_A\)[m]} & 346.071782 & & \\
\textit{\(r_E\)[m]} & 323.531486 & & \\
\textit{\(R\)} & 1.06967 & & \\
\textit{\(c\)} & 0.191691 & & \\
\textit{\(V\)[m\(^3\)]} & 398423031180.489 & 398423031174.718 & -5.771 \text{ m}\(^3\) \\
\hline
\textit{\(t\)[s]} & 0.093 & & \\
\hline
\end{tabular}
\caption{The results of testing of the module \textit{v.nn\_spatial\_stat} in three-dimensional space using 2000 randomly distributed points}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
\textit{n = 5000} & \textit{v.nn\_spatial\_stat} & \textit{Matlab [15] script} & difference \\
\hline
\textit{\(r_A\)[m]} & 251.243012 & & \\
\textit{\(r_E\)[m]} & 238.607135 & & \\
\textit{\(R\)} & 1.052957 & & \\
\textit{\(c\)} & 0.145707 & & \\
\textit{\(V\)[m\(^3\)]} & 399562811897.870 & 399562811870.293 & -27.577 \text{ m}\(^3\) \\
\hline
\textit{\(t\)[s]} & 0.496 & & \\
\hline
\end{tabular}
\caption{The results of testing of the module \textit{v.nn\_spatial\_stat} in three-dimensional space using 5000 randomly distributed points}
\end{table}

Considering value of test statistics \(c \in (-1.96; 1.96)\), it is possible to assume that points were distributed randomly in both cases. Differences in volume of MBB are inappreciable comparing them to the values.

Coordinates of point clusters in three-dimensional space were computed in surrounding of randomly generated points using random distances, bearings with step 36° and zenith angles...
with step $10^\circ$. The results of tests are shown in tables 5a and 5b.

$$n_0 = 100$$
$$\sigma = [0^\circ; 36^\circ; \ldots; 324^\circ]$$
$$z = [-90^\circ; -80^\circ; \ldots; 90^\circ]$$
$$r = \text{random}(\text{'Normal'}, 30, 10)$$

<table>
<thead>
<tr>
<th>$\tau_A [m]$</th>
<th>$\tau_E [m]$</th>
<th>$R$</th>
<th>$c$</th>
<th>$V [m^3]$</th>
<th>$t [s]$</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.03274</td>
<td>155.180422</td>
<td>0.04532</td>
<td>-2.626741</td>
<td>430279744723.451</td>
<td>6.773</td>
<td></td>
</tr>
</tbody>
</table>

Table 5a: The results of testing of the module $v.nn\_spatial\_stat$ in three-dimensional space using clusters of points with shorter distances from local centres

$$n_0 = 100$$
$$\sigma = [0^\circ; 36^\circ; \ldots; 324^\circ]$$
$$z = [-90^\circ; -80^\circ; \ldots; 90^\circ]$$
$$r = \text{random}(\text{'Normal'}, 300, 1000)$$

<table>
<thead>
<tr>
<th>$\tau_A [m]$</th>
<th>$\tau_E [m]$</th>
<th>$R$</th>
<th>$c$</th>
<th>$V [m^3]$</th>
<th>$t [s]$</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>182.221953</td>
<td>349.816030</td>
<td>0.520908</td>
<td>-1.318191</td>
<td>4784510371770.96</td>
<td>6.407</td>
<td></td>
</tr>
</tbody>
</table>

Table 5b: The results of testing of the module $v.nn\_spatial\_stat$ in three-dimensional space using clusters of points with longer distances from local centres

6. Outline of future work

It will be appropriate to enlarge testing of the module adding sample of points with maximal separation in three-dimensional space. Analogically to two-dimensional space where neighbouring points are arranged in hexagon around observed point, it will be necessary to find convex body with vertices located on equilateral triangles and plane cutting its vertices and center should also be composed of equilateral triangles. Body fulfilling condition that distances between vertices and centre definitely cannot be composed only of regular hexagons (proofed e.g. [17]: vertex of body is intersection of three polygons (faces) and sum of interior angles must be less than $360^\circ$). Except that, in case of putting few pieces of these bodies together, there should be no empty spaces between them. Analysis of properties of truncated regular Plato’s bodies described in Timaeus [18] or semi-regular Archimedes’ bodies [19] will be purpose of future work.

The next item is to develop the mathematical background to better model fact that most of the phenomena may behave differently in horizontal and vertical direction. This analysis will be based on derivation of average distance of the nearest neighbours expected in case of
randomly distributed points $\tau_E$ as function of two variables, horizontal distance $h$ and vertical difference of elevation $z$:

$$\tau_E = f(h, z)$$

Isotropic model of NNA that had been derived in the past and in this article was tested and completed for 3D GIS purposes may be useful for the applications mentioned in introduction, but it may be inappropriate for many phenomena on the Earth’s surface. This assumption may be supported by e.g. differences found in tests’ results. In test of randomly distributed points, there were both the samples detected as randomly distributed points in two- and also in three-dimensional space (see tables 1a, 1b and tables 4a, 4b). But in NNA of clustered points, results indicated randomness of distribution (tables 5a, 5b). This hypothesis may be verified testing the module on various samples including points located on three-dimensional pattern to compare behaviour of maximally separated points in 2D and 3D space.

**Appendix A** Derivation of $\sigma_{\tau_E}$, the standard deviation of average distance between the nearest neighbours expected in case of randomly distributed points. The formulas have been derived analogically to the method [2] for two-dimensional space. Variance of average distance between the nearest neighbours in dataset of randomly distributed points:

$$\text{var}(r) = E(r^2) - (\tau_E)^2$$

(A.1)

where $E(r^2)$ means dispersion. Standard deviation is then:

$$\sigma_{\tau_E} = \sqrt{\text{var}(r)}$$

(A.2)

**Derivation of dispersion $E(r^2)$**

$$E(r^2) = \int_0^\infty \left( \frac{4\pi n}{3} \cdot 3r^2 \cdot e^{-\frac{4\pi n}{3} r^3} \right) \cdot r^2 dr$$

(A.3)

It is necessary to express integral (A.3) as gamma function according to [5]:

$$\Gamma(z) = \int_0^\infty e^{-x^2} \cdot x^{2z-1} dx$$

(A.4)

If $z = 2/3$,

$$\int_0^\infty 4\pi n \cdot r^4 \cdot e^{-\frac{4\pi n}{3} r^3} dr = 2 \cdot \int_0^\infty e^{-x^2} \cdot x^{1/3} dx$$

(A.5)

Then

$$x^2 = \frac{4\pi n}{3} \cdot r^3$$
\[ r = \left( \sqrt{\frac{3}{4\pi n}} \cdot x \right)^{2/3} = \left( \frac{3x^2}{4\pi n} \right)^{1/3} \]  
\hspace{1cm} \text{(A.61)}

and also (a means substitution constant):

\[ 4\pi n \cdot r^4 = 2a \cdot x^{1/3} \]  
\hspace{1cm} \text{(A.62)}

**Derivation of constant a**

To simplify derivation, (A.7) may be expressed as

\[ a = \frac{4\pi n \cdot r^4}{2 \cdot (x^2)^{1/3}} = \frac{3}{2 \cdot (x^2)^{1/3}} \cdot \sqrt{\frac{3^4}{2^5 \cdot \pi n}} \cdot x = \frac{3}{2 \cdot (x^2)^{1/3}} \cdot \sqrt{\frac{3^4}{2^5 \cdot \pi n}} \cdot r^3 = \sqrt{\frac{3^4}{2^5 \cdot \pi n}} \cdot r^3 = \frac{3\sqrt{6}\pi n^2}{r^3} \]  
\hspace{1cm} \text{(A.7)}

\[ a = \frac{4\pi n \cdot r^4}{2 \cdot (x^2)^{1/3}} = 2\pi n \cdot \frac{3x^2}{4\pi n} \cdot \frac{4\pi n}{3} \cdot r^3 = \frac{3\sqrt{6}\pi n^2}{r^3} \]  
\hspace{1cm} \text{(A.9)}

After substituting (A.5) to (A.9):

\[ \int_{0}^{\infty} 4\pi n \cdot r^4 \cdot e^{-x^2 \cdot r^4} \cdot r^3 \cdot x = \frac{2 \cdot \int_{0}^{\infty} e^{-x^2 \cdot r^4} \cdot x^{1/3} \cdot dx}{\sqrt{6\pi^2 n^2}} = \frac{\Gamma(2/3)}{\sqrt{6\pi^2 n^2}} = \frac{1.35411793942640}{\sqrt{6\pi^2 n^2}} \]  
\hspace{1cm} \text{(A.10)}

**Derivation of variance \( \text{var}(r) \)**

\[ \text{var}(r) = E(r^2) - (E r)^2 = \frac{\Gamma(2/3)}{\sqrt{6\pi^2 n^2}} - \left( \frac{\Gamma(4/3)}{\sqrt{6\pi^2 n^2}} \right)^2 = \frac{1}{\sqrt{2\pi}} \cdot \left( \frac{\Gamma(2/3)}{\sqrt{3}} - \frac{\sqrt{6} \cdot (\Gamma(4/3))}{2} \right) = \frac{0.040536}{\sqrt{n^2}} \]  
\hspace{1cm} \text{(A.11)}

Standard deviation of average distance between the nearest neighbour in randomly distributed set of points will be:

\[ \sigma_{\text{E}} = \sqrt{\text{var}(r)} \]  
\hspace{1cm} \text{(A.12)}
References


