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A HYBRID APPROACH FOR ASSESSING PROBLEM SOLVING SKILLS UNDER FUZZY CONDITIONS

Michael Gr. Voskoglou

Abstract: *Volumes of research have been written about problem solving, which is one of the most important components of the human cognition affecting the progress of the human society for ages. In this work a hybrid method is applied for the assessment of a student group's problem solving skills with qualitative grades (i.e. under fuzzy conditions). Namely, soft sets are used as tools for a parametric assessment of the group's performance, the calculation of the GPA index and the Rectangular Fuzzy Assessment Model are applied for evaluating the group's qualitative performance, grey numbers are used as tools for assessing the group's mean performance and neutrosophic sets are utilized when the teacher is not sure about the individual grades obtained by some (or all) students of the group.*

***Keywords**: Problem Solving, Assessment Methods, GPA Index, Fuzzy Sets and Logic, Rectangular Fuzzy Assessment Model, Grey Numbers, Neutrosophic Sets, Soft Sets.*

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Introduction

Volumes of research have been written about problem solving (PS), which is one of the most important components of the human cognition affecting the progress of the human society for ages. In [Voskoglou, 2011] we have examined the role of the problem in learning mathematics and we have attempted a review of the evolution of research on PS in mathematics education from the time of Polya until today.

Polya laid during the 50's and 60's the foundation for exploration in *heuristics* for PS, being the first who described them in a way that they could be taught. The failure of the introduction of the "New Mathematics" to school education placed the attention of specialists during the 80's on the use of the problem as a tool and motive to teach and understand better mathematics. A framework was created describing the PS process and reasons for success or failure in PS, which was depicted in Schoenfeld's *Expert Performance Model (EPM)* for PS [Schoenfeld, 1980]. The steps of the PS process in this model (see Figure 1) are the *analysis* (S_1) of the problem, the *design* (S_2) of its solution through the *exploration* (S_3), the *implementation* (S_4) and the *verification* (S_5) of the solution.

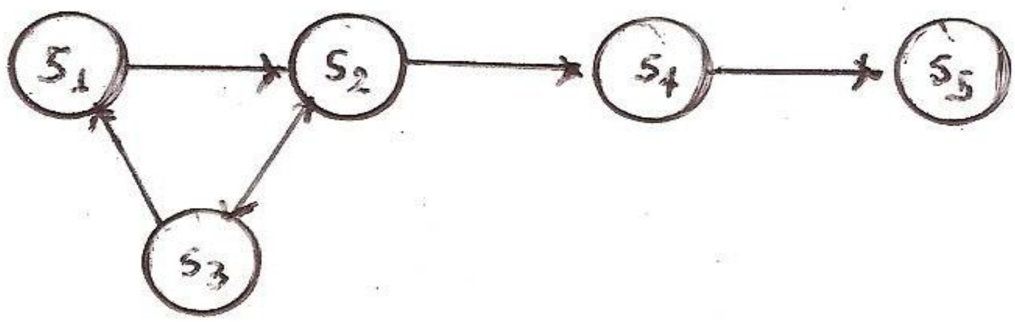

Figure 1. The "flow-diagram" of EPM

While early work on PS focused on describing the PS process, more recent investigations during the 2000’s focused on identifying attributes of the problem solver that contribute to successful PS. Carlson and Bloom drawing from the large amount of literature related to PS developed a broad taxonomy to characterize major PS attributes that have been identified as relevant to PS success. This taxonomy gave genesis to their *Multidimensional PS Framework (MPSF)* [Carlson & Bloom, 2005], which includes the following steps: *Orientation, Planning, Executing* and *Checking* (Figure 2).

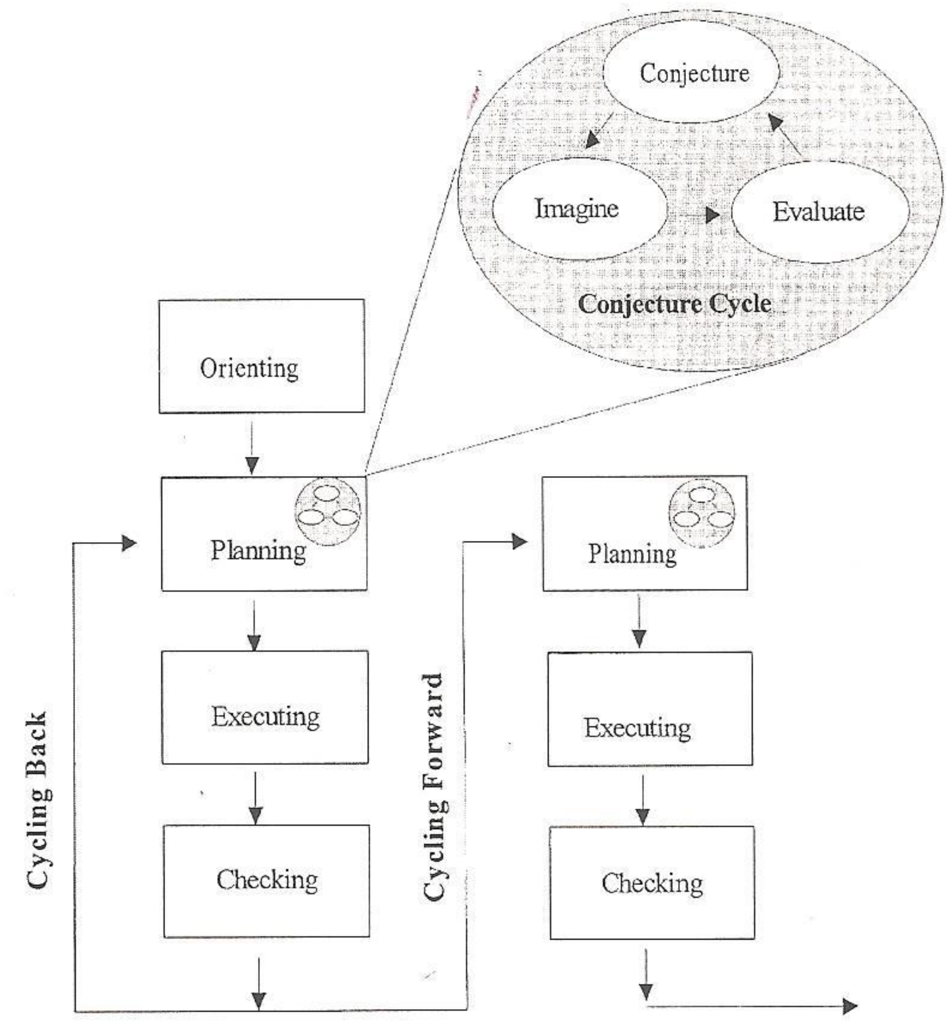

Figure 2. The “flow-diagram” of MPSF

It was observed that, when contemplating various solution approaches during the planning step of the PS process, the solvers were at times engaged in a *conjecture-imagine-evaluate* sub-cycle. It is of worth noting that a careful inspection of the two PS models shows that the steps of MPSF are in one-to-one correspondence to the steps of Schoenfeld's EPM, with S_1 corresponding to orientation, S_2 to planning, S_3 to the conjecture-imagine-evaluate sub-cycle, S_4 to executing and S_5 to checking.. However, there exists a basic qualitative difference between the two models: While in MPSF the emphasis is turned to the solver's behavior and required attributes, the EPM is oriented towards the PS process itself describing the proper heuristic strategies that may be used at each step of the PS process.

Schoenfeld, after a many years effort and research for building a theoretical framework providing rigorous explanations on how and why people during the PS process make the choices they did, concluded that the PS process, as well as many other human activities like cooking, teaching a lesson and even a brain surgery, are all examples of a *goal-directed behavior.* Thus, the individual's "acting in the moment" can be explained and modelled by a theoretical architecture in which knowledge, goals, orientations and decision-making are involved. The different individuals' decision choices can be seen as modelled by "expected-value" computations, where the quantities are the "subjective values" assigned by the individuals. In fact, the expected value of a decision equals the probability for the decision to be correct multiplied by the value of its profit minus its cost. But from each person's subjective point of view the value of a decision's profit is different and therefore its expected value is also different. That explains why different people will decide differently, because the subjective values they assigned are different. Schoenfeld argues that, once you understand an individual's orientations, you can see how the individual priorizes goals and outcomes and therefore you can model the possible courses of his action. Thus, when you understand how something skilful is done, you can help the others to do it successfully [Schoenfeld, 2010].

Quality is a desirable characteristic of all human activities. This makes assessment one of the most important components of the processes connected to those activities. Assessment takes place in two ways, either with the help of numerical or with the help of qualitative grades. When numerical grades are used, standard methods are applied for the overall assessment of the skills of a group of objects participating in a certain activity, like the calculation of the mean value of all the individual scores. The use of qualitative grades is usually preferred when more elasticity is desirable (as it frequently happens in case of student assessment), or when no exact numerical data are available. In this case, assessment methods based on principles of *fuzzy logic (FL)* are frequently used.

The present author has developed in earlier works several methods for the assessment of human/machine performance under fuzzy conditions including the measurement of *uncertainty* in fuzzy systems, the use of the *Center of Gravity (COG) defuzzification technique*, the use of *fuzzy numbers (FNs)* and of *grey numbers (GNs)*, etc. All these methods are reviewed in [Voskoglou, 2019a]. Recently, the same author developed a model for parametric assessment that uses *soft sets (SSs)* as tools [Voskoglou, 2022] and he also used *neutrosophic sets (NSs)* for student assessment when the teacher is not absolutely sure for the grades assigned to students [Voskoglou, et al., 2022].

In this paper a hybrid method is presented for the assessment of student PS skills with qualitative grades (therefore under fuzzy conditions) using the GPA index, the *Rectangular Fuzzy Assessment Model (RFAM)*, GNs, NSs and SSs as tools. The rest of the paper is organized as follows: The next Section contains basic information about GNs, NSs, SSs, GPA index and RFAM, needed for the understanding of the paper. The hybrid assessment method is developed in the third Section and the paper closes with a short discussion about future research perspectives and the final conclusions.

Mathematical Background

Fuzzy Sets and Logic

Zadeh, in order to deal with partial truths, introduced in 1965 the concept of *fuzzy set (FS)* as follows [Zadeh, 1965]:

Definition 1: Let U be the universe, then a FS F in U is of the form

$$F = \{(x, m(x)): x \in U\} \tag{1}$$

In equation (1) m: $U \rightarrow [0,1]$ is the *membership function* of F and m(x) is called the *membership degree* of x in F**.** The greater m(x), the more x satisfies the property of F. A crisp subset F of U is a FS in U with membership function such that m(x)=1 if x belongs to F and 0 otherwise.

Based on the concept of FS Zadeh developed the infinite-valued FL [Zadeh, 1973], in which truth values are modelled by numbers in the unit interval [0, 1]. FL is an extension of the classical *bivalent logic (BL)* embodying the Lukasiewicz’s “Principle of Valence”. According to this principle propositions are not only either true or false (according to the Aristotle’s principle of the “Excluded Middle”), but they can have intermediate truth-values too.

It was only in a second moment that FS theory and FL were used to embrace *uncertainty* modelling [Zadeh, 1978, Dubois & Prade 2001]. This happened when membership functions were reinterpreted as possibility distributions. *Possibility theory* is an uncertainty theory devoted to the handling of incomplete information [Dubois & Prade 2006]. Zadeh articulated the relationship between possibility and *probability*, noticing that what is probable must preliminarily be possible. For general facts on FSs and the connected to them uncertainty we refer to the book [Klir & Folger, 1988].

Neutrosophic Sets

Following the introduction of FSs, various generalizations and other related to FSs theories have been proposed enabling, among others, a more effective management of all types of the existing in real world uncertainty. A brief description of the main among those generalizations and theories can be found in [Voskoglou, 2019b].

Atanassov added in 1986 to Zadeh’s membership degree the *degree of non-membership* and introduced the concept of *intuitionistic fuzzy set (IFS)* [Atanassov, 1986] as the set of the ordered triples

$$A = \{(x, m(x), n(x)): x \in U, 0 \leq m(x) + n(x) \leq 1\} \quad (2)$$

Smarandache, motivated by the various neutral situations appearing in real life - like <friend, neutral, enemy>, <positive, zero, negative>, <small, medium, high>, <male, transgender, female>, <win, draw, defeat>, etc. – introduced in 1995 the degree of *indeterminacy/neutrality* of the elements of the universal set U in a subset of U and defined the concept of *neutrosophic set (NS)* [Smarandache, 1998]. The term neuttrosophic is the result of a synthesis of the words "neutral" and "sophia" meaning in Greek "wisdom". In this work we need only the simplest version of the concept of NS, which is defined as follows:

Definition 2: A *single valued NS (SVNS)* A in U is of the form

$$A = \{(x,T(x),I(x),F(x)): x \in U,\ T(x),I(x),F(x) \in [0,1],\ 0 \leq T(x)+I(x)+F(x) \leq 3\} \quad (3)$$

In (3) T(x), I(x), F(x) are the degrees of *truth* (or membership), indeterminacy and *falsity* (or non-membership) of x in A respectively, called the *neutrosophic components* of x. For simplicity, we write A<T, I, F>.