Geometric documentation of underwater archaeological sites

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Abstract

Photogrammetry has often been the most preferable method for the geometric documentation of monuments, especially in cases of highly complex objects, of high accuracy and quality requirements and, of course, budget, time or accessibility limitations. Such limitations, requirements and complexities are undoubtedly features of the highly challenging task of surveying an underwater archaeological site. This paper is focused on the case of a Hellenistic shipwreck found in Greece at the Southern Euboean gulf, 40-47 meters below the sea surface. Underwater photogrammetry was chosen as the ideal solution for the detailed and accurate mapping of a shipwreck located in an environment with limited accessibility. There are time limitations when diving at these depths so it is essential that the data collection time is kept as short as possible. This makes custom surveying techniques rather impossible to apply. However, with the growing use of consumer cameras and photogrammetric software, this application is becoming easier, thus benefiting a wide variety of underwater sites. Utilizing cameras for underwater photogrammetry though, poses some crucial modeling problems, due to the refraction effect and further additional parameters which have to be co-estimated [1]. The applied method involved an underwater calibration of the camera as well as conventional field survey measurements in order to establish a reference frame. The application of a three-dimensional trilateration using common tape measures was chosen for this reason. Among the software that was used for surveying and photogrammetry processing, were Site Recorder SE, Eos Systems Photomodeler, ZI’s SSK and Rhinoceros. The underwater archaeological research at the Southern Euboean gulf is a continuing project carried out by the Hellenic Institute for Marine Archaeology (H.I.M.A.) in collaboration with the Greek Ephorate of Underwater Antiquities, under the direction of the archaeologist G.Koutsouflakis. The geometric documentation of the shipwreck was the result of the collaboration between H.I.M.A. and the National Technical University of Athens.

Keywords: underwater photogrammetry, trilateration, underwater camera calibration, visualization, orthophotomosaics, 3D reconstruction, ancient shipwreck

1. Introduction

With 17,000 kilometers of coastline, equivalent to 25% of the total Mediterranean coast, with almost 3,500 islands and at least 1,000 shipwrecks detected in the Greek seas, Greece is a country with one of the largest and perhaps the most important underwater archaeological
heritage. Ancient shipwrecks, submerged settlements or ancient harbors are housed for centuries in the Greek seas. Nevertheless, practical implication of theoretical and technological developments in the fields of surveying and photogrammetry for the geometric documentation of this underwater heritage is far behind the rapid developments and innovations that are applied when it comes to surveying ‘terrestrial’ monuments. This paper presents an effort to improve and experiment on the synergy of conventional surveying techniques, such as simple tape measurements and trilateration adjustments, with modern software and digital technology, in order to produce 3 dimensional reconstructions that can assist underwater archaeologists in reaching their scientific conclusions, through a geometrically accurate, documentation of the site and the excavation process, as well as to bring those who do not have the opportunity to access this submerged monument, on a ‘digital trip’ to an ancient shipwreck in deep waters.

1.1. Description of the object

The Hellenistic shipwreck, whose case is examined in this paper, was found in 2006 in the northwest side of the island Styronisi at Southern Euboean gulf, at a depth range of depth between 39 and 47 meters below the sea surface. The shipwreck dates back to the Late Hellenistic period (late 2nd to early half of the 1st century B.C.) and it is the only ancient shipwreck that was detected in Southern Euboean gulf, in such a relatively good condition. The dimensions of the exposed shipwreck are approximately 18 meters long and 7 meters wide. The cargo of the ship consists, mainly, of intact and broken amphorae, 90% of which are considered as Brindisi type of amphorae. Additionally, among the ship’s cargo interesting objects were found, such as parts of luxurious bronze furniture, bronze and steel spikes, a stone wash basin, parts of the harness of the ship and broken tiles. Among the most important finds of the whole archaeological survey, is a small part of the dress of a natural size bronze statue and beneath the surface layer of sand, two parts of the wooden hull of the vessel, something very rare, since wood cannot be preserved for such a long time in underwater archaeological sites.

Since the discovery of the specific wreck is considered of great importance, H.I.M.A. and the supervising archaeologist intended to launch a systematic investigation and excavation of this monument. Therefore, the detailed and accurate documentation of the site became an immediate priority. Orthophotomosaics and 3D rendered models of the wreck were considered as the ideal products, in order to map the site in the condition that it was found and prior to excavation [2]. Of course, when it comes to the excavation period, the requirements are increasing; daily recording of the excavation trenches, mapping of the 3D locations of the artifacts, 3D reconstruction of the shipwreck excavation, production of daily 2D plans or 3D measurement and modelling of finds are some of the needs that arise for the complete documentation of such a monument.

1.2. Underwater surveying & underwater photogrammetry

It is well-known that conventional mapping is a process subject to human error in underwater archaeology [3, 4, 5], while photogrammetry has long been a viable technique in such situations [6]. Thus the main objective is to create a 3-dimensional model of the site using photogrammetry, which could be dynamically updated in the future according to the progress of the ongoing archaeological excavation. Underwater photogrammetry clearly offers
some advantages for the surveying of a submerged site thus overcoming difficulties such as limited on-site accessibility and non-destructive efficiency. On the other hand, some crucial and inevitable matters that have to be faced and co-estimated arise in such conditions: no operational control on data acquisition, low image quality caused by poor underwater lighting (e.g. variations of scattering or absorption of red wavelength especially in deep waters) even if artificial lighting is used, two-media (air-water) data collection, significant diffusion that complicates the object recognition and the tie point measurements and, last but not least, control point establishment limitations as common tape measurements and 3D trilateration methods are perhaps the only plausible methods. Despite all the difficulties encountered, photogrammetric software can be increasingly extended from land-based applications to underwater applications.

2. The geometric documentation of the hellenistic shipwreck in south Euboea

2.1. Establishing an underwater control points network

One of the main tasks of the surveying procedure on site was to establish an underwater network of control points, which would be measured and calculated with tape trilateration adjustment. Once the theoretical control network had been designed in terms of adequate geometry, i.e. widely dispersed control points and efficient stability of the points, it had to be set up on the site. It is at this point, where the problems associated with surveying under water start to affect the quality of the survey. The tape survey is dependent on the divers’ ability to install control points in geometrically correct positions of high rigidness, as well as to measure the distances between the points with sufficient accuracy. In this case, 20 control points were established. They were made of targets stuck on 10x10cm² Plexiglas tiles; fourteen of them, fitted onto 0.5m long metal rods, were inserted in sand as deep as possible (Fig.1a) and the remaining six were fitted, with common tie-wraps, on the mouths of 6 intact amphorae (Fig.1b). The tiles bearing the target points were also labeled with numbers, so that they could be easily identified by the divers.

Figure 1: (a) Control points inserted in sand, (b) Control points fitted on the mouth of amphorae

The position of each control point was measured from at least 5 other control points of the
network. From a total number of 119 measured distances, 82 were selected and adjusted using the Site Recorder SE software through a large least-squares network adjustment. In order to obtain three-dimensional coordinates for a point, the minimum number of measurements is of course three. With three measurements, error or reliability cannot be estimated. Therefore, at least 5 measurements from each point were taken, so that the accuracy of the coordinates of each control point could be estimated. The total RMS of the trilateration adjustment resulted to 0.027m.

2.2. Data acquisition

For the optimal organization of the photogrammetric restitution, a photomosaic of the shipwreck was created as an approximate complete mapping of the site. The Hugin open source software, a piece of software typically used for stitching and blending a series of photographs was employed. This software was developed by B. Hartzler, an archaeologist and member of H.I.M.A. [7]. This first photomosaic proved to be a very useful tool for the photogrammetric image data acquisition that followed.

![Figure 2: Photo data capture](image)

For the image data acquisition, a SONY DSLR-A700 camera and an Ikelite® protecting housing were available. The camera has a 12-mm lens and all individual images are of a resolution of 4272x2848 pixels. The diver-photographer “flew” over the wreck (Figure 2), taking about 120 photos in 4 strips, with a 70-80% forward overlap and 50% side overlap. The physics of underwater light diffusion requires that images should be taken as close to the object as possible. Images taken from longer distances have, as a result, much lower quality. A standard “flying height”, a strictly straight strip line and a satisfying overlap between images are definitely requirements of an optimal data acquisition for photogrammetric processing purposes. Nevertheless, it seems to be a really challenging task when photographing under such conditions. In this case, the limited available time of the archaeological research, the increased difficulty to approach the site and the strong underwater currents did not favor the image acquisition process with the aforementioned requirements.
3. Photogrammetric processing

3.1. Underwater camera calibration

The accurate 3D reconstruction, as well as the pose estimation of an object, from images, requires the thorough knowledge of the intrinsic camera parameters i.e. focal length, principal point’s coordinates and lens distortion. The underwater camera calibration problem has been treated in several ways so far. A ‘standard case’ of multimedia photogrammetry [8]: three media; an object in water, a sensor located in air and a transparent plane of the camera housing separating the object from the sensor. As far as using images for underwater surveying is concerned, there are generally two categories for approaching camera calibration; the first is based on dry camera calibration methods, where the intrinsic parameters of a camera immersed in water, or any other fluid, can be calculated from an air calibration, as long as the optical surface between the two fluids presents some simple geometrical properties [9]. The second approach, is not based on modeling any parameters that have to do with different media through mathematical models, but treats the system camera-housing (or air-glass-water) as a unique system.