For example, let U be the set of the players of a basketball team and let A be the SVNS of the good players of U. Then each player x of U is characterized by a *neutrosophic triplet* (t, i, f) with respect to A, with t, i, f in [0, 1]. For instance, x(0.7, 0.1, 0.4) ∈ A means that there is a 70% belief that x is a good player, a 10% doubt about it and a 40% belief that x is not a good player. In particular, x(0,1,0) ∈ A means that we do not know absolutely nothing about x's affiliation with A.

In an IFS the indeterminacy coincides by default to 1- T(x) – F(x). Also, in a FS is I(x)=0 and F(x) = 1 – T(x), whereas in a crisp set is T(x)=1 (or 0) and F(x)= 0 (or 1). In other words, crisp sets, FSs and IFSs are special cases of SVNSs.

When the sum T(x) + I(x) + F(x) of the neutrosophic components of x ∈ U in a SVNS A on U is <1, then x leaves room for *incomplete* information, when is equal to 1 for *complete* information and when is greater than 1 for *paraconsistent* (i.e. contradiction tolerant) information. A SVNS may contain simultaneously elements leaving room to all the previous types of information. For general facts on SVNSs we refer to [Wang et al., 2010].

Summation of neutrosophic triplets is equivalent to the neutrosophic union of sets. That is why the neutrosophic summation and implicitly its extension to neutrosophic scalar multiplication can be defined in many ways, equivalently to the known in the literature neutrosophic union operators [Smartandache, 2016]. Here, writing the elements of a SVNS A in the form of neutrosophic triplets we define addition and scalar product in A as follows:

Let (t_1, i_1, f_1), (t_2, i_2, f_2) be in A and let k be appositive number. Then;

- The *sum* $(t_1, i_1, f_1) + (t_2, i_2, f_2) = (t_1+ t_2, i_{1+} i_2, f_{1+} f_2)$ (4)

- The *scalar product* $k(t_1, i_1, f_1) = (kt_1, k i_1, kf_1)$ (5)

Soft Sets

A disadvantage connected to the concept of FS is that there is not any exact rule for defining properly the membership function. The methods used for this are usually empirical or statistical and the definition of the membership function is not unique depending on the "signals" that each observer receives from the environment, which are different from person to person. For example, defining the FS of "tall men" one may consider as tall all men having heights more than 1.90 meters and another all those having heights more than 2 meters. As a result, the first observer will assign membership degree 1 to men of heights between 1.90 and 2 meters, in contrast to the second one, who will assign membership degrees <1. Consequently, analogous differences is logical to appear for all the other heights. The only restriction, therefore, for the definition of the membership function is to be compatible to the common sense; otherwise the resulting FS does not give a reliable description of the corresponding real situation. This could happen for instance, if in the FS of "tall men", men with heights less than 1.60 meters have membership degrees ≥0.5.

The same difficulty appears to all generalizations of FSs in which membership functions are involved (e.g. IFSs, NSs, etc.). For this reason, the concept of *interval-valued FS (IVFS)* [Dubois & Prade, 2005] was introduced in 1975, in which the membership degrees are replaced by sub-intervals of the unit interval [0, 1]. Alternative to FS theories were also proposed, in which the definition of a membership function is either not necessary (*grey systems/GNs* [Deng, 1982]), or it is overpassed by considering a pair of sets which give the lower and the upper approximation of the original crisp set (*rough sets* [Pawlak, 1991]).

Molodstov, in order to tackle the uncertainty in a parametric manner, initiated in 1999 the concept of *soft set (SS)* as follows [Molodstov, 1999]:

Definition 3: Let E be a set of parameters, let A be a subset of E, and let f be a map from A into the power set P(U) of all subsets of the universe U. Then the SS (f, A) in U is defined to be the set of the ordered pairs

$$(f, A) = \{(e, f(e)): e \in A\} \tag{6}$$

The term "soft" is due to the fact that the form of (f, A) depends on the parameters of A. For example, let U= {C_1, C_2, C_3} be a set of cars and let E = {e_1, e_2, e_3} be the set of the parameters e_1=cheap, e_2=hybrid (petrol and electric power) and e_3= expensive. Let us further assume that the cars C_1, C_2 are cheap, C_3 is expensive and C_2, C_3 are hybrid cars. Then, a map f: $E \rightarrow P(U)$ is defined by f(e_1)={C_1, C_2}, f(e_2)={C_2, C_3} and f(e_3)={C_3}. Therefore, the SS (f, E) in U is the set of the ordered pairs (f, E) = {(e_1, {C_1, C_2}), (e_2, {C_2, C_3}, (e_3, {C_3}}.

A FS in U with membership function y = m(x) is a SS in U of the form (f, [0, 1]), where f(α)={$x \in U$: m(x)$\geq$α} is the corresponding $\alpha - cut$ of the FS, for each α in [0, 1]. For general facts on SSs we refer to [Maji et al., 2003].

Obviously, an important advantage of SSs is that, by using the parameters, they pass through the need of defining membership functions. The theory of soft sets has found many and important applications to several sectors of the human activity like decision making, parameter reduction, data clustering and data dealing with incompleteness, etc. One of the most important steps for the theory of soft sets was to define mappings on soft sets, which was achieved by A. Kharal and B. Ahmad and was applied to the problem of medical diagnosis in medical expert systems [Kharal & Ahmad, 2011]. But fuzzy mathematics has also significantly developed at the theoretical level providing important insights even into branches of classical mathematics like algebra, analysis, geometry, topology etc.

We ought to note, however, that, despite the fact that IFSs and SSs have already found many and important applications, there exist reports in the literature disputing the significance of these concepts and considering them as redundant, representing in an unnecessarily complicated way standard fixed-basis set theory [Garcia & Rodabaugh, 2005, Shi & Fan, 2019]. In the Abstract of [Shi & Fan, 2019], for example, one reads: "In particular, a soft set on X with a set E of parameters actually can be regarded as a 2E -fuzzy set or a crisp subset of E × X [the correct is E x P(X)]. This shows that the concept of (fuzzy) soft set is redundant". We completely disagree with this way of thinking. Adopting to it, one could claim that, since a FS A in X is a subset of the Cartesian product X x m(X), where m is the membership function of A, the concept of FS is redundant!

Grey Numbers

Approximate data are frequently used nowadays in many problems of everyday life, science and engineering, because many constantly changing factors are usually involved in large and complex systems. Deng introduced in 1982 the *grey system (GS)* theory as an alternative to the theory of FSs for tackling such kind of data [Deng, 1982]. A GS is understood to be a system that lacks information such as structure message, operation mechanism and/or behaviour document. The GS theory, which has been mainly developed in China, has recently found many important applications [Deng, 1989].

An interesting application of the closed intervals of real numbers is their use in the GS theory for handling approximate data. In fact, a numerical interval I = [x, y], with x, y real numbers, x<y, can be considered as representing a real number with known range, whose exact value is unknown. The closer x to y, the better I approximates the corresponding real number. When no other information is given about this number, it looks logical to consider as its representative approximation the real value

$$V(I) = \frac{x+y}{2} \qquad (7)$$

[Moore et al., 1995] introduced the basic arithmetic operations on closed real intervals. In the present work we shall make use only of the addition and scalar product defined as follows: Let $I_1 = [x_1, y_1]$ and $I_2 = [x_2, y_2]$ be closed intervals, then their *sum* $I_1 + I_2$ is the closed interval

$$I_1 + I_2 = [x_1+ x_2, y_1+ y_2] \tag{8}$$

Further, if k is a positive number then the *scalar product* kI_1 is the closed interval

$$kI_1 = [kx_1, ky_1] \tag{9}$$

When the closed real intervals are used for handling approximate data, are usually referred as *grey numbers (GNs)*. A GN [x, y], however, may also be connected to a *whitenization function* f: [x, y] → [0, 1], such that, ∀ a ∈ [x, y], the closer f(a) to 1, the better a approximates the unknown number represented by [x, y].

We close this subsection with the following definition, which will be used in the assessment method that will be presented later in this work.

Definition 4: Let $I_1, I_2, \ldots, I_n$ be a finite number of GNs, n≥2, then the *mean value* of these GNs is defined to be the GN

$$I = \frac{1}{n}(I_1 + I_2 + \ldots + I_k) \tag{10}$$

GPA Index and the Rectangular Fuzzy Assessment Model

The calculation of the *Grade Point Average (GPA) Index* is a classical method, very popular in USA and other western countries, for evaluating a group's *qualitative performance*, when greater coefficients are assigned to the higher grades. For this, let n be the total number of the objects of the group under assessment and let n_X be the number of the group's objects obtaining the grade X, X =A, B, C, D, F, where A=excellent, B=very good, C=good, D=mediocre and F=unsatisfactory. Then, the GPA index is calculated by the formula

$$GPA = \frac{0n_F + n_D + 2n_C + 3n_B + 4n_A}{n} \tag{11}$$

[Voskoglou, 2017] (Chapter 6, p. 125)

In the worst case ($n=n_F$) equation (11) gives that GPA=0, whereas in the best case ($n=n_A$) it gives that GPA=4. We have in general, therefore, that $0 \leq GPA \leq 4$, which means that values of $GPA \geq 2$ indicate a satisfactory qualitative performance.

Setting $y_1 = \frac{n_F}{n}$, $y_2 = \frac{n_D}{n}$, $y_3 = \frac{n_C}{n}$, $y_4 = \frac{n_B}{n}$ and $y_5 = \frac{n_A}{n}$, equation (11) can be written as

$$GPA = y_2 + 2y_3 + 3y_4 + 4y_5 \tag{12}$$

Voskoglou developed a fuzzy model for representing mathematically the process of learning a subject matter in the classroom [Voskoglou, 2000]. Later, considering a student class as a fuzzy system, he calculated the existing in it *total possibilistic uncertainty* for assessing the student mean performance [Voskoglou, 2009]. Subbotin et al., based on Voskoglou's model, adapted properly the *Center of Gravity (COG) defuzzification technique* for use as an assessment method of student learning skills [Subbotin et al., 2004]. Since then, Subbotin and Voskoglou applied, jointly or separately, the COG technique, termed by them as the *Rectangular Fuzzy Assessment Model (RFAM)*, in many other types of assessment problems; e.g. see [Voskoglou, 2017] (Chapter 6).

There is a commonly used in FL approach to represent the fuzzy data by the coordinates (x_c, y_c) of the COG of the level's area between the graph of the corresponding membership function and the OX axis [Van Broekhoven & Debaets, 2006]. In our case, keeping the same notation as for the GPA index, it can be shown that the coordinates of the COG are calculated by the formulas

$$x_c = \frac{1}{2}(y_1+3y_2+5y_3+7y_4+9y_5) \tag{13}$$

$$y_c = \frac{1}{2}(y_1^2+y_2^2+y_3^2+y_4^2+y_5^2) \tag{14}$$

[Voskoglou, 2019a] (Section 4)

It can be also shown the following result [Voskoglou, 2019a] (Section 4**):**

Assessment Criterion:

- Between two groups, the group with the greater x_c demonstrates the better performance.
- For two groups with the same value of x_c, if $x_c \geq 2.5$ the group with the greater value of y_c performs better, and if $x_c < 2.5$ the group with the lower value of y_c performs better.

Combining equations (12) and (13) one finds that $x_c = \frac{1}{2}(2GPA + 1)$ or

$$x_c = GPA + \frac{1}{2} \tag{15}$$

Thus, with the help of the first case of the previous criterion, one concludes that, if the GPA value of two student groups is different, then the RFAM and the GPA index give the same outcomes concerning the assessment of the qualitative performance of the two groups. If the GPA index, however, is the same for the two groups, then one MUST apply the RFAM to see which group performs better.

The Hybrid Assessment Model

A hybrid method is applied in this Section for the assessment of a student group's PS skills with qualitative grades. Namely, SSs are used as tools for a parametric assessment of the group's performance, the calculation of the GPA index and the RFAM are applied for evaluating the group's qualitative performance, GNs are used as tools for assessing the group's mean performance and NSs are used when the teacher is not sure about the individual grades assigned to some (or all) students.

Parametric Assessment Using Soft Sets

Assume that a mathematics teacher wants to assess the PS skills of a group $U = \{S_1, S_2, \ldots, S_n\}$ of students. Let E = {A, B, C, D, E} be the set of parameters A=excellent, B=very good, C=good, D=mediocre and F=unsatisfactory. Assume further that the first four students of the group demonstrated excellent performance, the next five very good, the following 7 good, the next eight mediocre and the rest of them unsatisfactory performance. Let f be the map assigning to each parameter of E the subset of students whose performance was assessed by this parameter. Then, the overall student performance is represented mathematically by the SS

$$(f, E) = \{(A, \{S_1, S_2, S_3\}), (B, \{S_4, S_5, \ldots, S_8\}), (C, \{S_9, S_{10}, \ldots, S_{15}\}), \quad (16)$$
$$(D, \{S_{16}, S_{17}, \ldots, S_{23}\}), (F, \{S_{24}, S_{25}, \ldots, S_n\})$$

The use of SSs enables also the representation of each student’s individual performance at each step of the PS process. In fact, let T_1=orientation, T_2=planning, T_3=conjecture-imagine-evaluate, T_4=executing and T_5=checking be the steps of the previously described MPSF. Set $V = \{T_1, T_2, T_3, T_4, T_5\}$, consider a particular student of U and define a map $f: E \rightarrow \Delta(V)$ assigning to each parameter of E the subset of V consisting of the steps of the PS process assessed by this parameter with respect to the chosen student. For example, the soft set

$$(f, E) = \{(A, \{T_1, T_3\}), (B, \{T_5\}), (C, \{T_4\}), (D, \{T_2\}), (F, \emptyset)\} \quad (17)$$

represents the profile of a student who demonstrated excellent performance at the steps of orientation and conjecture-imagine-evaluate, very good performance at the step of checking, good performance at the step of executing and mediocre performance at the step of planning (he/she faced difficulties, but he/she finally came through).

Use of the COG Technique and the RFAM for Assessing a Group's Qualitative Performance

The following example illustrates this method:

Example 1: The students of two classes obtained the following grades in a mathematical PS test: Class I: A=5 students, B=3, C=7, D=0, F=5, Class II: A=4, B=4, C=7, D=1, F=4. Which class demonstrated the better qualitative performance?

Solution: Equation (11) gives that $GPA_I = GPA_2 = \frac{43}{20}$. The RFAM model must be used, therefore, for comparing the two classes' qualitative performance. Thus, by equation (13) one gets that $x_{C_I} = x_{C_{II}} = = \frac{53}{20} > \frac{5}{2}$. But equation (14) gives that y_{C_I} = 54 and $y_{C_{II}}$ = 49, therefore, by the second case of the RFAM assessment criterion, one concludes that Class I demonstrated a better qualitative performance. Further, since GPA_I =

$GPA_2 = \frac{43}{20} > 2$, both groups demonstrated satisfactory qualitative performance.

Use of Grey Numbers for Evaluating a Group's Mean Performance.

When the student individual assessment is realized with qualitative grades, a student group's mean performance cannot be assessed with the classical method of calculating the mean value of the student scores. To overcome this difficulty, using the numerical climax 1-100 we assign to each of the student qualitative grades a closed real interval (GN), denoted for simplicity with the same letter, as follows: A = [85, 100], B = [75, 84], C = [60, 74], D = [50, 59] and F= [0, 49]. It is of worth noting that, although the GNs assigned to the qualitative grades satisfy generally accepted assessment standards, the previous assignment is not unique, depending on the teacher's personal goals. For a more strict assessment, for example, the teacher could choose A = [90, 100], B = [80, 89], C = [70, 79], D = [60, 69], F= [0, 59], etc.

The estimation of a group's mean performance with the help of the previously defined GNs is illustrated with the following example:

Example 2: Reconsider Example 1. Which class demonstrated the better mean performance?

Solution: Under the light of equation (10), it is logical to accept that the GNs $M_I = \frac{1}{20}(5A+3B+7C+0D+5F)$ and $M_{II} = \frac{1}{20}(4A+4B+7C+1D+4F)$ respectively can be used for estimating the two classes' mean performance. Straightforward calculations with the help of equations (8) and (9) give that $M_I=\frac{1}{20}[1070, 1515] = [53.5, 75.75]$ and $M_{II}=\frac{1}{20}[1110, 1509] = [55.5, 75.45]$. Equation (7) gives, therefore, that $V(M_I) = 64.625$ and $V(M_{II}) = 64.75$. Thus, both classes demonstrated good (C) mean performance, with the mean performance of Class II being better.

Using Neutrosophic Sets for the Assessment

In many cases the teacher has doubts about the grades assigned to some (or all) students. In such cases the use of NSs is more appropriate for estimating the student group overall performance. This process is illustrated in the following example:

Example 3: Let $\{s_1, s_2, …. , s_{20}\}$ be a class of 20 students. The teacher of the class is not sure about the grades obtained by them in a test on mathematical PS, because some of the students did not give proper explanations about their solutions. The teacher decides, therefore, to characterize the students who demonstrated excellent performance in the test using neutrosophic triplets as follows: $s_1(1, 0, 0)$, $s_2(0.9, 0.1, 0.1)$, $s_3(0.8, 0.2, 0.1)$, $s_4(0.4, 0.5, 0.8)$, $s_5(0.4, 0.5, 0.8)$, $s_6(0.3, 0.7, 0.8)$, $s_7(0.3, 0.7, 0.8)$, $s_8(0.2, 0.8, 0.9)$, $s_9(0.1, 0.9, 0.9)$, $s_{10}(0.1, 0.9, 0.9\}$ and for all the other students (0, 0, 1). This means that the teacher is absolutely sure that s_1 demonstrated excellent performance, 90% sure that s_2 demonstrated excellent performance too, but at the same time has a 10% doubt about it and also a 10% belief that s_2 did not demonstrated excellent performance, etc. For the last 10 students the teacher is absolutely sure that they did not demonstrate excellent performance. What should be the teacher's conclusion about the class's mean mathematical level in this case?

Solution: It is logical to accept that the class's mean mathematical level can be estimated by the neutrosophic triplet $\frac{1}{20}$[(1, 0, 0)+(0.9, 0.1, 0.1)+(0.8, 0.2, 0.1)+2(0.4, 0.5, 0.8)+2(0.3, 0.7, 0.8)+(0.2, 0.8, 0.9)+2(0.1, 0.9, 0.9)+10(0, 0, 1)], which by equations (8) and (9) is equal to $\frac{1}{20}$(4.5, 5.3, 16.3) = (0.225, 0.265, 0.815). This means that a random student of the class has a 22.5 % probability to be an excellent student, however, there exist also a 26.5% doubt about it and an 81.5% probability to be not an excellent student. Obviously this conclusion is characterized by inconsistency.

The teacher could work in the same way by considering the NSs of students who demonstrated very good, good, mediocre and unsatisfactory performance in the test, thus obtaining analogous conclusions.

Discussion and Conclusions

A hybrid assessment method was applied in this work for assessing student PS skills under fuzzy conditions (with qualitative grades). The discussion performed leads to the following conclusions:

- SSs can be used for realizing a parametric assessment of the student group's overall performance
- The qualitative performance of a student group (where greater coefficients are assigned to the higher grades) can be measured

either by the classical method of calculating the GPA index, or by applying the RFAM, which is based on the COG defuzzification technique. When two groups have the same GPA index, however, then the RFAM model must be applied to find which group demonstrates the better performance.

- In case of using qualitative grades for assessing the student performance, the assessment of a student group's mean performance cannot be realized by the classical way of calculating the mean value of the student individual scores. The student mean performance in this case can be estimated by using GNs (closed real intervals).

- When the teacher has doubts for the grades obtained to some (or all) students, NSs can be used for assessing the overall performance of a student group.

Our experience from the present and earlier works implies that hybrid methods, like the previous one, give usually better and more complete results, not only in the assessment processes, but also in decision-making, in tackling the existing in real world uncertainty and possibly in various other human or machine activities. This is, therefore, an interesting subject for further research.

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SEMANTIZATION OF THE WEB-ORIENTED ADVISORY SOFTWARE: MODELS, METHODS AND TECHNOLOGIES

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Abstract: *We consider actual trends in use of semantic technologies for development of the Web-oriented advisory software. Requirements and expressiveness of knowledge representation in this domain cause use of ontological knowledge model, and the Semantic Web standards and tools provide the technological foundation for creation of intelligent advisory applications that use external ontologies as sources of domain knowledge.*

Personification of advisory services needs in analysis of learning outcomes of informal and non-formal learning, and therefore we propose method of their formalization with use of background knowledge about with classifications of professions and qualifications in agricultural domain. This method is based on matching of semantic properties of information objects with different structure represented by atomic competencies. Services provided by advisory system are considered from the point of view of semantic technologies. Proposed approach is used for development of applied advisory system AdvisOnt aimed to combine the market of educational services with the labor market. AdvisOnt characteristics satisfy requirements to distributed semantic application.

Keywords*: semantic application, advisory system, ontology, knowledge representation.*

***ITHEA Keywords**: I.2.4 Knowledge Representation Formalisms and Methods, I.2.1 Applications and Expert Systems, H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6)*

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Introduction

Semantic technologies considerably change methods and models used for development of information systems. Processing and representation of knowledge becomes the significant component of such systems, influence on their functionality and effectiveness.

One of the important actual trends of intelligent information systems (IISs) deals with migration from the processing and storage of large amounts of data (Big Data, data lakes, etc.) to processing and storage of more compact knowledge acquired from this data by various techniques of Data Mining, Artificial Intelligence (AI) and Business Analytics (BI). IISs have to process information resources (IRs) with a much more complex structure and big number of relations between elements of content. Here we consider IR in the most general understanding as various data with infrastructure for its storage, retrieval and processing that can be estranged from sources and authors that is represented in digital forms that use computers, networks equipment and appropriate software. Domain knowledge formalized in various ways provide basis for semantization on all steps of information processing [Warren, 2006]. One of the most used approaches for interoperable representation of domain knowledge is ontological analysis [Guarino, Oberle and Staab, 2009].

Now semantization of the Web-oriented applications is based on standards of the Semantic Web (SW) [Decker et al, 2000]. This project is aimed to transform the Web into global knowledge base (KB) [Berners-Lee, Hendler and Lassila, 2001] and defines the set of requirements for applications functioned in this environment. Now SW provides a large number of standards and tools for knowledge representation and processing by intelligent applications [Sabou, 2008]. The main components of the Semantic Web are:

- ontologies for knowledge representation [Obrst et al, 2007];
- Web services [Studer, Grimm and Abecker, 2007] for knowledge processing;
- software agents for representation of individual needs of users [Hendler, 2001].

SW proposes open standards that allow formalizing the semantics of information resources (IRs) and software tools for their search and processing:

- metadata description language RDF [Lassila and Swick, 1998];
- ontology representation language OWL [Bechhofer et al, 2004];
- query language SPARQL [Pérez, Arenas and Gutierrez, 2009] for RDF and OWL.

Semantic applications (SAs) are considered in this work as a subset of IISs with some specific features of knowledge processing [Hoppe, Humm and Reibold, 2018]. The most important of these features is the requirement for differentiation of processing tools and processing information: Such approach ensures use of various external knowledge bases (KBs) without changes of software, and the same KBs can be used by different IISs without data transformation. In practice selection of the knowledge representation tools and languages depends of specifics of domain and task of IIS, but large majority of them are based on the Semantic Web standards OWL and RDF.

Semantic technologies (STs) are the technologies of software development that allows efficient creation and support of SAs aimed on meaningful processing of information. Ontology-based STs use knowledge representation grounded on ontological analysis. Effectiveness of STs depends on relevance of solved tasks with used IRs, knowledge representation models and software solutions. Therefore we have to match possibilities and restrictions of analyzed ST with information needs of potential IIS user.

In this work we consider the specific features of advisory SAs and demonstrate advantages of STs on example of the Web-oriented advisory system AdvisOnt [Pryima et al, 2020]. Advisory SA is a special case of recommender system oriented on specific classes of information objects (IOs) such as competencies, vacancies, professions, etc. such systems are defined by combination of advisory, competence and agricultural knowledge from national and international standards, KBs and IRs processed by the search and matching services.

Problem definition

Aimed by development of advisory SA, we analyze tasks caused combining of the market of educational services with the labor market that can solve problems caused by informal and non-formal learning. Therefore, we take into account specifics of educational domain, its subjects and objects and their relations into the labor market. We use information about them from open sources and apply methods of knowledge acquisitions and semantic matching.

Goals of advisory system

Agricultural advisory systems are widely used now for fast dissemination of agricultural knowledge and information, introduction of modern scientific re- search and technologies in production, mobility and constant advanced training of agricultural specialists. Their implementation becomes an important factor in competitiveness of rural economy.

Development of the agricultural sector causes the dissemination of modern knowledge among agricultural manufacturers, relevant and efficient training and information support of their employees. In this work we describe the development of AdvisOnt. This SA is an agro-advisory system that ensures consulting services for the agricultural sector of economy. It implements an ontological representation of advisory knowledge. Now AdvisOnt provides formalization and harmonization of semantic models of advisory objects with use of semantic identification and documentation of non-formal and informal learning outcomes and competence-based representation of advisory IOs [Rogushina and Priyma, 2017].

AdvisOnt is intelligent software that provides wide number of advisory functions. This system is developed for automated semantic matching [Giunchiglia, 2009] of qualifications and competencies of various IOs (humans, organizations, learning courses, requirements of employer, etc.). Information about structure of these IOs is acquired from external KBs that represent knowledge about competence standards of various countries and international communities (selection of KBs depends on particular task of system, and their collection can be changed and extended without changing of advisory services). From the other point of view, the set of advisory services can be changed and extended without additional requirements to external IRs.