The camera calibration in this project’s case is based on the second approach and was carried out using the Photomodeler® calibration module. A SONY DSLR A700 camera, in a waterproof Ikelite housing device, was immersed into water and a total number of 24 images of the board bearing the calibration pattern, i.e. a grid of specific dots (Figures 3a, b, c) were taken. Photomodeler, firstly, analyses each picture using a line interpolation algorithm to find and mark the dots and the 4 control points of the plane pattern [10]. Seventeen (17) images were processed into an image processing software in such a way that the algorithm could detect only the coded dots-targets (Figure 3b). The scale was constrained by the 4 known distances between the control points of the pattern.

Figure 3: (a) Initial calibration image, (b) Corrected calibration image, (c) Camera positions.

On completion of the calibration, the intrinsic parameters of the camera were determined, including the principal point’s coordinates, the radial distortion values and a focal length of 15.03mm. As far as the focal length is concerned, the ratio computed-to-nominal value (15.03mm/13mm) was found to be 1.16. When compared to the refractive index (1.34), it is obvious that underwater refraction is not the only parameter that has to be estimated, contrary to the dry camera calibration procedures. Depth, temperature and salinity can be considered as unstable parameters affecting a typical photogrammetric camera calibration. In comparison to the refractive index, there are no mathematical models that can describe these parameters, thus not permitting the achievement of a reliable camera calibration procedure. Eventually, it would be desirable, given an unrestricted underwater time, if a camera calibration could be completed in identical conditions to each archaeological photogrammetric dive.
3.2. Photogrammetric bundle adjustment

A matter of high importance is to have the acquired images prerectified before using them in the photogrammetric processing [11]. Preprocessing adjustments include radiometric enhancement of images, i.e. brightness adjustment, contrast enhancement, edge enhancement, noise reduction etc. Therefore, 46 images were selected and processed using Adobe Photoshop software, through ‘Neutralize’, ‘Brightness-Contrast’ and ‘Color balance’ commands (Figures 4a and 4b).

Once all 46 images were preprocessed, the photogrammetric adjustment was implemented using Topcon’s ImageStation® software. The block adjustment was done using 46 images at an approximate range of scale from 1:200 to 1:600, as the diver-photographer could not swim parallel to the site. Twenty (20) points with known coordinates, as resulted from the trilateration adjustment method with Site Recorder, were recognized, marked on the images and utilized as control points. The a priori control point precision was set at $\sigma_{XY} = 0.04m$ and $\sigma_{Z} = 0.07m$. Table 1 shows the results of the bundle adjustment.

<table>
<thead>
<tr>
<th>Table 1: Bundle adjustment results</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSxy ($\mu m$)</td>
</tr>
<tr>
<td>Pixel size ($\mu m$)</td>
</tr>
<tr>
<td>RMSXY (m)</td>
</tr>
<tr>
<td>RMSZ (m)</td>
</tr>
</tbody>
</table>

A fact which has to be stressed is that the block included images of regions of sandy seabed. This was a problem, as far as finding a sufficient number of common points between images, is concerned. To increase the number of common points, Plexiglas strips with coded targets, similar to Photomodeler® calibration targets, were positioned in those sandy areas. This method proved to be very helpful in the end, in the attempt to evaluate the accuracy of the final orthophotomosaic of the site, especially in sandy areas where the control point distribution could not be very dense.

3.3. Orthophotomosaic of the shipwreck

One of the main goals of the work was to produce an accurate and radiometrically correct orthophotomosaic of the entire area of the shipwreck. Therefore, once the photogrammetric bundle adjustment of the block was completed, the extraction of a Digital Surface Model
Approximately 54000 points and 2000 break lines were collected manually through stereoscopic vision of the oriented models, thus producing a dense DSM (Figure 5). The attempt for automated DSM extraction failed, due mainly to problems connected with a weak image radiometry, e.g. similar tones especially due to the absorption of the red wavelength, repetitive features and poor textures like sandy areas, scale variations and large rotation differences between images and, finally, occlusions. As a result, the acquired data did not reach the classical image matching methods standards and a manual DSM extraction was the only solution.

Once the DSM was extracted, an orthophotomosaic of the shipwreck’s area, made out of 46 orthorectified images (Figure 6), was produced using Z/I’s ImageStation OrthoPro® software. The final product was evaluated in two ways:

1. By comparing the control points network, as it resulted from the trilateration adjustment, with the orthophotomosaic
2. By measuring on the orthophotomosaic the known distances between the Plexiglas strips of Photomodeler coded targets.
3.4. 3D reconstruction of the shipwreck

The ship’s cargo consisted mainly of amphorae of one type, i.e. Brindisi amphorae. A 3D theoretical revolved model was obtained using 2D scaled drawing of one such amphora, which was taken off the site using the Rhinoceros® software (Figures 7a, 7b and 7c).

Due to the fact that most of the objects were partially visible on images or even broken, photogrammetric measurements were not enough for the complete 3D reconstruction of the site. The main reason for not using the already constructed and dense DSM for plotting each object is that it is a 2.5 D plan. This means that many objects’ attributes were not visible on images, thus hiding an important amount of information. Therefore, characteristic features of each object were photogrammetrically measured, so that accurate shape, size and direction of the amphorae could be restored. The final 3D model is a combination of the theoretical models and the photogrammetrically measured attributes of the various finds (Figure 8). The choice of attributes is based on measuring particular parts of the finds, i.e. rims, bodies, mouths or handles of each amphora, so that each object could be positioned as well as oriented efficiently. The photogrammetric measuring of those attributes was performed using Photomodeler® software, in which approximately 60 images were oriented. Photomodeler provides the opportunity of orienting a large number of images taken from various angles, thus regaining the lost information of hidden objects that led to the optimal 3D reconstruction of the site. Measured objects were divided into three layers in Photomodeler; a) the ‘terrain’ layer, which plays the role of a DTM and consists of points of sand and rocks, b) the ‘finds’ layer, which includes all measured attributes of finds and c) the ‘control points’ layer, which includes the control points network.

A DXF file of points of the above layers, followed by images with the IDs of all points of interest
upon (Figure 8), was extracted from Photomodeler® and then imported in Rhinoceros®. The entire 3D reconstruction of the site was implemented finally in Rhinoceros® by creating the terrain surface at first and placing, afterwards, each find in its right position (Figure 9).

A more realistic representation of the site was achieved by assigning texture extracted from images through a suitable rendering procedure (Figure 10). The rendering was implemented in Autodesk’s 3DS max®.

![Figure 9: 3D wireframe model of the shipwreck](image9.png)

![Figure 10: 3D rendered model of the shipwreck, Autodesk 3DS max](image10.png)
4. Conclusions

Estimating the accuracy of any underwater surveying technique is notoriously difficult [12]. The results of recording the shipwreck of the South Euboean gulf represent an attempt for the best possible achievable accuracy, when combining conventional tape measurements with modern and user-friendly photogrammetric software. Given the nature of the control points (some robust, others more fragile), it is likely that the points themselves had an uncertainty in their position, which affected the accuracy of the photogrammetric bundle adjustment. Therefore, the task of obtaining a robust control points’ network seems as challenging as the task of using photogrammetry for underwater surveying without establishing a control points’ network at all. The second task requires a perfectly calibrated camera and a way to restore the scale during the bundle adjustment of a block of images. Evaluating, finally, the work that has been done underwater, given the aforementioned available diving time, it seems that it should be preferable to consume more diving time on calibrating cameras under several conditions underwater, in order to obtain an optimal interior orientation and avoid to spend time on the really time consuming task of measuring distances with common tapes.

Moreover, the implementation of different software for one final goal may be over consuming too, in terms of time and work, but in this case, it was unavoidable to use several pieces of photogrammetric software. Each one was used as a different tool. Photomodeler, provides, firstly, the opportunity of a user-friendly automated camera calibration module and secondly, the opportunity of orienting a large amount of images taken from different angles, so that more information of the object could be obtained. On the other hand, ImageStation software was chosen as a more reliable way, comparing to Photomodeler®, to create a DSM and an orthophoto, thanks to the DSM collection through stereo vision.

In conclusion, the application of photogrammetry in terms of generating accurate and radiometrically efficient orthophotomosaics and 3D rendered models, combining inescapable traditional surveying techniques with contemporary digital software support, has proven to be a unique way to achieve a virtual exploration, a “digital trip”, to an ancient shipwreck in deep waters, to a deep ancient cultural heritage.

References


Abstract

Looking at the concept of the virtual model of Terezín Memorial, the model consists of two main parts: the geometric 3D model which depicts the place and the lexical base of data which describes the history of Terezín, mainly during the II. World War.

Taking a closer look, the heterogeneous nature of existing both analogue and digital documents about the history leads to use a content management system (CMS). CMS is used, together with a relational database, for the lexical data. Each document in CMS has its unique identifier, identifier of a place to which is referred to and two dates referring to a time period. The spatial part of the Terezín model consists of detailed models of all historically valuable buildings and constructions. These models are complemented with less detailed models of the rest of buildings and constructions in the Terezín town.