As a SA, AdvisOnt needs in dynamically updated external knowledge sources and in non-trivial methods of their processing on semantic level with use of this domain knowledge. Therefore we have to use the Semantic Web standards that supports these possibilities that can't be achieved in other ways: system solves the problem of integration with various external KBs by use of knowledge representation based on ontological approach and SW standards. AdvisOnt provides processing of ontology formats (OWL and RDF) and their transformation into more usable representations.

Advisory services are considered as special cases of ontology matching [Shvaiko and Euzenat, 2008] where ontological structures (from one common ontology or from different ones) define compared IOs. Ontology of competencies and methods for processing of atomic competencies become the ground for semantic matching of such objects described by different terms from various qualification systems.

Related work

In general, the content of advisory services is any information relevant to the decision-making of the advisor. We consider literature review of advisory software proposed by [Mommsen-Ghosh, 2004] that defines investment advisory services and their role in solving of problem of information transmission into customer-specific process. Advisory tools vary from simple presentations to complex software for mathematical simulations and statistical analyses. Education and the contact frequency with the advisor affect the level of his/her individual knowledge that influences on advisory results.

Advisory tools can be used either as a part of a service module where the advisor interprets the results of the tool, thereby enhancing the service brought to the customer; or they can be sold as an isolated module where the tool is put at the customers' disposal via the Web. Service modules serve as the conceptualization to understand the involved domain knowledge.

Knowledge used by advisory services includes organizational routines, processes, practices and norms, framed experiences, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information.

Modern Web-oriented systems use ontological approach for interoperable and personified representation of advisory knowledge [Erriquez and Grasso, 2008]. Important part of this background knowledge [Sabou, 2008] represents learning outcomes of various forms of learning.

Semantic technologies

Semantics allows to define explicitly meanings and relations between domain concepts represented by data (words, phrases, symbols, etc.) that depend on context. Semantics of the same piece of information, can be defined differently depending on formalization and the user's view of the world. Ontologies can be used as a formal, explicit specification of conceptualization of terms at a certain level of details [Guarino, 1998] that can fix various believes of users about some domain and process them in objective way.

In the most general understanding, semantic processing of information includes:

- means of knowledge representation that can be used to define meaning of considered IOs, their properties and relations between them;
- methods of integration and logical inference of new knowledge from existing heterogeneous information (knowledge and data);
- retrieval of IRs based on knowledge about user information needs and acquisition of knowledge from them.

Semantic processing of information by the Web-oriented SAs has some specific features:

- means of knowledge representation are oriented on the distributed heterogeneous information that changes dynamically and includes inconsistent elements;
- integration of knowledge supports various knowledge models and needs in alignment tools;
- retrieval of IRs based on knowledge about user information needs supports processing of big amounts of information (the Web resources, Big Data storages, etc.).

In [Gorodetsky and Tushkanova, 2018] STs are described through a combination of three main components: ontologies; semantic resources; models of semantics of natural language (NL) entities. This approach is concentrated on NL processing. In our study we take into account more wide classes of IOs with various structure defined by appropriate ontologies. For example, advisory systems analyze people, organizations, vacancies, learning courses, etc. that cam contain NL definitions, multimedia elements and structured data.

We analyze use of SW technologies in design of informational retrieval systems [Gladun and Rogushina, 2009] and increase models of processed information for more general types of IO that can contain multimedia elements and structured data.

From the point of view of SA development, we distinguish three hierarchical ST components:

- ontologies and other KBs are the upper abstraction level of the knowledge structure;
- IO models represent the intermediary level that allows to distinguish typical IOs and their properties and characteristics;
- semantic IRs are the lower level that provides information about individuals of classes.

Semantic IRs can include links between content elements (IOs of various types and structure) and with elements of IO models (for example, links with other Wiki pages or with data). Meaning of links is provided by means specific for IR representation and markup. For example, Semantic MediaWiki uses semantic properties.

Semantic IRs explicitly define relations between content elements and formalized knowledge representations. Usually they use some common standards (such as MPEG21 for multimedia) or problem-specific domain ontologies. Structure of IO models can contain relations with other IOs (for example, some IO of category “Person” has semantic link with IO of category “Organizations” by relation “Place of work”, and such link can be used into page content only if is present into the IO model). IO models can be formalized by various representations such as templates and forms. Domain ontologies contain classes and individuals of concepts and formalize their properties and characteristics.

Processing of learning outcomes in advisory systems

Learning outcomes of some person consist of his/her knowledge, skills, abilities and competencies. These outcomes are statements that describe personified knowledge or skills should acquire by the end of a particular assignment, class, course or program, and define for students why that knowledge and those skills can be useful to them.

Important part of advisory services deals with processing of non-formal and informal learning outcomes that characterize a significant part of employees` competencies. Official recognition of non-formal and informal learning outcomes obtained outside formal learning systems of partial qualifications has to take into account all outcomes obtained by persons in process of lifelong learning. Lifelong learning is a key factor in personal and professional development of human defined by Global Standard for Lifelong Learning and Worker Engagement to Support Advanced Manufacturing (http://www3.weforum.org/docs). Validation of the results achieved in the process of non-formal and informal learning (knowledge, skills, competencies, etc.) with use of open educational IRs is necessary for access to the labor market and lifelong learning [Colardyn and Bjornavold, 2004]. Information about these outcomes can be proposed by person or be acquired from various external IRs.

Recognition of such outcomes that is achieved through non-formal and informal (spontaneous) learning with the help of various open educational resources is necessary for semantic matching of resumes with vacancies of labor market and propositions of learning organizations. Validation allows the recognition of learning outcomes obtained outside the institutions of formal learning (in non- formal and informal education) and is necessary for access to the labor market and lifelong learning [Pryima, Rogushina and Strokan, 2018]. In previous research we produce some algorithms that provide matching of non-formal learning outcomes with more formal advisory IOs on base of atomic competencies that are used as values of semantic properties for IOs with different structure [Rogushina and Pryima, 2017].

The tools used in this process have to take into account changes in the open world and be dynamic, and they need in semantic retrieval components based on ontological models of user and domain [Pryima et al, 2020].

Ontologies in semantic advisory system

Ontological analysis is widely used now for formal modeling of various domains [Gruber, 1991]. Ontology provides a formal explicit description of domain concepts (classes and individuals), their properties, attributes and relations. Moreover, ontology can contain some domain-specific restrictions on use of all these elements and their combinations. Modern intelligent applications use ontologies as interoperable KBs [Staab and Studer, 2013].

A lot of SW-oriented SAs use ontologies as a source of domain knowledge for semantic markup of various documents (NL texts, Wiki resources, other semi-structures and structured texts, multimedia context etc.) and for creation of their metadata. For example, Wiki resources can be semantizied in this way. Widely used semantic markup of the Web resources is realized by various intelligent extensions of the Wiki resources (such as Semantic MediaWiki [Krötzsch, Vrandečić and Völkel, 2006], OntoWiki [Auer, Dietzold and Riechert, 2006], IkeWiki, SemanticXWiki, and KawaWiki [Kawamoto, Kitamura and Tijerino, 2006]). There is a number of Wiki software that provides semantic functionality. Some of them are standalone Wiki applications, and others are realized as extensions or plugging to standard Wiki software. Semantic Wiki-based IRs differ in their degree of formalization. Some of them support integration with external ontologies (RDF and OWL) and can generate local ontologies for group of the Wiki pages. For example, Semantic Media Wiki provides to users such tools of semantic structuring as categories and semantic properties.

Advantages of the ontological approach for semantic representation for learning domain and competencies ([Miranda et al, 2016], [Lundqvist, Baker and Williams, 2017]) are substantiated by many researchers. The most important reasons for their use deals with:

- explicit representation of knowledge with unambiguous interpretation,
- availability of common standards, languages and tools;
- theoretical background of descriptive logic.

Categories help to link Wiki pages with more general terms and group them, and semantic properties allow defining various semantic features and their values of concept linked with some page. Categories and semantic properties of the Wiki pages can be used as classes and object properties of domain ontology, and names of Wiki-pages – as individuals of ontology. Such domain ontology can be built automatically by special functions of Semantic Media Wiki or by special algorithms according to personal needs of users. Unfortunately, there are no logical or semantic restrictions on ontology building in Semantic Media Wiki. Therefore, ontologies provided such possibilities remain the important content of semantic technologies as a source of domain knowledge

In order to support the process of validation of learning outcomes in both formal and non-formal and informal learning, the European Commission has developed a free internet portal for multilingual classifier ESCO (European Skills, Competencies, Qualifications and Occupations – https://ec.europa.eu/esco/portal/home). ESCO that joins the labor markets of the EU member states and allows jobseekers and employers to communicate more effectively with definitions of skills, training and work in all European languages. The main elements of ESCO are professions, skills and qualifications related to the labor, education and training market in the EU (see Figure 1). Current number of these IOs is represented on ESCO Web-site.

Figure 1. ESCO taxonomy of professions and skills

ESCO allows users to determine what knowledge and skills are usually required to work in a particular profession. Important feature of ESCO is orientation on multi-linguistic information. Each ESCO concept is associated with at least one term in all ESCO languages. Thus, ESCO is a source of information on competencies relevant to the labor market in the international dimension, both for the development of higher education standards and for the review of educational programs in higher education, given that professional standards are currently lacking in many professions. ESCO is published as Linked Open Data, and developers can use RDF format. In this work we consider ESCO as source ontology for semantic application that needs in information about structure of skills and competencies. Information from ESCO can be used for creation of IO structure for advisory SAs.

AdvisOnt architecture

The general architecture of AdvisOnt defines relations between main subjects of advisory activities (see Figure 2):

- applicant – person needed in some work in agricultural domain and has a set of relevant competencies and skills;
- employer – person or organization needed in employees for execution of some task or work on some position;
- providers of learning services – organizations that propose various (formal, non-formal and informal) learning means for expansion of personal competencies;
- advisors – experts specialized in agricultural domain of fixer region that can use domain knowledge for refinement

of mutual interests of employers and applicants and provides advising services if applicant qualification needs in additional learning according to employer demands.

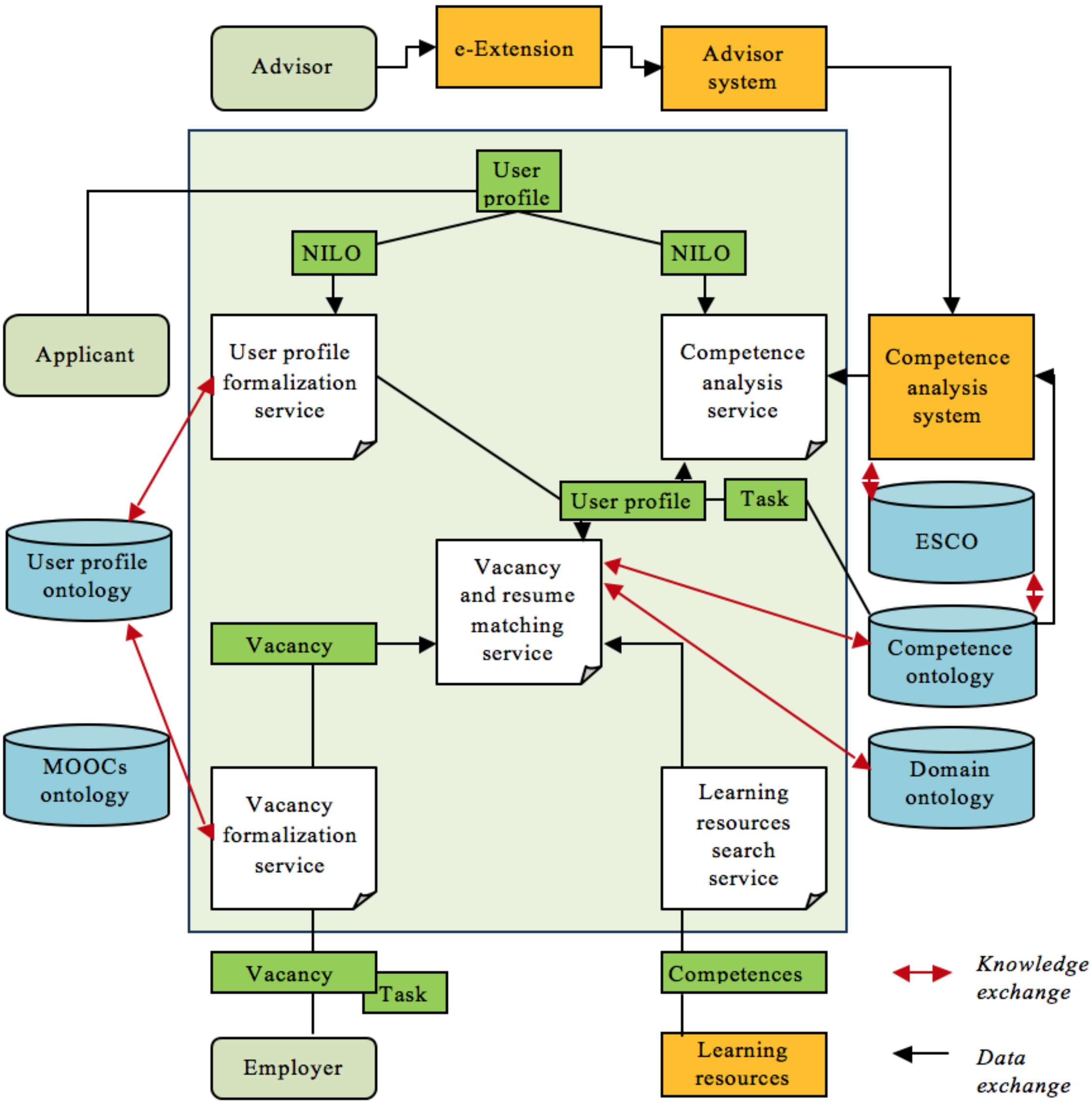

Figure 2. General architecture of AdvisOnt advisory system

AdvisOnt provides the set of traditional advisory services such as:

- user profile formalization;
- generation of formalized resumes;
  - vacancy formalization;
  - matching of resumes and vacancies;
  - matching of resumes and learning courses;
  - recommendation of learning programs.

It is important that all these services can use not only built-in knowledge but support export of domain knowledge from external KBs. AdvisOnt helps in interaction between expert-advisor and other subjects by e-Extension interface and uses external semantic IRs and knowledge bases: ESCO as a source of structured representation of domains competencies and qualifications; user profile ontology to determine the structure of the applicant’s model; domain ontologies containing facts and rules of specific agricultural tasks; expert knowledge and soft skills used for semantic formalization and matching of vacancies and resumes; ontology of open online learning services (such as Massive Open Online Courses (www.mooc.org)).

All classes of ESCO ontology used by AdvisOnt are stored into Turtle file. SPARQL queries and connectors are used for selection of skills and occupations from this RDF repository. The answers of SPARQL queries can be represented as result sets or RDF graphs. In the same way, the results of requests are returned to the RDF repository. Analysis of this ontology is used to define semantic similarity estimates for competence concepts [Rogushina, 2019]. Domain ontologies are integrated into the RDF repository with use of database of semantic graphs GraphDB. This database complies with W3C standards and links data from various IRs, indexes them for semantic search and uses elements of NL analysis. GraphDB connectors provide fast search for keywords and aggregations usually realized by external services with use of synchronization on level of entities defined by URI, properties and property values.

Semantic components of AdvisOnt

We can distinguish such components of SA that AdvisOnt contains:

- external KBs represented by ESCO ontology, MOOC ontology for learning courses, various agriculture domain ontologies and user profile ontologies from other IISs and internal ontology of competencies and qualifications;
- ontological models that formalize structure and features of typical advisory IOs AdvisOnt (competencies, skills and professions, applicants, vacancies and resumes, etc.) that supports system integration with other SAs;
- semantic IRs used by AdvisOnt that contain markup based on structure of typical IOs and provide additional actual information about individuals of classes: semantic Wiki resources that can contain marked NL text and multimedia – such as vue.gov.ua (see Figure 3).

Figure 3. Example of Semantic Wiki resource pages.

External semantic Wiki resources and domain ontologies that are used for their semantic markup provide AdvisOnt by current and dynamic information from open environment and support system adaptation to new tasks.

All these elements are integrated with the help of AdvisOnt ontology that defines relations between main components of advisory process and information sources used in this process. Main class that is used as object property for other AdvisOnt IOs is “Competence” (see Figure 4). is

“Competence” (see Figure 4). AdvisOnt ontology shows the meaning of relations between subjects (employers, tutors, organizations and persons) and objects (competencies, skills, professions, resumes, vacancies) with the help of names and annotations of relevant object properties.

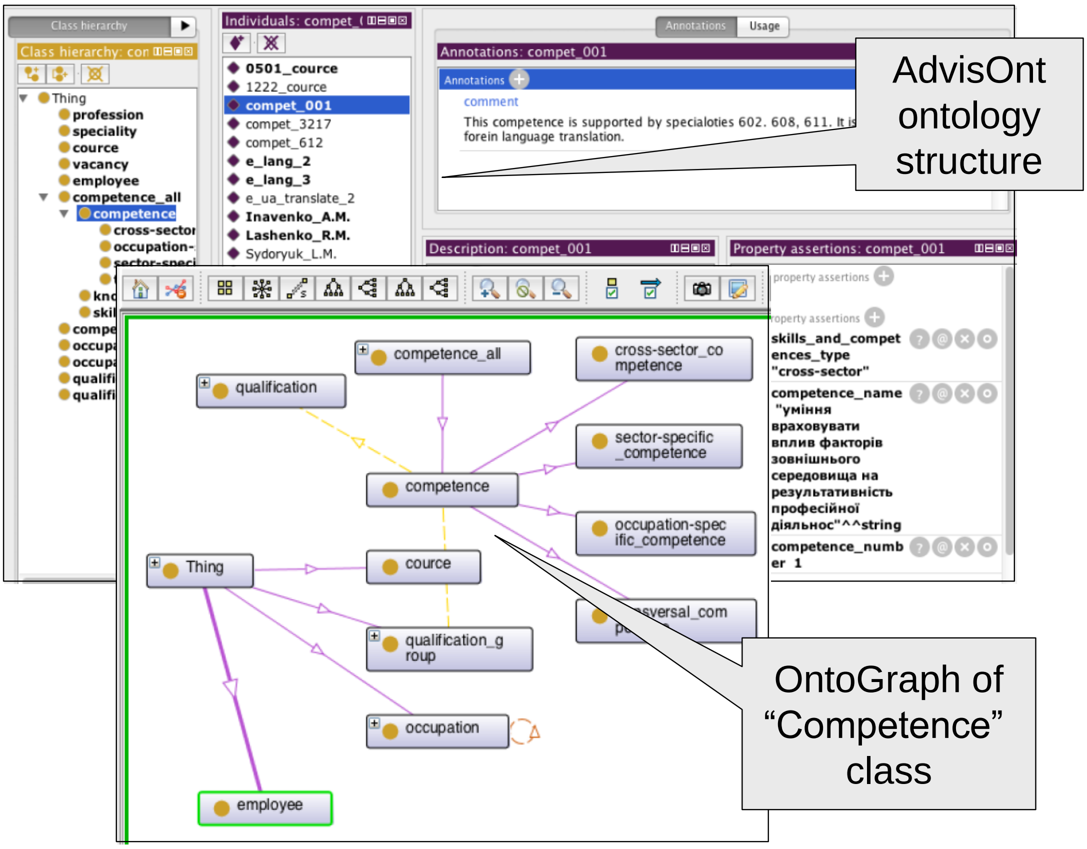

Figure 4. AdvisOnt ontology

AdvisOnt as semantic application

We match characteristics of AdvisOnt and can consider this application as SA (according to SA requirements from Semantic Web Challenge. URL: http://challenge.semanticweb.org/) because it requires the most important SA conditions [Pryima, Strokan et al, 2020]:

- AdvisOnt supports personified interaction for potential employers and job seekers based on use of personal intelligent agents that acquire user preferences from his/her profile;
- registration services for vacancies and resumes transform used terms according to common terminology on base of analysis of their semantic (with the help of NL texts markup bases on ESCO and other domain ontologies);
- comparison of resumes and vacancies is executed with use of semantic similarity evaluations of domain terms and semantic relations between professions, knowledge, skills, competencies and qualifications defined by ESCO ontology;
- search of educational services and training courses is personified on base of analysis of formal, informal and non-formal learning outcomes of person (processing of the informal and non-formal learning results is a specific feature of AdvisOnt that differs this system from similar ones);
- system provides comparison of requires professions from vacancies with training courses and programs that can improve employee competencies for vacancy satisfaction –

on base of ontological model of atomic competencies [Gladun, Khala et al, 2015].

We can rate AdvisOnt as semantic application because this IS conforms to the requirements of the Semantic Web Challenge: Minimum requirements of the Semantic Web application for AdvisOnt can be interpreted like this:

- data meaning plays a key role in its functioning: AdvisOnt process meaning of vacancies and resumes with use of ontologies to link various terms with concepts and realize original non-trivial approach based on atomic competencies for matching of IOs that cannot be obtained without analysis of their semantics;
- AdvisOnt uses ontologies and IRs from different owners (ESCO, MOOCs, etc.) that can be hanged by other ones (for example, by ontology of national qualification system or other e-learning platform) without changes of software, these sources are heterogeneous syntactically (ontologies, Wiki IRs, thesauri, etc.) and semantically (use different NL languages and describe various domains), and contain real-world data used by other commercial applications;
- Search for information is carried out in the real information space of the Web: results of AdvisOnt depend on user requests and actual information retrieved from the Web about vacancies, resumes and learning courses.

AdvisOnt works into the open information space, i.e. recommendations are not absolutely optimal but are based on available data and knowledge of system. This system is based on processing of semantic IRs that are represented on languages developed by the Semantic Web – RDF and OWL.

Conclusion and future work

Semantization of the Web-oriented advisory software needs in specific models of knowledge representation, methods of their processing and integration with up-to-date distributed information technologies. In this research we consider advantages and problems caused by semantic approach to development of applied advisory software.

Results obtained in process of AdvisOnt development show necessity in methods and software tools for automation of semantic markup of the Web information resources (natural language and multimedia) and for retrieval of domain ontologies that can become a meaningful basis for this markup. Other important problem deals with dynamics of information that can be acquired from available data. Therefore we propose to increase the set of traditional advisory services by elements of artificial intelligence and machine learning.

The advisory Web-oriented intelligent system AdvisOnt, developed by us, expands the functionality of traditional advisory systems by validating the results of informal and informal learning, applying ontological representation of domain knowledge and semantization the services proposed to users. An important feature of AdvisOnt is the focus on interoperable knowledge representation formats based on SW standards, which provides the ability to apply new external ontologies without additional changes in the basic architecture of the system.

Semantization of the advisory system requires external sources of information regarding various elements of advisory activity, in particular, repositories of ontologies, electronic encyclopedias and dictionaries, data obtained from social networks. The analysis of information in AdvisOnt performed at the semantic level uses this knowledge to compare the values of various complex IOs and their advanced characteristics (hierarchical relations with other IOs, synonymy, homonymy, semantic similarity of concepts and relations, etc.). Competence classification systems, information about open educational resources, the structure of user profiles and the needs of employers should be obtained from relevant ontologies.

One of the most important tasks of AdvisOnt development is a generation of the theoretical basis for comparison of real and reference competencies, which is included in the analysis of competencies by the apparatus of atomic competencies. Such fixed finite sets of atomic competencies are acquired from NL descriptions of professions, qualifications, vacancies, etc. and various learning courses and disciplines.

Employees obtain a significant part of new knowledge and skills as a result of informal and non-formal learning, and informality of such learning results greatly complicates their analysis and matching with vacancies. Differences in the terminological base and competence classification systems of educational institutions and the requirements of employers require the use of the domain knowledge for their semantic comparison.

We associate the further development of AdvisOnt with algorithms and methods of Data Mining and Machine Learning to solve the problems of classification, clustering and prediction that provide separate policies for semantically similar groups of users.

In addition, we plan to integrate AdvisOnt with social networks, retrieval and recommender systems that can both import information from AdvisOnt user profiles to adapt work of these software to the individual needs of users and export knowledge about users to supplement their profiles in AdvisOnt. Social networks are carriers of Big Data, so we plan to use semantic analysis of metadata to select and filter relevant, reliable data obtained from the external environment and for selection of relevant ontologies in repositories.

The increase and accumulation of knowledge into AdvisOnt on base of the integration with a wide range of national and international knowledge bases and structured information resources ensures the improvement of its services.

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A METHOD OF INCREASING THE ACCURACY OF SEGMENTATION OF A SPEECH SIGNAL BASED ON ITS FRACTAL CHARACTERISTICS

Yana Bielozorova

Abstract: *The paper considers the analysis of approaches to the segmentation of the speech signal into vocalized and not vocalized fragments. The necessity of improving the accuracy of segmentation due to a more accurate description of the process of speech signal representation is shown. A rational method for calculating the fractal dimension to increase the accuracy of the speech signal segmentation process has been determined.*

Keywords: *voice signal, Morlet wavelet, segmentation, special structures, fractal dimension, speaker identification.*

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Introduction

Segmentation of the speech signal can be defined as the process of finding boundaries (with a specific characteristic) in a conversation between words, syllables or phonemes [Al-Mamie et al., 2009, Makowski et al., 2014].

The main purpose of speech signal segmentation is to serve other speech analysis problems, such as speech signal synthesis, training data for speech signal recognition, identification of vocalized fragments for person identification or for the production and labeling of speech databases. With this, speech signal segmentation is an important subtask for various fields of speech analysis.