Both lexical and spatial part of the virtual model is filled up with large amount of data. Therefore it is crucial to build such a method of (both lexical and spatial) data selection, which is fast and serve relevant information to the user. Whereas well known one dimensional data indexes can be used for descriptive data, situation is a bit more complex in 3D, where common geographic (two dimensional) data indexes cannot be used. In 3D, size of bounding box (BB) of each potentially portrayed object is calculated, based on the observer position, its view direction and the distance from the object. When the size of BB of each object is calculated, different level of detail (LOD) of each object can be displayed. Different LODs are used also in two dimensional maps, where they are used for creation of a scale dependent map, but there is again principal difference between 2D and 3D. While in 2D always just one LOD at a time is portrayed in the map, objects closer to the observer are displayed in higher detail then farther ones in 3D. It leads to a situation, where objects are displayed in different LODs in one 3D scene. This issue poses a major challenge to a creation of a multi-scale 3D model, because different LODs have to share major shape (at least footprints and heights). Moreover the virtual model has to be also time aware, therefore each piece of information in the database has to have a time period for which it is valid.

Introduction – investigation of purposes of 3D modeling

The topic of 3D modeling of cultural heritage objects is nowadays widely spread. There is possible to find out a lot of projects dealing with this topic, but the purpose or utilization of
such projects can be different. There is a schema in figure 1 showing examples of a use of 3D models of cultural heritage objects (taken from Jedlička et al. (2012)).

Figure 1: Examples of possible purposes of 3D model in heritage preservation (derived from Jedlička et al. (2012))

A short summary of purposes of 3D cultural heritage models is shown below (derived from Jedlička et al. (2012)):

- Visualization – the most frequented usage of such models. It is for the purposes of presentation of objects, increasing of accessibility of cultural heritage objects to the public (e.g. through the internet). See examples in Miyazaki et al. (2002), Foni et al. (2010) or Angelini et al. (2011).

- 3D Documentation – a model can be used as a reference for a documentation about the object of interest with an advantage of spatial determination. See examples in Angelini et al. (2011). 3D model as a part of a database – connecting a 3D model to a database means creating of information system about cultural heritage. It’s the main purpose for these models, because the collected spatial data can be used not only for the form of presentation. The model and the created database can be also connected to other relevant databases about the object of interest (usually county or national level databases). See examples in Durdag & Batuk (2011) or in Yan & Limin (2011),

- Virtual Reality – allows creation a 3D scene, in which the user can interact. See example in Damala et al. (2013)

- Reconstruction – a model persist the appearance of the object in time, so it can be used as a reference for reconstruction or restoration of the damaged objects, objects which don’t exist anymore or for the preservation of the contemporary appearance of an object. See examples in He (2011) or in Lin et al. (2011).

A similar point of view at this issue is depicted e.g. in Scopigno et al. (2011). It is said in this reference that the main purposes of 3D models is for 3D visualization, for studying artwork and as a medium stored in a database allowing to map, analyze, index, retrieve and compare such a model. This is handful particularly for cultural heritage researchers, archaeologists and curators.

Our approach consists of interconnecting a 3D visualization and a content management system
(CMS) in order to build an information rich model and particularly to allow interactive querying on buildings and places in the Terezín Memorial for purposes of getting information about the situation of this site at the period of World War Two.

Object of the Case study – the Terezín Memorial

The fortress of Terezín was constructed between the years 1780 and 1790 by the orders of the Austrian emperor Joseph II in the north-west region of Bohemia. It was designed to be a component of a projected but never fully realized fort system of the monarchy, another piece being the fort of Josefov. By the end of the 18th century, the facility was obsolete as a fort due to changing paradigm of warfare. In the 19th century, the fort was used to accommodate military and political prisoners. However darkest part of the history of Terezín took place during the WW II. The Gestapo took control of Terezín and set up the prison in the Small Fortress (kleine Festung) on June 10th, 1940. And the Main Fortress (große Festung, i.e. the fortified town of Theresienstadt) was turned into a ghetto by November 24th, 1941. Altough it was presented by the Nazis as a model Jewish settlement to outsiders, in reality it was a concentration camp where over 33,000 inmates died as a result of hunger, sickness, or the sadistic treatment meted out by their captors. In memory of these events, the newly created Czechoslovak government, opened the National Suffering Memorial (later on renamed the Terezín Memorial) in Terezín in 1947. The key mission of the Terezín Memorial, the only institution of its kind in the Czech Republic, is to commemorate the victims of the Nazi political and racial persecution during the occupation of the Czech lands in World War II, to promote museum, research and educational activities, and look after the memorial sites connected with the suffering and death of thousands victims of violence. See more about the history of Terezín Memorial at its Web page http://www.pamatnik-terezin.cz/en?lang=en&lang=en.

The project “Landscape of memory. Dresden and Terezín as places of memories on Shoah”

The Terezín Memorial – the memento of Shoah – was selected as the object of the case study in the project with the title: “Landscape of memory. Dresden and Terezín as places of memories on Shoah”. The main project goal is to develop and populate a data model suitable for 3D visualization of large-volume spatial data (the whole area of the Terezín town) together with related descriptive data.

The project is a part of the program of cross-border cooperation between the Free State of Saxony and the Czech Republic. It consists of these partners:

- Technische Universität Dresden, MitteleuropaZentrum für Staats-, Wirtschafts- und Kulturwissenschaften (lead partner),
- Terezín Memorial,
- University of West Bohemia (UWB), Geomatics section at Faculty of Applied Sciences.

TU Dresden as the lead partner coordinates the project activities and together with the University of West Bohemia is involved in the developing and determining of a conception, techniques and technologies for creation of 3D models based on various sources such as old maps, plans and other archival documents. The other partner Terezín Memorial has the
Hájek, P. et al.: Conceptual approach of information rich 3D model...

main historical and background knowledge that is crucial to ensure the creation of a realistic 3D model with necessary descriptive spatial and lexical information. This information will for example help visitors to search for available information about their relatives situated in Terezín during WW II or it will help them to get familiar with the city’s appearance in this period.

Data mining of information about the Terezín Memorial

At the beginning of the project it was necessary to search for available information, documents and materials about the situation in Terezín Memorial during the WW II. There was a need to select proper information from huge amount of collected materials, which are useable for both descriptive data about the life in Terezín ghetto during the WW II and also for 3D geovisualization of the memorial. All original archive materials were kept by the following institutions:

- Terezín Memorial (http://www.pamatnik-terezin.cz),
- State Regional Archive in Litoměřice (http://www.soalitomerice.cz/en),
- Austrian State Archive in Vienna – Military Archive (http://www.oesta.gv.at),

For example, almost 3000 files (such as digital scans of plans, photos, documents, etc.) have been obtained just from Military Historical Archive.

There are three main sources for modelling 3D objects in this project.

- Plans of buildings, facades and reconstruction plans of buildings. Examples of used plans are in figures 2 and 3. The plans of interiors were used rarely, because the project goal does not claim for interiors to be modelled (interiors of buildings will not be visualized, besides very few exceptions).

- Plans of fortifications. The plans of the city fortification are very detailed because of its historical importance. Because of the complexity of the plans and a simple geometry of the fortification it has been decided that the main source of spatial information about fortification will be a stereo photogrammetric measurements on current aerial images. Plans are consequently used just for clarification of such fortification parts, whose cannot be acquired from photogrammetry. Furthermore it has been decided that the detail of the fortification will be restricted to the expression of the basic shape of bastions and trenches.

- Technical map of the city Terezín. This map shows the contemporary state-of-the-art of the currently standing buildings in the Terezín.

Obtained plans of buildings are just occasionally in metric rate, more frequently in fathom rate. During a detailed research of those plans, it has been set up a uniform conversion rate between fathoms used in plans and meters. This could be done, because the proportions of buildings were on the same plan in both metric and fathom rate occasionally. But looking at the standardized sizes of fathoms there has not been found out any of them fitting to the calculated one from the plans.
Figure 2: Plan of the building called Knabenheim in Terezín (Military Historical Archive in Prague).

Figure 3: Plan of the Church in Terezín (Military Historical Archive in Prague).

Another issue we were dealing with was that even after a calculated conversion between these rates a lot of proportions didn’t fit to the real proportions of the buildings derived from the
Technical map of the city, which was geodetically surveyed. The difference in proportions was presumably caused by disproportion between the plan and real construction. It is a common phenomenon, that the plan of the building is created and the building itself is built in different way than it is described in the plan. These plans are called project documentations, not the representation of the actually built building. In this case, the proportions from the old plans and profiles of the buildings were transformed to the real proportions. This could have been done because the proportions of the standing building were not changed since the World War II.

**Conceptual model of Terezín**

The concept of the virtual model of Terezín Memorial consists of two main parts: geometry and related descriptive data. The geometric part consists of 3D models which capture how the Terezín ghetto looked like during the WW II. The descriptive part is based upon structured database of collected documents (descriptive data) which describes the historic information of many particular places in Terezín, again mainly during the WW II. For these main parts of the model have been used two main approaches. A Content Management System for the descriptive data and principle called Level of Detail for the geometric spatial part is used.

Content Management System (CMS) is a tool for handling, together with a relational database, with all the descriptive data (because historical documents of varied characters need to be shown). Each document in CMS has not only its own unique identifier, but also an identifier of a place where the document is referred to and two dates referring to a time period (e.g. the origin and extinction of a building).

As mentioned above, there are a huge number of documents related to events and places in Terezín. But on the other hand, the spatial part of the model is also information-rich. Thus there is a need for dealing with this huge amount of spatial 3D data in the sense of quick querying on data, data visualization and serving relevant data to the user. That’s where the principle of various Levels of Detail (LOD) is implemented. The principle comes from the CityGML specification (see OGC (2012)) and it deals with different models for a building, while each model has its own amount of displayed details of the building and the more detailed model is built up on the base of the less detailed model.