Related works

The traditional approach to solving this problem consists in manual segmentation of the speech signal, which is most often performed by specialized phoneticians. However, this method is based on listening to fragments and creating a judgment due to visual images of various characteristics of the speech signal, which makes it quite time-consuming, but highly accurate compared to the methods of automatic segmentation of the speech signal [Chefir et al., 2001].

Speech recognition systems require the decomposition of the speech signal into some basic units such as words, phonemes or syllables. The word is the most natural unit of segmentation, it is more likely to carry the characteristics of a person in contrast to phonemes or syllables. That is why, identification of a person by listening to individual phonemes or syllables has not found opportunities for use at the present time [Sharma et al., 1996].

Phonemes are the smallest segmental unit of sound used to form meaning. The same phoneme in different words has a different meaning. There is an overgeneralization of phonemes. So the mixture of phoneme and word gives rise to the next level of the basic unit of language, which is called syllables [Van Hemert, 1991].

The realization of a phoneme is strongly influenced by neighboring phonemes. Phonemes are very context dependent. Consequently, the acoustic variability of basic phonetic units due to context is extremely large and poorly understood in many languages [Lee et al., 2003].

Strategies for automatic speech signal segmentation can be grouped by different perspectives, but one common classification is the division into blind and self-segmentation methods.

1. Blind segmentation. This type of segmentation does not have prior knowledge of linguistic characteristics (spelling, full phonemic notation of a character or its fragment). In order, to solve problems of this kind, methods are used that are based on static analysis and do not require complete knowledge of the audio material. The method of blind segmentation is carried out in 2 stages. The first stage depends entirely on the acoustic properties of the voice signal, while the second stage (or, as it is also called, bottom-up signal processing) focuses on determining the parameters of voice perception, often using MFCC, LP or MFP [SaiJayram et al., 2002].

2. Self-segmentation. This type of segmentation refers to the so-called auxiliary methods. The idea of the method is that during operation it uses only some part of the external data of the voice signal to divide the signal into certain segments. Self-segmentation can include recognition with dynamic time transformation (DTW), or artificial neural networks (ANN), or with hidden Markov models (HMM) [Tanqueiro, 2017], [Toledano et al., 2003], [Mporas et al., 2008], [Go´mez et al., 2011], [Siniscalchi et al., 2007]. The method of self-segmentation by hidden Markov models (HMM) has been widely used in voice recognition. This method has successfully

supplanted other techniques due to the low computational complexity and high recognition speed.

Table 1. Existing methods of speech signal segmentation

Researchers	The essence of the segmentation method	Segmentation accuracy
The use of wavelet - analysis		
B. Zio´łko, S. Manandhar, R. C. Wilson, and M. Zio´ łko [Zio´łko et al., 2006].	The speech signal was segmented due to the selection of phonemes	High efficiency
S. Ratsameewichai, N. Theera-Umpon, J. Vilasdechanon, S. Ua-trongjit, and K. Likit-Anurucks [Ratsameewichai et al., 2002].	Divided the speech signal into components (low-frequency and high-frequency), and further worked within the limits of words or phonemes	Accuracy of 96.0%, 89.9%, 92.7% and 98.9% for initial consonants, vowels, final consonants and silences respectively

M. Tolba, T. Nazmy, A. Abdelhamid, and M. Gadallah [Tolba et al., 2005].	Segmentation is focused on finding boundaries between consonant and vowel parts of the speech signal	Segmentation accuracy is about 88.3%
Artificial neural nets		
Y. Suh and Y. Lee [Suh et al., 1996].	Proposed the technique of using the phoneme segmentation method using a multilayer perceptron	84% accuracy was obtained for 5 ms and 87% accuracy for 15 ms speech signal
Black area blocking method		
M.M. Rahman, F. Khatun, and M. A.-A. Bhuiyan [Rahman et al., 2015].	Proposed an automatic segmentation method with a dynamic threshold	Average accuracy 90.58%
The method of changing short-term energy		

E. A. Kaur and E. T. Singh [Kaur et al., 2010].	Used short-term energy to segment the speech signal into pauses, words and syllables	The proposed method was implemented and analyzed for speech signals of different languages
Hybrid method of speech signal segmentation		
M. Kalamani, S. Valarmathy, and S. Anitha [Kalamani et al., 2017].	Segmented the speech signal by detecting speech boundaries (using the method of threshold values)	Segmentation accuracy 95.33%
Markov models		
P. Bansal, A. Pradhan, A. Goyal, A. Sharma, and M. Arora [Bansal et al., 2014].	proposed phonetic segmentation and speech analysis at the phonetic level	Segmentation accuracy 78,14%
J. Dines, S. Sridharan, and M. Moody [Dines et al., 2002].	They proposed segmentation based on learning strategies	Segmentation accuracy 95,4%

A. Stolcke, N. Ryant, V. Mitra, J. Yuan, W. Wang, and M. Liberman [Stolcke et al., 2014].	Segmentation based on statistical models for boundary correction (due to additional information about the structure of the speech signal)	Segmentation accuracy from 93.9% to 96.8% (intervals of 20 ms were analyzed)

Taking into account the performed review of speech signal segmentation methods, it can be concluded that there are a number of limitations of these methods and "floating" characteristics of segmentation accuracy, which poses the task of developing a method of its segmentation based on speech signal analysis methods.

Materials and methods

According to existing studies, the process of forming a speech signal is a process which constant oscillation of individual parts of the speech tract. Given the fact that these parts practically do not change during speech, self-similar or multifractal structures are formed in the speech signal. Thus, at the beginning of the speech, we will observe sharp changes describing the fractality of the speech signal. To develop a speech signal segmentation method, it is necessary to evaluate the variability of these characteristics during the transition from speech to pauses and make a decision about the possibility of their use. We will use the fractal dimension as a fractal characteristic that allows us to describe the characteristics of a speech signal of this type.

There are many methods of calculating fractal dimension. For use in linguistic information identification tasks, it is necessary to evaluate these methods and choose a rational approach for their calculation. Let's consider each of them in more detail.

The Yard Stick Method. First, a fixed window size is selected r, which divides the speech signal into fragments covering its profile. Thus, the signal will be represented as $N(r)$. When calculating the fractal dimension by this method for each fragment n the length of the curve is calculated L_i, and everyone r_i is matched with the obtained length. The obtained series (r_i, L_i) is built on a logarithmic scale for both coordinates, and the line is fitted to the graph using the method of least squares. Based on the resulting graph, the fractal dimension is calculated, as $D = 1 - \alpha$, where α - regression coefficient.

The Hausdorff method. The method is based on covering the signal profile with square grids. When the grid width r the number of grid elements changes $N(r)$ will change too. Relations between $N(r)$ and r are presented as: $N(r) = kr^{-D}$. Given that the width of the square grid will be $r_1, r_2, r_3, \dots, r_k$, the number of elements will be accordingly $N(r_1), N(r_2), N(r_3), \dots, N(r)$. Calculation of the fractal dimension according to this method is performed as follows. A graph of the obtained series is constructed $(r_i, N(r_i))$ on a logarithmic scale for both coordinates, and a linear regression method is used for data analysis. As a result, we get the regression coefficient α. The fractal dimension is calculated as $D = -\alpha$.

The variational method. For calculation using this method, the profile is covered with rectangles with width r. For each rectangle, a reference point is selected and the deviation is calculated H_i between the highest and the lowest position. If the width r very small, H_i approximately equal to the length of the curve $V(r)$. Thus, the measure is equal to $V(r) =$

$\sum \frac{rH_i}{r^2} = \sum H_i/r$. A graph of the obtained series is constructed $(r_i, V(r_i))$ on a logarithmic scale for both coordinates and a linear fit is performed. The fractal dimension is calculated as $D = 2 - \alpha$, where α - the slope of the obtained function.

The method of structural function. The structure function method is also called the augmentation approach. The profile is considered as a sequence of height function $z(x)$. For any two points from a distance r in sequence $z(x)$ the function of the structure is determined $S(r)$, which is the arithmetic mean of the square of the height difference. Relationships between sequences $z(x)$ and structure function $S(r)$: $S(r) = E[z(x + r) -$ $zx2=cr4-2D$, where r called the interval scale. When calculating the fractal dimension, different scales are chosen r, and function values are obtained $S(r)$. and function values are obtained $(r_i, S(r_i))$ on a logarithmic scale for both coordinates. The fractal dimension is calculated as $D = 2 -$ α /2, where α - the slope of the obtained function.

The root mean square method. The basic principle is similar to the structural function method. The study showed that the scale function ratio $z(x)$ the following formula corresponds to fractal characteristics

$$z(x) - z(x_0) = \zeta |x - x_0|^{2-D} \# \quad (1)$$

Let $x_0 = 0$ to $z(0) = 0$, We can then calculate the variance or correlation moment of the function sequence $z(x)$

$$S(r) = D(r)^{1/2} = cr^{2-D} \# \quad (2)$$

where r is an interval scale, and $r = x - x_0 = x$. Equation (2) shows that the relationship between the correlation moment $S(r)$ and interval scale r is the power exponent, and the power is a function of the fractal dimension. Fractal dimensionality is calculated as follows for each interval scale $r_i (i = 1,2, \dots, n)$. The dispersion is calculated $S(r)$. A graph of the obtained series is constructed $(r_i, S(r_i))$ on a logarithmic scale for both coordinates. The fractal dimension is calculated as $D = 2 - \alpha$, where α is the slope of the line.

The Hurst method. For the height function $z(x)$, at a given scale r, the average value is calculated in the form: $\overline{z_r} = \frac{1}{r}\sum_{x=0}^{r} z(x)$, cumulative deviation: $z(x,r) = \sum_{x=0}^{r}[z(x) - \overline{z_r}]$, maximum difference $R(x) = \max_{0 \le x \le r} z(x,r) - \min_{0 \le x \le r} z(x,r)$, and standard deviation $S(r) = \sqrt{\frac{1}{r}\sum_{x=0}^{r}[z(x) - \overline{z_r}]^2}$. Hurst's research found that a statistical law R/S is equal to

$$R/S = cr^H \# \quad (3)$$

where, c it is constant, H its Hurst index. Taking the logarithm on both sides of equation (3), we get

$$\ln(R/S) = \ln(c) + H * \ln(r) \# \quad (4)$$

After determining the maximum difference $R(r)$ and standard deviation $S(r)$ with different scale r, on the basis of equation (4), the Hurst index H can be calculated using the method of least squares. Calculation of fractal dimension has the form: $D = 2 - H$.

The Higuchi method. The original formulation of the calculation method is explained by Higuchi in [Sapozhkov, 1963]. Higuchi fractal dimension (HFD) with X is calculated as follows: For each $r \in \{1, \ldots, r_{max}\}$ and $m \in \{1, \ldots, r\}$ the length is determined $L_m(r)$ on

$$L_m(r) = \frac{N-1}{\left[\frac{N-m}{k}\right] r^2} \sum_{i=1}^{\left[\frac{N-m}{r}\right]} \left| X_N(m+ir) - X_N\big(m+(i-1)\big)r \right| \# \qquad (5)$$

Length $L(r)$ is determined by the average value r length $L(r) = \frac{1}{r}\sum_{m=1}^{r} L_m(r)$. The slope of the best-fit linear function through the data points $\left\{\left(\log\frac{1}{r}, \log L(r)\right)\right\}$ is defined as the Higuchi fractal dimension.

Experiments

Let's determine which of the fractal dimension calculation methods is the best for estimating the fractal dimension of the speech signal. 2 test speech signals, presented in Figure 1, were used for preliminary adjustment of the methods. Moreover, Fig. 1a) is a vocalized fragment, and Fig. 1b) is a not vocalized fragment or pause.

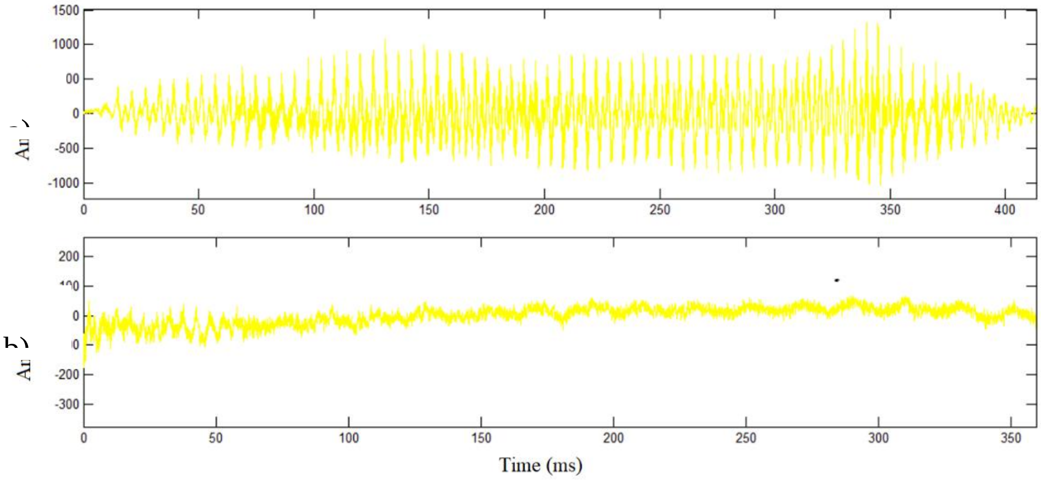

Figure 1: Test speech signals a) vocalized fragment, b) not vocalized fragment

For the calculation of each of the options, a rational value of the indicator was selected r – it is chosen in such a way as to ensure the level of significance of the correlation coefficient 0.03. This was achieved by changing the indicator r with a step of 0.1 and calculating the value of the fractal dimension of the corresponding method $D(r)$, taking into account the coverage of the speech signal curve according to the established indicator of the correlation coefficient.