The figure 4 shows the use of the conceptual model. It depicts interconnection among a data base (stores links to created 3D models), a content management system (stores collected descriptive data) and an original data (provided from Historical Military Archive). The conceptual workflow is as follows:

On the base of available historical documents and maps which were stored within archives (see chapter *Data mining of information about the Terezín Memorial*) there were identified objects of interest and Unique IDs were related to them. The ID is created on the base of the designation of rectangular streets system used by Germans in the 1940’s. Than on the base of such documents, of the current state of the art of buildings and of the consultancy with the historians from the Terezín Memorial the 3D models were created and stored separately on a disk in a form of kml files, COLLADA respectively. Using a CMS the models are loaded and visualized at kiosk’s screen (or via a web client) according the rules of the displayed size of a building (see Figure 6) which are implemented in kml files.
**Technical realization of the Terezín Case Study**

As mentioned before, this contribution is based on the work and role of the Geomatics section of the University of West Bohemia in this project. Thus, there will be described technical realization of the spatial 3D model of Terezín Memorial in this chapter, which is the part of the role of UWB in this project.

The first question about modeling of such a model was to decide what tool to use for creating models of buildings. The first idea was to use a Geographical Information System (GIS) as a reference for all spatially referenced data to store them in defined geographic coordinate system. The next workflow had been intended as follow: to create a layer consists of footprints of buildings (refer to LOD0, see further text) and export this layer to Computer Aided Design (CAD) program and use such a program for creating more detailed models. CAD programs have versatile tools for creating 3D models of different objects and they are more suitable for creating a 3D model then GIS programs.

But this approach had met its limitation during the definition of proper proportion of buildings’ footprints. The ArcGIS 10.1 had been chosen as a GIS program for creating these footprints. But a problem with a storing of data into a geodatabase had appeared. The problem dealt with perceiving of data accuracy (difference between stored and retrieved proportions of modeled footprints). According to Dive-in section in ArcGIS Resources (2013) this problem is connected with storing coordinates into geodatabase and changing between integer and float type of stored and retrieved numbers. Using such footprints created in this way would cause problems with creation of 3D models later. Therefore it has been decided to use a CAD system as a reference tool also for creating footprints.
Another issue of software for modeling of 3D objects is to contain proper and easy to use modeling tools. In this way a CAD program supposes to have a lot of intuitively usable tools for modeling 3D objects comparing with tools which GIS program has for such a thing.

The Trimble SketchUP 8 Pro has been chosen as a CAD program, because it satisfies the conditions of creating the proper proportions of buildings and usability during the process of modeling. And it also has a Georeference Tool, which can georeference an object (building) on the base of Google maps. And moreover the model makers have experiences with this program so it makes an ease, fast and intuitive work with such a tool for them.

On the base of mentioned information it has been decided, that the optimal way for creating all levels of details will be done via Trimble SketchUP software. It is very capable of creating complex 3D objects and when one program for creating all models is used, there is no need for data conversion between data formats so no added possible errors from data conversion are presented. For information about Trimble SketchUP program and creating models in this software, see e.g. Chopra (2011).

Since the beginning of this project it has been known that there will be a huge amount of spatial data. Therefore it has been decided to use a concept of LOD based on LOD in CityGML standard (see OGC (2012)). This concept is made for lowering severity of 3D visualization of objects, which are stored in a spatial base of data. The principle consists of dividing objects into successive component parts. They share the shape of the footprint of the building. It also enables visualization (and also analysis) of the same object depending on different desired LOD.

The example of using this principle is shown in figure 5. There are depicted different LODs of the Resurrection Church placed on the square of Terezín (called just Church in further text). LOD0 (the most left one) consists of the footprint of a building. LOD1 shows the prismatic shape of a building (there is distinguished the nave of the Church and the tower of the Church). LOD2 displays roof-shaped structures and thematically differentiated boundary
surfaces on the exterior shell of a building. LOD3 comprises of architectural models with detailed wall and roof structures. LOD4 is not shown in this picture, because this level of details shows interior of a building and for the purposes of Terezín Memorial LOD4 is not necessary to be modelled (see the beginning of chapter Data mining of information about the Terezín Memorial).

Each LOD of a building is stored in a base of data separately. Using different LODs facilitates so called view-dependent visualization, while the models which intend to be displayed are chosen based on the position, view-direction and distance of the observer. Each building has a bounding box, abbreviated as BB (BB = minimum volume that encloses a set of objects or data points), which represent the building for purposes of selecting appropriate LOD of the building. The definition of displaying a particular building in a particular level of detail is based on KML built-in features. Switching of different LOD for a building is based on calculated size of a bounding box. When the size of BB in pixels is between MIN and MAX values of <LodPixels> attribute, the BB with proper LOD of a model is visualized (see figure 6; note – in this figure the illustrations of LODs with bounding boxes are in the same size, the real proportions of these bounding boxes are depicted in the left bottom side of this figure). This size of a bounding box is calculated for a position of the observer and then a suitable LOD is selected for displaying according to the size of the bounding box and limits embedded in the model. More information about this KML feature can be found in OGC (2008) or Wernecke (2009).

The principle of using different LODs makes visualization faster. For different view at data, during their visualization, an appropriate model with its suitable LOD is sent to the client.

(i.e. visualized). It means no additional computation for e.g. generalization or loading of huge amount of data is necessary. The example of this view-dependent visualization is depicted in figure 7. In this picture, in the vicinity of an observer, on the right side of the picture, are portrayed very detailed models (LOD3) of the Church and a building called “Knabenheim”. Near the observer position, on the left side of the picture, a block of buildings, which is a combination of two levels of details, LOD 2 and LOD3, but less detailed than the previously mentioned buildings, are shown. In the centre of the picture several buildings in prismatic shape (LOD1) are depicted. In the distance is a footprint of another building, which is displayed in LOD0.

![Figure 7: View-dependent visualization of different LODs of buildings in Terezín (adopted from Janečka et al. (2013)).](image)

Just for explanation - as it can be seen in figure 7, buildings are typified in two categories for purposes of the project, the yellow and the grey. It’s because the importance of a particular building. In gold category are very important buildings, in grey category are buildings with nearly no importance (related to the purpose of the project). Relevance of a building to a category is based on two aspects. The first is, if considerable events took a place there or significant people lived there (during period of WW II). The second associated aspect is existence of preserved documentation about a place or people. If a building satisfies one of these two aspects, the building is classified as “yellow”. The “yellow” is just a temporary category, the final model will be distinguishing between non-important grayscale buildings and important ones – coloured buildings (such i.e., the Church or Knabenheim in the current state of the project).

The process of creation various levels of 3D model is described using the Church as an example. There is a lot of documentation about the church, from which the model can be created. But first of all, just the footprint (acquired from the Technical Map of the city Terezín) is required for LOD0. LOD1 is created by extrusion of footprints into roof heights measured by stereo photogrammetry. Old plans and archive information are firstly used during the construction of LOD3, where the roof-shape is reconstructed – there it is crucial to deal with unit conversion (see at the end of chapter Data mining of information about the Terezín Memorial). The archive materials are the main source for creating the LOD4 of the building (again, after the unit conversion) – see the figure 8 for reconstruction of the ornament above the front wall of...
the Church. Upper part of the figure 8 shows a scan of the original plan of the Church’s front side, lower part is illustration of its virtual model created via Trimble SketchUP. Although level of details 3 is very detailed, the view at such buildings will not be so close. From that reason and because of need of effective work during the modelling process, a certain degree of accuracy or generalization is used (generally speaking for all LODs). It is not necessary to model every detail, it is important to capture the substantiality of a building or its part. This is shown in the picture 8, the detail of drawing of flowers is simplified so as the drawing on abutments on the sides.

Figure 8: Plan and model of a detail on the front wall of the Church (Military Historical Archive).

The next step of the workflow is to connect descriptive data to each particular 3D representation of a building or a place. It is realized using unique CMS identifiers stored in the KML models of buildings. The development of the data structure used for storage of descriptive data into a content management system is also a part of the project “Landscape of memory. Dresden and Terezín as places of memories on Shoah”, but the technical realization is not described in this article.

Discussion

There has been used a way how to deal with 3D models repository. This way is based on using a PostGIS as a database which stores just links to proper kml files (containing 3D models) stored in a different repository. There had been thought about another way of dealing with storing and retrieving 3D models. The other thought way is based on the storing 3D models
directly in PostGIS via its native data types. But it would take longer time for visualization of 3D objects, because the km1 files would need to be populated with collada files (data type for storing 3D models directly in PostGIS) on-the-fly. Therefore the actually used way seems to be more reasonable then the second one described above. The other thought way was using the CityGML for conceptual modelling. Even though these discussed ways are equal in the sense of dealing with 3D objects, the selected solution has been chosen on the base of already created Google Earth plug-in obtained from the project partner TU Dresden. This solution is based on mentioned GE plug-in and open Content Management System called Plone CMS and a web client for visualization of data in CityGML is not sufficient.

Summary

This contribution shows an approach to visualize of large-volume data in a case Study at the Terezín Memorial. First it introduces motivation of the project “Landscape of memory. Dresden and Terezín as places of memories on Shoah”. Afterwards the concept that has been used for model creation was presented and explained. Further the paper describes the used technical solution and realization in detail. On the basis of created model there will be realised a result of the project, which will be an interactive information system displaying 3D models of Terezín Memorial containing the multimedia historical content. The model of Terezín will be available at Terezín Memorial’s premises and installed on interactive kiosks and alternatively it will also be presented online on the web.

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Web client for PostGIS—the concept and implementation

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Abstract

PostgreSQL with PostGIS extension plays one of the major roles in many complex GIS frameworks. There exist many possibilities how to access such data storage, but most of them might be seen as not simple for new users. In this paper we would like to introduce the concept of the implementation of a web based PostGIS client application. The main emphasis of described solution is placed on simplicity and straightforward approach for visualisation of general SQL queries.

Introduction

Fast and online visualisation of complex SQL queries, that includes a spatial content without any scale limitation, is a challenge that can be hardly fulfilled with the software tools that are available nowadays. PostgreSQL with PostGIS plays a role of the flagship of Open Source RDBMS but there is just limited possibility of simple and fast queries visualisation. Widely used GIS applications offer certain solutions, but their approaches have some limits and can be seen as too complex.

We have designed the concept and implementation of software that will make output of SQL queries available through a web services. KML format was chosen as output data format as it is the most common format in the Internet environment. We have also designed a mechanism that helps to simplify the output data so that even large scale results can be easily cartographically visualised.

Server-side Java application with REST API has been implemented for that propose. The application accepts user’s SQL query, executes it in the database and provide the HTTP service with results in KML format. Such KML is recursively generated according to bounding box of user request and provides relevant level of detail of particular data.

Benefits of the developed application are in a simple access and straightforward visualisation with the utility of SQL together with comprehensive list of spatial functions available in PostGIS. The developed application can be useful for data mining and analyses as well as for the education proposes in the field of the spatial databases.

Current state

Let us consider a situation that a vector data are stored in a spatial database. A user manages this database by an administration software tool, runs analysis in form of SQL query and receives results as ordinary table including the situation that geometry is the main result of
the analysis. If a user wants to see geometry results in an appropriate map view there are several ways how to preview spatial data.

One way is connecting this database to an ordinary GIS application. We can mention one of very popular GIS applications QGIS. QGIS can connect to several types of databases and add a table with the geometry column as a new layer. Spatial features of this layer can be filtered by a search or by a query [1].

Second common way is publishing the data through a web service. There can be mentioned GeoServer [2] and MapServer [3] as examples of very popular server side software for serving spatial data through the web. A database can be connected to these products and then there is a possibility to publish particular data through standardised services (WMS, WFS [4]). Such a solution is very useful, but if we consider arbitrary queries, we will have to prepare specific configuration for each of those. GeoServer and MapServer support lots of standards for publishing spatial data e.g. WMS, WFS and WCS.

Another way is using some specialized desktop administration software for viewing and managing spatial data in the database. One of these is GeoRaptor, what is an extension for Oracle SQL Developer. GeoRaptor enables easy adding table as a layer into Spatial View where features are drawn in coordinate frame [5]. This solution provides an easy way how to preview spatial data directly in the administration tool where SQL queries are run, but usually doesn’t enable adding any underlying map.

When we consider large volume of data we need also to use advanced visualisation algorithms into account (such as clustering and simplification [6]). Another possibility is to render data in advance to raster tiles and then provide the output in the raster format. Such a solution improves the data availability, but the drawback is in more complicated data update.

Software concept

Our use case can be described as follows. We have lots of large datasets stored in the PostGIS database and we need to run analyses and effectively publish large results of spatial queries. It means that we need an application that would satisfy given requirements – accepting queries in form of SQL and quickly displaying of results of spatial queries. The spatial results mean to be displayed directly in a map window or exported in some common GIS format (e.g. Shapefile, KML, GeoJSON) without any additional configuration. The main goals of the proposed solution are:

1. Analyses will be performed directly by database management system (DBMS).
2. Application will accept SQL.
3. Results of analyses with geometry columns will be produced in common GIS format or displayed directly in a map window.
4. Large data obtained from spatial queries will use convenient type of simplification to improve display performance.
5. Application will minimize number of steps on the process from analysis draft to display result.
If spatial data are stored in the database it is more convenient to access and process the data directly by SQL commands rather than by using third party software. Usually the SQL commands can be run in an administration client and query results are opened directly in a form of tables. Spatial databases mostly have conversion functions to convert the geometry data type to several GIS formats. Afterwards, the results can be exported from the database and can be opened in common GIS applications.

Several GIS formats were considered during design phase of the application. The GML format was taken into account because it is an OGC standard. GML format is very complex and is focused more on description of geographic objects than on their visualizing. ESRI Shapefile was excluded because it is a set of several files and it would bring more administration during files transfer. For the purpose of the application we have chosen the KML format as the output format for the geometry column. The reasons are:

- KML is an OGC standard for spatial data
- KML is widely supported by GIS application and very popular among amateur users at this time
- KML has an element called NetworkLink for bi-directional communication between server and client application

The developed application can use PostGIS function ST_asKML() to convert the geometry data type into the KML format [7]. Basically there are two concepts of such a KML output. First is a common static KML file with specific part of query result. This static KML file will contain geometry, other than geometry attributes and style how the geometry should be drawn. Second option is dynamic KML file that will contain description of data and NetworkLink element. The NetworkLink element enables bi-directional communication between a server and a client application [8]. Such an element contains URL of the server, the bounding box (BBOX) for the selection of appropriate part of the result that fits current map window and finally parameters describing conditions for data refreshing. An example of NetworkLink element with defined BBOX parameters of current map window is shown in Example 1.

The designed application can be divided into three main parts – database, server-side and thin web client. Design of the parts will be detailed described below.

Database part

The database part of designed application is the core part for storing and analysing of data. This part consists of database schema, data model and stored functions. The schema guarantees keeping tables with query results separate from other schemas with spatial data. Designed data model contains one metadata table, stored procedures and tables that contains query results. Fig. 1 shows designed metadata table schema and an example of one query result table.

Metadata table is designed to contain information of processed SQL query and values that facilitate selecting of the appropriate part of the result matching the map window which user is looking at.

Stored procedures control the launching of given SQL query and create new entry to metadata
Example 1: Source code of NetworkLink element

```xml
<NetworkLink>
  <name>Geometry Features</name>
  <visibility>1</visibility>
  <open>1</open>
  <description>Feature from database specified by SQL query</description>
  <refreshVisibility>0</refreshVisibility>
  <flyToView>0</flyToView>
  <Link>
    <href>http://whatstheplan.eu/analyst_p4b/KMLServlet?queryId=1375356214822</href>
    <refreshInterval>2</refreshInterval>
    <viewRefreshMode>onStop</viewRefreshMode>
    <viewRefreshTime>1</viewRefreshTime>
    <viewFormat>BBOX=[bboxWest],[bboxSouth],[bboxEast],[bboxNorth]</viewFormat>
  </Link>
</NetworkLink>
```

Table after finishing of SQL. Procedures hold processing of one SQL query as one transaction to keep consistency of the model. Main procedure returns identifier of query result to the server-side part of application. Another function enables update of SQL and finally there is a function that deletes result table and relevant entry in metadata table by given identifier of query result.

Server-side part

Server-side part of designed application manages and controls the whole application. This part can be further divided into several modules that are shown in Fig. 2 below.

There is a module called Connector that manages connections to the database with using connection pool mechanism. Module Receiver receives SQL queries from user interface, checks their correctness as SELECT query and transfers they to created function in the database through the Connector module. Receiver receives parameters of the map window to select appropriate part of result. SQL for data selection are compiled in SQL creator module. KML creator module receives from database the identifier of finished query result and returns it to the user interface. Result modeller module receives features of query result requested by user interface for visualization and prepares list of objects for KML output files. KML creator module is designed to use FreeMarker template (see [8] for FreeMarker details). The publishing module of the application has been designed according to the Representational State Transfer (REST) software architecture [9].

Graphical user interface

Graphical user interface (GUI) is another part of the designed application. This part keeps responsibility for communication with users, enables SQL queries insertion and simple result visualization in the map window or downloading results in form of KML files. GUI has been designed as a web thin client with basic functionality for SQL handling and result visualization.
As has been already mentioned we take into consideration also the large datasets and large query results. The utilization of some simplification method for geometric parts of query results was considered already in first draft of the application. The query results could be simplified for an effective visualization after the analyses is made. It is necessary to select that kind of simplification methods that is not too much time-consuming and nevertheless can substantially facilitate visualization of results.

We can consider several methods for simplification on account of the datasets that have been available during the application development.
k-means method

This method [10, 11] divides the set of data into predefined number of clusters. The clustering starts with definition of centroids. Each point is classified to the nearest centroid. New centroids are computed according to current shapes of clusters after classifying of all points. This procedure is iteratively repeated till reaching defined convergence criterion. Convergence criterion can be minimal change of clusters or minimal move of centroids between steps. The advantages of this method are their simplicity, short running time and the existence of k-means clustering module to PostgreSQL database [12]. The disadvantage is that solution depends on initial choice of first centroids. Several modifications of the basic method exist that refine diverse characteristics of basic method [13, 14]. Optimized k-means method already refines cluster centroids during classification of each point. K-medoids method selects existing points as clusters centroids that are closest to a precise centroid. Fuzzy k-means method determines degree of membership in clusters. Spherical k-means method differs from the previous method in method of cluster creation. This method starts with all points in one cluster. The first cluster is progressively divided into defined number of cluster.