The results of calculating the fractal dimension by each of the methods presented above are given in Table 2.

Table 2. Comparison of fractal dimension calculation methods for speech signal (shown in Figure 1)

The method of calculating the fractal dimension	Vocalized fragment		Not vocalized fragment	
	Fractal dimension	Correlation coefficient	Fractal dimension	Correlation coefficient
The Higuchi method	1.75	0.995	1.221	0.981
The Hurst method	1.72	0.968	1.181	0.979
The root mean square method	1.657	0.979	1.119	0.982
The method of structural function	1.701	0.997	1.199	0.998
The Yard Stick Method	1.422	0.993	1.011	0.992
The variational method	1.353	0.996	1.154	0.999
The Hausdorff method	1.68	0.998	1.197	0.995

Previous studies for test fragments of speech and pauses showed poor correlation indicators when calculating the fractal dimension using the Higuchi, Hurst and root mean square methods, the highest correlation indicators are provided when using the structural function method and the Hausdorff method.

The next stage of the research was to analyze the performance of the methods for a larger set of test data with settings according to the test fragments. 300 prepared vocalized and non-vocalized fragments were used in the study. The results of the study are presented in figure 2.

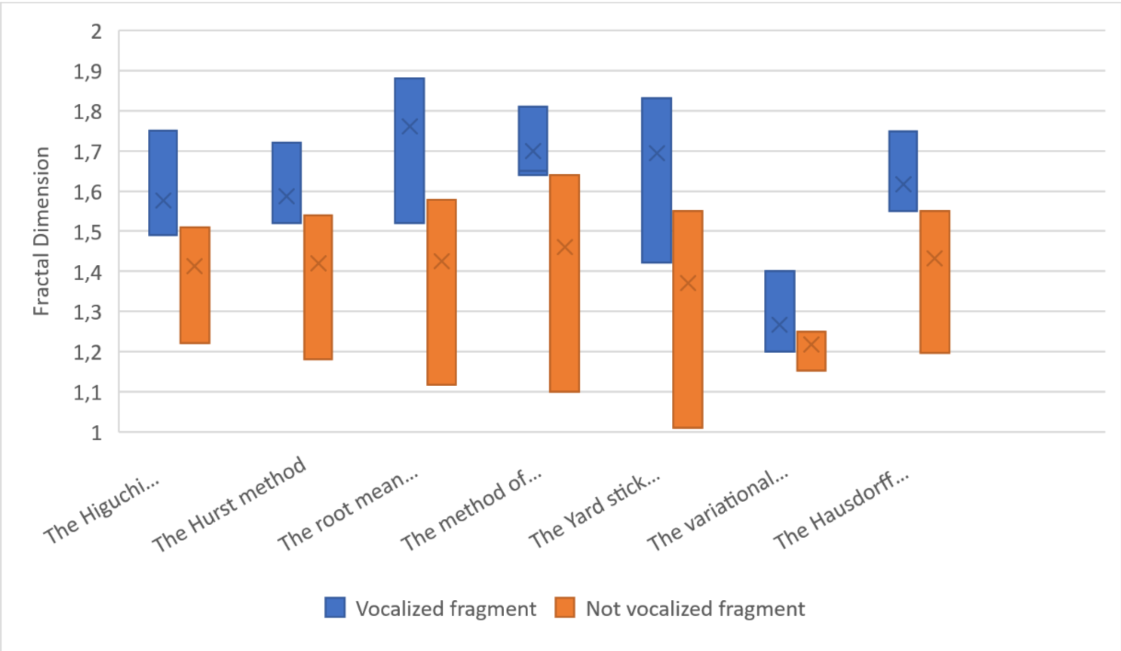

Figure 2: Comparison of fractal dimensionality calculation methods for fragments of the speech signal

Based on the analysis of the results, it can be concluded that the Hausdorff and structural function methods are the most suitable for use in speech signal segmentation, because they provide a smaller overlap of the fractal dimension ranges for vocalized and non-vocalized fragments, the variational method cannot be considered in the tasks of segmentation in communication due to the small range of variation of the fractal dimension under the given conditions, the "Yard Stick" and mean square methods have a wide range of overlapping values of the fractal dimension, which will lead to a decrease in the accuracy of segmentation when using these methods. Higuchi and R/S analysis methods can be satisfactorily used for speech signal segmentation, but their quality will be significantly lower than that of Hausdorff and structural function methods.

In summary, the Hausdorff and structure function methods are more suitable for computing the fractal dimension in the speech signal segmentation task. Given the higher computational complexity of the structural function method for speech signal segmentation, we choose the Hausdorff fractal dimensionality calculation method.

Results

To study speech signals and approximate the graphs of time series of sound wave amplitudes by certain sums (cell-type breakdowns), we turn to the Hausdorff dimension. The Hausdorff fractal dimension Dx is defined as follows

$$S(p) \sim p^{2-Dx} \text{ at } p \to 0\# \quad (6)$$

where $S(p)$ - the full area of the complex, with the scale of division p.

From a practical point of view, when trying to calculate Dx on the basis of (6), a number of problems arise. This is due to the fact that real time series will always have a minimum scale p_0 and at the same time, the transition to the asymptotic representation in (6) is quite slow.

Unlike the conventional time series considered in most signal processing tasks, speech signals have significant differences. One of the main differences is that the amplitude of a sound wave is well described as a sum of harmonic oscillations (both from a physical and mathematical point of view). This approach allows you to significantly reduce the number of readings, which are necessary to conduct a real analysis of fractal dimension.

The next, important point is the possibility of evaluations in a number of tasks of language technologies of the order of the minimum fractal scale. Based on previously conducted research, it is known that all important speech information is contained in a certain frequency range, namely up to 4500 Hz, thanks to which it is possible to perform a qualitative assessment of minimally rational fractal scales of speech fragments.

As an example, consider a speech signal with a sampling frequency of F_s and a bit rate of r bits. This means that F_s is in the range of 8000 Hz to 44100 Hz and r is in the range of 8 to 24 bits. Therefore, in order to systematically cover the graph of the investigated sound wave, it is necessary to use some minimum values similar to the size of the rectangle $a * b$. Where a will be defined as the minimum possible change in the amplitude of the sound wave for a specific bit rate of the sound file. As an example, for an 8-bit sound file, $a = 2/256$. This means that all sound files are converted to wav. format, which means that the amplitude value is considered in the range from -1 to +1 and is represented as a floating-point number. For the general case

$$a = 2/2^r \# \quad (7)$$

The minimum value of the side of the rectangle for the time axis b_0 will be equal to $1/Fs$. And since the size is not essential for this case, we will take the minimum size $b_0 = 1$. We use the following method of calculating the fractal dimension according to Hausdorff: each time window of the speech signal will be represented as a set of rectangles of size $a \times b$ covering the graphic representation of speech signal. Let the representation scale :

$$p = k \cdot b \# \quad (8)$$

where $k = 1,2,3, \ldots$ is the representation scale factor.

It is known that the calculation of the fractal dimension according to Hausdorff is performed as

$$D = 2 - \lim\left[\ln\left(N(p)\right)/\ln(p)\right] \# \quad (9)$$

where $\ln\left(N(p)\right)$ is the natural logarithm of the scale-dependent representation of the number of rectangles $N(p)$, which include at least one value of the amplitude of the speech signal, $\ln(p)$ is the natural logarithm of the scale of the representation.

We determine the fractal dimension D on the basis of [Soloviov, Bielozorova, 2013, Zybin, Bielozorova, 2020]

$$D = 2 - Dx \# \quad (10)$$

Depending on the sampling frequency, this time interval corresponds to the number of counts $N = F_s * 2/100$.

Let's introduce the minimum fractal scale $k \geq 3$. After numerous studies of different fragments on different audio files, the value of the fractal dimension was estimated, which showed a large variability of the value of Dx at minimum values of $k \geq 2$. Along with this, the value of the fractal dimensionality estimate will change slightly within some time intervals of 20ms.

For a specific realization of the time window of the pause of the audio file, we will change the scale. To do this, we will plot the graph of the dependence $\ln\big(N(p)\big) = f(\ln(p))$. The next step, after constructing the graph, is to approximate the first points of the graph using a linear relationship

$$f = c * \ln(p) + c_0 \# \quad (11)$$

where c, c_0 are approximation coefficients.

Previous studies have shown the need to approximate the first few points of the speech signal, so the size of the approximation of 10 points was adopted, which will be adjusted during a more detailed study.

Within the framework of this method, the value is equal to Dx

$$Dx = abs(c)\# \quad (12)$$

It should also be noted that when calculating the fractal dimension based on the method described above, using the minimum fractal scale $k = 1$, the values of the fractal dimension differ significantly. So, in the proposed method of estimating the fractal dimension based on Hausdorff, its calculated value does not correspond to the definition of Hausdorff dimension. But, after numerous studies of sound files based on a modified approach, the effectiveness of using parameter (11) in language technology tasks was proven.

The calculation of the fractal dimension made it possible to construct figure 3, which shows the value of D - the fractal dimension for a fragment of a speech signal for the entire time window.

An overview of the graph shows a sufficiently high level of tracking the fractal dimension of the change in the amplitude values of the speech signal, which can be used for segmentation of the speech signal.

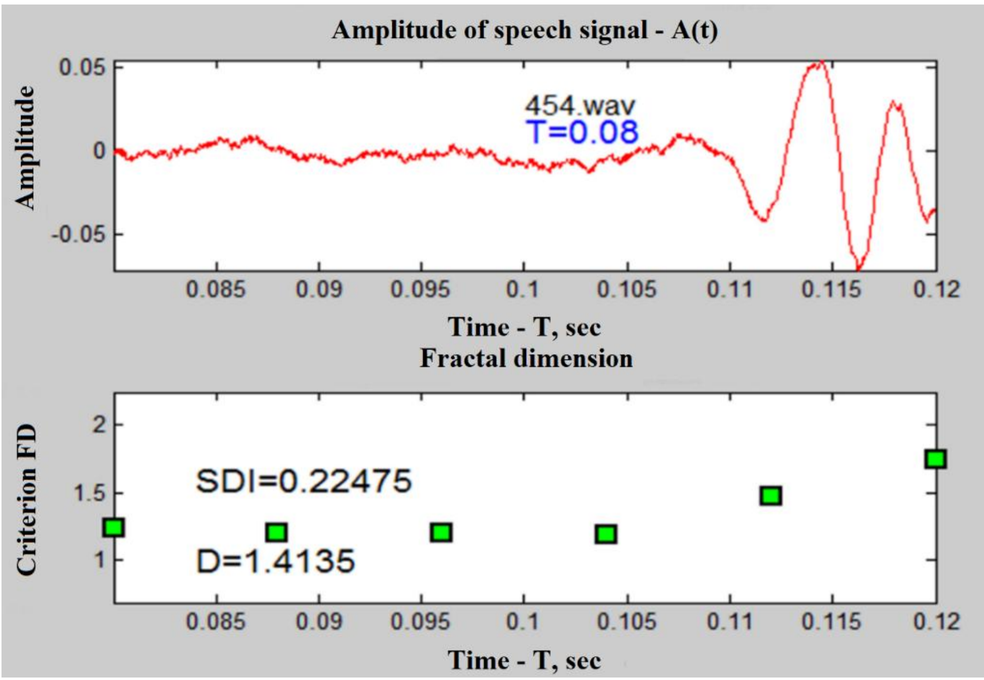

Figure 3: Fractal dimension during the transition from pause to speech

On the basis of the performed research, the following method of speech signal segmentation using fractal dimension is proposed.

1. division into time frames;
2. preliminary approximation of the speech signal (dependency 11);
3. determination of the fractal dimension with a given time window in each time fragment (dependency 10);
4. distribution of time fragments into vocalized and non-vocalized fragments according to the established threshold of the fractal dimension.

The proposed method for calculating the fractal dimension can be used in many areas of speech signal analysis. As an example, consider the use of the proposed method in the task of speech segmentation. Given the structural complexity of the task, the following research methodology was proposed (Figure 4).