Geohash method

Geohash is a geocode system that subdivides space into grid shape according to geographic coordinates [15, 16]. Geohash uses the region quad tree data structure and then assigns string codes to particular quads by using base32 character set. Length of the Geohash code defines precision of the encoding. The advantage of this method is arbitrary precision and unique identification of a cell. PostGIS contains method that returns Geohash representation of the geometry [4].

Modified Facility location algorithm

In accordance to the previous development, a clustering method developed at the Department of Computer Science at the University of West Bohemia was selected for the point datasets [11]. This method is based on a local search algorithm for the facility location but with several modifications. This clustering is not parameterized by a number of clusters as the original method is but by the facility cost. The higher facility cost faster reduces the amount of data and produces fewer clustering levels. Another modification is that this method stores all intermediate clusters and builds hierarchy of them. Method makes a single linear pass over the data and builds a hierarchy of clusters. Each cluster is represented by point nearest to centre of cluster, this point is called representative. The clustering is done according to given criteria. The basic criterion is the geometrical distance of points, but other point attributes can be used. If the number of representatives reaches defined count, representatives are processed and representative of the cluster of these representatives is selected. The clustering ends if all points are processed and all representatives on higher levels can’t be further clustered.

Storing clusters in database

The selected clustering method saves created hierarchy of clusters in separate file for each level of hierarchy on hard disk. Because the developed application works with data stored in the database therefore it was necessary to design a way how to save the hierarchy to the database. Several possibilities were considered and the expected properties were satisfied.
properly by the modified preorder tree traversal algorithm [17]. The whole hierarchy is stored in one table with fixed number of columns. Only identifiers of points that refer to a query result in another standalone table are stored in this table. Table for the hierarchy contains the point identifier, the identifier of cluster representative, the level of hierarchy and the left and right value of index. The point indexing enables selection of the tree or a subtree in one query. Another benefit of this index is that the number of children of one node can be easy calculated from a difference of right and left value.

An example of the hierarchy is shown in Fig. 3 below with the direction of indexing. Fig. 3 shows the reason, why it is necessary to store identifier of point and parent together with the level number. It can be seen that the same point-parent pair could be found on several levels in the hierarchy.

![Figure 3: Example of cluster hierarchy](image)

Table 1 shows storing of part of the hierarchy displayed in Fig. 3. Points from the table can be selected by several ways. The first way is to select points by defining the range of left and right value and alternatively with or without given level number. Another way is to utilize spatial functions from the database. Geometry of desired extent and appropriate hierarchy level is defined and points on given hierarchy level that intersect the extent geometry are selected.

The visualization of query result with available clustering is based on visualization of component levels of the created hierarchy of clusters. The level of hierarchy that will be visualized is selected according to the current extent of a map window in GIS viewer. The main problem of the cluster visualization was matching hierarchy levels with BBOX size of map windows. Because the number of levels of the hierarchy is derived from the number of points in dataset,

<table>
<thead>
<tr>
<th>ID_POINT</th>
<th>ID_PARENT</th>
<th>LEVEL_POINT</th>
<th>LEFT_INDEX</th>
<th>RIGHT_INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>0</td>
<td>15</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>42</td>
</tr>
</tbody>
</table>
it was necessary to select the matching way in addiction to spatial extent of dataset. The idea is based on matching the highest hierarchy level with maximum BBOX of the result dataset. Lower hierarchy levels are subsequently matched with smaller map window BBOX sizes. The matching is based on the size of ratio of current map window extent to maximum extent of dataset. That means that the smaller the value of the ratio is, the lower the level of the hierarchy is selected.

In standard case, the data for visualization are selected if they intersect current map window BBOX. Together with simplification, suitable level of the hierarchy is selected first and then the data on given level that intersect current map window BBOX are selected. This method further reduces the amount of data that user application receives. The disadvantage is the necessity of creation of the hierarchy over the query results.

Experiments and results

The new client application has been designed and then developed as a Java application called PostMap. The PostMap has been developed according to designed structure that was described previously. Basic modules three modules of PostMap are shown in Fig. 4.

First step represents running the analysis where SQL query is on the beginning and an identifier of the result is at the end in Web client. Second step stands for preview of the result where the identifier of the result and BBOX of current map window are on the start of process and KML file with part of result data intersecting current map window is at the end.

Graphical visualization of the query results was implemented by two methods. Both of implemented methods have certain advantages and disadvantages. First method is direct visualization of entire query result content in the map window of web graphical user interface (GUI). Second method is based on publishing results in KML files and using another GIS
viewer as visualization client.

**Graphical User Interface**

The first part of PostMap which user meets is a web graphical user interface (GUI). The web GUI is a Javascript thin client in a form of web page that contains functional sections with client-server communication. The web GUI enables inserting and editing of SQL queries, contains list of last 5 user queries and a map window. After finishing of analysis, the content of query result is directly displayed in the map window. According to finished rendition of query result user can edit previous SQL query to reach intended result. Fig. 5 shows web client with opened query result.

Another simplification method was implemented to current version of PostMap. Geohash method is using for large results where is necessary an overview of features distribution rather than precision of features position. In cases of important position is used clustering method described above. An example of simplified result by Geohash method is shown on Fig. 6.

The second visualization way is based on publishing query results in KML format. The query result is exported from the application as dynamic KML file with the NetworkLink element after finishing of given query. In this case, user can open output file in any compatible GIS viewer according to his needs (e.g. GoogleEarth). Prerequisite for correct dynamic visualization is supporting of KML format with NetworkLink element in the selected GIS viewer. This support is necessary for communication between the server part and the third party GIS viewer. The KML file with NetworkLink is opened in a selected GIS viewer, GIS viewer starts to communicate with the server application and the server application starts to send requested part of query result. The GIS viewer requests part of a query result by sending the extent of current map window. The advantage of this visualization is the minimization of feature details, which can be useful for large datasets.
The disadvantages are necessity of repeated transfer of small data amount over net and using of third-party GIS viewers to displaying query results. An example of visualization clustered features of query results through dynamic KML file is shown in Fig. 7.

REST API

The current version of PostMap uses REST API for two tasks. The first task is the management of the user queries. There are implemented several URL for inserting, updating, deleting and listing of user queries. Responses of these requests depends on used HTTP methods, but mostly are returned responses in JSON format or only response codes. The second task is the management of stored queries metadata. This group of URLs returns description of stored user queries listed by several parameters. The main advantages of these RESTful services are the easier way how to add new functions to the PostMap and the easier dealing with URL requests. PostMap can be uses as a middleware to another application by accessing services over REST API.

Discussion

PostMap and its user interface enables to perform SQL queries based on the SELECT easily. Unlike current solutions there is no need for any configuration of data visualisation and results can be visualised on to a map. On other side we have identified these limitations:

- The SQL results have to be stored as temporal tables. Update of particular result essentially means to delete and create new temporal table again.
- There exists the risk of SQL injection what is a security issue. Such an issue can be
solved by set-up of authentication and authorization layer on the level of REST services.

- There is no possibility to apply cartographic visualisation of certain attribute in the form of cartograms. Such a problem can be solved in the future through the collection of templates for KML style.

- In case of using KML file with Networklink, geometry features are loaded only according to the current BBOX regardless of previously loaded data, although BBOXs could be partially overlapping with the one that were loaded before. Such an issue can be solved for example by storing previously published geometry features, comparison new BBOX to the previous and sending only the missing geometry features.

### Conclusion

The main usage of the PostMap can be found in two fields. The first field are technical projects where can be used as basic software tool for user spatial analyses and their visualization. The PostMap stands for a middleware that connects database with stored data and functions with visualization module e.g. a web geoportal or another standalone application. The PostMap consumes regular SQL SELECT queries that can contain spatial functions and produces. The input SQL queries can be predefined and users fill up only several parameters. The outputs are represented by query results exported in form of common KML files or visualized in own web client directly. We suppose that the query result contains exactly one geometry attribute.
The use of the KML format enables the export of whole query result or performs the dynamic visualization.

The second field of use is education of general GIS subjects or subjects focused on spatial databases. PostMap can be used to introduce spatial functions and predicates. It is possible to demonstrate use of functions and predicates into SQL queries and to demonstrate the connection of SQL queries outputs to parameters change. The contribution of this application consists in very quick and easy web visualization of query results without using any other clients.

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Development and testing of INSPIRE themes Addresses (AD) and Administrative Units (AU) managed by COSMC

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Abstract

Main content of this article is to describe implementing INSPIRE themes Addresses and Administrative Units in Czech Republic. Themes were implemented by Czech Office for Surveying, Mapping and Cadastre. Implementation contains developing GML files with data and designing its structure, developing and testing of INSPIRE services and preparing metadata for data and services. Besides harmonised INSPIRE themes COSMC manages also non-harmonised themes Cadastral map (KM) and Units eXtended (UX).

Keywords: INSPIRE, Cadastre, Addresses, Cadastral Parcels, Administrative Units, Buildings, Metadata, RÚIAN, services, WMS, WFS, GML

1. Introduction

INSPIRE – INfrastructure for SPatial InfoRmation in Europe is a Directive of European Commission and Council, which was transposed into Czech legislation in 2009 by the law number 380/2009 Col., which amends laws number 123/1998 Col., on the right to information about environment and number 200/1994 Col., about surveying.

From the law number 123/1998 Col. come (among others) following duties:

- create and manage metadata for spatial data files and for network services,
• harmonise spatial data sets according to the Directive,
• create interoperable network services.

Important part of implementation is also giving information on implementation to public. All basic information about implementation of data and services are available at geoportal COSMC\(^1\) in czech and in english in a bookmark INSPIRE. Pages for themes Cadastral Parcels (CP), Addresses (AD) and Administrative Units (AU) have a special look and structure. It was designed for better intelligibility of data and services for users. From the geoportal, there is also possibility of downloading data and access network services. Data, services and informations are available on national INSPIRE geoportal\(^2\), administered by CENIA, Czech environmental agency.

![Figure 2: COSMC geoportal](image)

This geoportal should collect all datasets relevant to INSPIRE including services and metadata. Unfortunately, at least in my opinion, it’s used more like trash can for all data sets which contain some part of data even distantly similar to those relevant to INSPIRE.

Searching of data and series is mediated through INSPIRE Discovery services. Discovery services are searching in metadata, specifically in keyword elements. Every provider can write into keywords anything he wants. That could be, and is, a problem. For accessing all data and services managed by COSMC, either by Section of central database or by Surveying Office, I conclusively recommend using the geoportal COSMC.

2. Implementation

During implementation of INSPIRE themes Addresses and Administrative Units, datasets and services harmonised by Implementation rules of INSPIRE Directive were designed, developed

\(^1\)http://geoportal.cuzk.cz/
\(^2\)http://geoportal.gov.cz/
and tested. Technical guidances for services and Data specifications were used during the implementation. Next step was making of metadata records. Metadata records serve as a description of data or services, not only human readable, but primarily computer readable.

I am personally engaged in a process of implementation since making of metadata records for data of the theme Cadastral Parcels. Themes Addresses and Administrative Units were implemented from the beginning to the very end with my participation. During implementation of themes Addresses and Administrative Units, metadata and data of the theme Cadastral Parcels were revised. This implementation took place in a few steps in the following order:

- analysis of Data specifications and Technical guidances INSPIRE,
- analysis of data in databases of COSMC,
- design of a data files structure,
- design of supported operations and planned limits for view and download services,
- creating of metadata records,
- testing and analysis of prepared data and services,
- revision of data files and services,
- revision of metadata,
- creating of promotional materials,
- publishing of data, services and metadata on the web http://services.cuzk.cz/,

In the future, Section of central database is going to continue in the implementation of INSPIRE Directive with the theme Buildings (BU). Concurrently with implementation of next INSPIRE theme, revisions of already done themes are taking place in legislation. Revisions are based on experience and users feedback.

2.1. Data

Preparation of data is based on Data specifications on themes. Preparation of data is divided into three phases. In the first one, I have studied Data specifications on Addresses and Administrative Units. Second step was to analyse corresponding data in COSMC databases. During the analysis it’s necessary to decide which data from database are suitable to data structure according to the specification. For that purpose, I have made schemes of usage. In the third phase I have prepared sample file in GML 3.2.1 format. The sample file for each theme was sent to the firm Geovap, the developer of software Marushka®, which mediates generating of predefined GML files according to sample file for each theme.

The basic dispensing unit is different for each theme. For the theme Cadastral Parcels, there is one predefined file for each cadastral zoning. Addresses have one file for each municipality and all data for the theme Administrative Units are distributed in only one file for the whole

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3ISKN – Information system of cadaster of real estates, ISÚI – Information system of territorial identification, ZABAGED – Fundamental Base of Geographic Data
Figure 3: UML diagram of Application scheme on theme Addresses

Czech Republic. Predefined files are generated daily and are available for free on the page http://services.cuzk.cz/gml/inspire.

Marushka® software, besides providing of predefined files, also mediates INSPIRE harmonised download and view services according to the INSPIRE Technical guidance for services. These services are realised through OGC and ISO standards about WMS 1.3.0 and WFS 2.0.0.

2.2. Services

According to the INSPIRE Directive there is five types of services, which has to be provided for rightful implementation. These services shall be implemented:

- Discovery services – allow to search for data ad services according to keywords in metadata,
- View services – allow viewing data through Web Mapping Services in version 1.3.0,
- Download services – allow downloading data through Web Feature Service in version 3.0 or through predefined GML files,
- Transformation services – allow transformation of spatial data,
- Startup services – allow access for other types of services.

From the INSPIRE implementations point of view I was especially interested about implementation of download and view services, which allow direct access to the data. Data are continually updated in Publication Database. Sources of the data of Publication Database
are ISÚI and ISKN. Data are essentially current, as the age of data two hours are featured.

Figure 4: Process of managing data from databases ISÚI and ISKN for predefined GML files and WMS and WFS services Source: Ing. Petr Souček, Ph.D.

INSPIRE View services are realised through Web Mapping Service 1.3.0. Besides this version, older version 1.1.1 is also supported, but not forced by INSPIRE Directive. Access point for service is web address according to this model: http://services.cuzk.cz/wms/inspire-[theme]-wms.asp?. For example, view service for the theme Addresses has access point on address http://services.cuzk.cz/wms/inspire-ad-wms.asp?. In order to simplify accessing data I have created a set of guidelines for using WMS services. There is one document for each theme:

- http://services.cuzk.cz/doc/inspire-ad-view.pdf – for Addresses,
- http://services.cuzk.cz/doc/inspire-au-view.pdf – for Administrative Units,
- http://services.cuzk.cz/doc/inspire-cp-view.pdf – for Parcels,

which contains list of available layers, supported coordinate systems and samples of requests.

Download services are realised according to Technical guidelines via WFS in version 2.0.0 and through predefined data files in GML format. Older versions of WFS aren’t supported. Problem is, that WFS 2.0.0 is not supported by most software. Only one I know about, that supports this service is QGIS. Access is mediated through plugin WFS 2.0 written by Jürgen Weichand. Manual on downloading and using this plugin, including basic examples of working with it, is to found on this page: http://services.cuzk.cz/doc/manual-wfs20-qgis.pdf.

Access point for Web Feature Service is web page according to the model http://services.cuzk.cz/wfs/inspire-[theme]-wfs.asp?. Here’s an example for Addresses: http://services.cuzk.cz/wfs/inspire-ad-wfs.asp?. Same as for WMS, for WFS I have created manuals too. They contain information about structure of data available through Web Feature Service and about the usage of this service. There is one document for each theme at the following addresses:

- http://services.cuzk.cz/doc/inspire-ad-download.pdf – for Addresses,
- http://services.cuzk.cz/doc/inspire-au-download.pdf – for Administrative Units,

Besides on-line access to data there is also a possibility to get a data through predefined GML files as described before.

### 2.3. Metadata

Metadata harmonised to INSPIRE has to follow Technical guideline for metadata. Its newest version (1.3) has been released on the 6th of November 2013. Metadata published by COSMC within INSPIRE is possible to divide into two parts. First one could be called "static", second one 'dynamic'. Static metadata include metadata for Series of INSPIRE datasets, metadata for INSPIRE Download services and metadata for INSPIRE View services. Dynamic metadata include getCapabilities documents for WMS and WFS, getFeatureInfo document, describeStoredQueries and other documents relative to network services. As the INSPIRE harmonised metadata are considered all metadata from the first category.

Technical guideline for metadata comes from technical norms ISO 19115 and ISO 19119 and National metadata profile and Metadata profile of COSMC also follow these norms. Metadata profile of COSMC includes everything what is required by INSPIRE Technical guidelines and National metadata profile and even more. Therefore I have used COSMC profile while I was creating metadata for INSPIRE themes.

All metadata has an identifier, which is unique in the scope of COSMC namespace. Combination of an identifier and namespace identifies metadata record uniquely in the scope of the whole INSPIRE. Metadata describe service or metadata they are attached to. Besides description info they contain keywords. Keywords serves for discovering products through INSPIRE Discovery services. Every metadata record has a keyword according to GEMET thesaurus. For the data metadata, GEMET keyword serves as an identifier of the INSPIRE theme. Services metadata have an additional GEMET keyword which serves as an identifier of the type of INSPIRE service.

Other keywords should come from Vocabulary of COSMC, but not all INSPIRE related keywords are included. Currently we have initialized negotiations with Terminological commision about adding new keywords to the Vocabulary. Most of them are related to INSPIRE and Basic registers.

Metadata also include information about Data quality and its testing. For data and services, only tests used were on INSPIRE consistency and data completeness.

### 3. What’s next?

By publishing data, metadata and services, implementation of INSPIRE isn’t done yet. We have found a lot of mistakes and comments during implementation and I believe that so did most of European developers and analysts working on implementation of INSPIRE. That’s a reason why Maintainance and Implementation Group (MIG) and Pool of Experts were founded. Ing. Jiří Poláček, CSc. is MIG member and both authors of this article are members of Pool of Experts. Implementation of INSPIRE is moving from the opening phase into the maintanance phase.

Within improvement of INSPIRE data and services it’s really important users’ feedback and
continual development of data, metadata and services. During my work on Addresses and Administrative Units I have revised metadata for Cadastral Parcels, which were published more than a year ago.

In the same time, interoperability of data and services between neighbour countries is going to be tested. Czech data and services are now tested together with Slovaks and cooperation with other neighbour states will follow.

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