When conducting a study of the effectiveness of segmentation, the following were chosen as the signs of making the decision "vocalized/non-vocalized fragment":

1. root mean square deviation of the fractal dimension;

2. range of time window sizes.

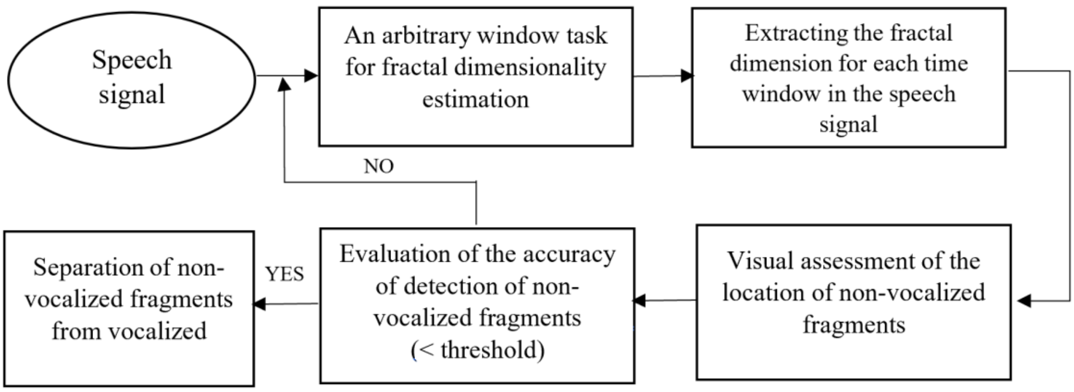

Figure 4: Methodology of speech signal segmentation studies

Given the dependence of the fractal dimension on the size of the window, at the next stage, we set an arbitrary value of the window to estimate the fractal dimension. At the next stage, we calculate the fractal dimension for each window in the speech signal. Next, the speech signal is divided into pauses and speech fragments (visually). The subjectivity of the method of dividing pauses and fragments of speech at this stage of research should not have a significant impact on the following conclusions and results, given the significant differences in the fractal dimension of pauses and fragments of speech.

To carry out a comparative analysis of speech signal segmentation methods, the following methods were implemented: frame-by-frame; singular; deviation from the average; black area blocking; analysis of the spectral shape and the own method proposed in paper. The study involved 50 people (men and women with different linguistic backgrounds) who pronounced the same set of words. In the created test set, automatic marking of vocalized fragments and pauses was performed. When the comparison was made, all methods used their standard settings recommended by the developers. Each method performed segmentation of the marked speech signal, when the marking and the decision of the segmentation method coincided, the value 0 or 1 was set for each observed fragment of this method. When determining errors of the 1st and 2nd kind, an analysis was performed and a summary of the correspondence of the values of the previous marking 0 and 1, set by each method segmentation relative to the total number of pauses and vocalized fragments. The results of the study are presented in table 4.

Thus, in terms of effectiveness, the developed speech signal segmentation method performs its functions better, and can be recommended for use in the speech analyzing systems.

Table 4. The results of the study of the effectiveness of speech signal segmentation methods

Method	Error of the 1st kind	Error of the 2st kind
Frame by frame	0,177	0,1
Singular	0,133	0,1
Deviation from the average	0,180	0,17
Blocking of the black area	0,156	0,11
Analysis of the spectral form	0,141	0,1
The proposed method	0,108	0,1

Conclusion

The conducted review of speech signal segmentation methods showed a number of limitations of these methods and "floating" characteristics of segmentation accuracy, which requires analysis and development of a speech signal segmentation method. It was determined that the similarity of structures in the speech signal is possible due to their scaling. Considering this, it is shown that fractal and wavelet analysis can be the main approaches in the problem of speech signal identification. A comparative analysis of methods for calculating the fractal dimension was performed and it was determined that for the task of segmenting the speech signal into vocalized and non-vocalized fragments, the method of calculating the fractal dimension according to Hausdorff is the most effective, on the basis of which the method of segmentation of the speech signal is proposed. As a result of the research conducted on the basis of the proposed method of segmentation of the speech signal, as well as the modified assessment of the fractal dimension of fragments of speech signals, stable characteristics of the increase in the value of the modified fractal dimension for fragments of speech signals containing speech were established. The fractal dimension for pauses in 99% was within $1{,}04 \leq D \leq 1{,}45$, and the fractal dimension of speech fragments was not observed less than $D = 1{,}55$ for a time frame of 20 ms.

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ABOUT THE ORGANIZATION OF REGIONAL SITUATIONAL CENTERS OF THE INTELLECTUAL SYSTEM "CONTROL_TEE" WITH THE USE OF UAVS

Julia Pisarenko, Alexander Koval, Kateryna Melkumian, Alexander Kryachek, Olga Gavrilyuk,

Abstract: *The basics of the principles of creation and filling of the technopark of unmanned aerial vehicles (UAV) are offered. The business process of UAV registration in the technopark of the situation center robots is described. The use of attributes (tags) to the UAV will increase the efficiency of a suitable device selection with a complete set that meets the task. It is proposed to organize regional situational centers, which will coordinate the work of state systems, urban life support systems, private services on the one hand and UAV on the other as executors. At this time, principles and methods of automatic selection of UAVs are being developed for the prompt solution of the given task. The system should be based on the classification of the UAV during registration and on the basis of the UAV compliance function to the specific task, key features of the UAV, the time required to complete the task, the distance to the task and the policy to involve the UAV in such tasks to select those devices, who can quickly perform tasks. The function of classification of a specific UAV by tasks is offered. The function takes into account the configuration of the UAV. For each task, experts and automation select weights that indicate how large the impact of certain typical modules to perform a particular task, and for each UAV in the database stores information about whether the UAV takes into account a certain characteristic, or there is a* *corresponding module. To update the approach to professional training today, one of the main tasks is to create interactive mock-up training systems in real physical space. The principles of building a basic laboratory stand, its equipment and the control system of a mobile modular robot, which helps to master the basic functions of a UAV or mobile operation of a ground base, are under development.*

***Keywords**: UAV, situational center, traffic control, professional education.*

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Introduction

Obviously, the city of the future is a smart city, a city that in real time controls most of the processes that take place in its bowels automatically and does it optimally, a city where security is raised to a whole new level, and access to information, the benefits of civilization, city services, any necessary human things as simple as possible. And how will this city regulate the work of rapidly developing UAVs at the moment? After all, it is obvious that with the increase in the number of UAVs, if they begin to take over the routine functions of employees, we need a management system that will ensure safety and minimal accidents, regulate their movement, pave special air routes, simplify UAVs, standardize them, harmoniously integrates UAVs into the structure of the city, puts them at the service of the common good.

Formulation of the problem

Existing issues:

– the need to certify the movement of UAVs [1] in order to regulate it and prevent unauthorized actions. As a result, it is necessary to build air routes with the formalization of their purpose, taking into account the adaptive management of traffic dynamics;

- the ability to automatically switch remote control in case of emergency: loss of signal from the UAV at the base [2], the actual transfer of UAV data about its pre-emergency condition, UAV interception, interference / protocol breakage, radio weather interference;
- automated data collection [3] in the monitoring process for learning neural networks and after gaining new knowledge for further forecasting, passive collection of information for specific purposes;
- selection of the communication channel and data transmission protocol between the triad "ground station information storage" + "UAV board" + "decision maker".

Topicality

Let's take a closer look at the issues that we are already slowly facing in the use of UAVs. There is no need for long explanations of the fact that an unmanned vehicle equipped with a good camera and image transmission equipment hanging in front of someone's room is both bad and illegal, that an unmanned carrier with a heavy parcel on board should probably not carry it over kindergarten or over crowds, because in the event of an accident, its consequences can be very serious. Therefore, UAVs in the transition to their widespread use require mandatory regulation of their movement, certification, accurate construction of routes and informing them about the services of a smart city in real time. Certified UAVs are likely to be able to quickly transfer control to a specialist or automated city system to deal with a variety of emergencies and assist city services. UAVs that are constantly scurrying here and there are likely to have to do some useful things for the city, directly serve the common good, such as passively or actively collecting data for monitoring, looking for people, garbage, something unusual that needs intervention, find something which can be difficult to find with conventional stationary cameras, to provide communication. And in fact, it would be strange not to use the capabilities of flying cameras that capture the city from new angles. The use of communication channels for UAV control, various protocols, special software must be clearly regulated, the components of a smart city must work as a coherent mechanism and not interfere with each other.

To ensure the solution of the described requirements, the authors of the study propose to create a network of regional situational centers (RSC), and, in fact, ground stations covering a certain area, which provide comprehensive control of UAV traffic. These stations should be subordinated to the Central Situation Center (CSC), which will house the decision-making center [4] and the main information repository.

Figure 1 shows an illustration of the interaction of the UAV, the central situational center and the regional situational center.

The central situational center receives all information about the movement of UAVs in the city from the regional situational centers, it receives all requests for UAVs to perform certain actions via the Internet, this information is processed and decisions are made here, and all services necessary for communication are deployed here.

Regional situational centers (RSC), located in the protected perimeter, at the same time directly conduct radio exchange with UAVs in their area of operation, manage their area according to the general plan dictated by the CSC, perform all necessary calculations, store temporary information and have functionality for fully autonomous traffic control and execution of requests in the event of termination of communication with the CSC.

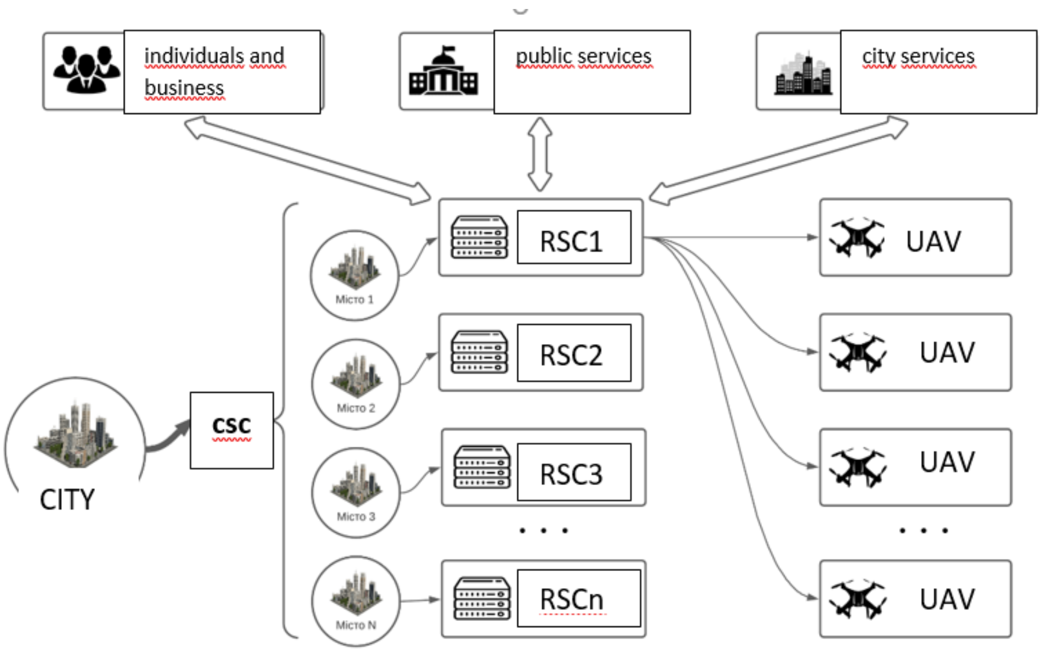

Fig. 1. The interaction structure of the UAV, the central situational center and the regional situational center

Thus, the UAV, flying through the city, is always in the coverage area of one or more RSCs controlling its movement, and thanks to the work of the CSC, it can be guided according to a single plan. A diagram of the interaction between the parts of the described system (the system itself, the UAV, various stakeholders) has been developed. Thus, the state, smart city services, private individuals and businesses turn to the RSC, directly to the CSC, with any requests and tasks they need, and the RSC gives answers, coordinates, controls, manages and selects a specific executor, if necessary.

Tracking information to be transmitted to the RSC:

1) Own coordinates transmitted on request or at certain intervals to build the exact path flown by the UAV

2) Displays the battery charge level and the rate of its consumption at each point of the route. Or similar information, which can be used to judge the time the UAV is in the air, to make predictions.

3) Displays of the main on-board instruments installed on the UAV - altimeter, accelerometer, gyroscope tied to coordinates. That is, at what height it was, where it was turned and how it moved at each point.

4) Information about the operation of the UAV manipulator or autonomous loading/unloading system.

5) The shooting vector of all the cameras installed on the UAV.

6) Information about the use of certain additional modules installed on a specific UAV.

7) Information about what is currently available to the user, what he sees, if the UAV is not flying in automatic mode, but under his control.

8) Information about the commands given by the user when the UAV is flying under his control.

9) Similar information about sound recording

10) Streaming video and photos from cameras. At intervals/on demand/continuously.

11) General information about the flight (start time, type of movement, type of mission, destination, who is the owner, Id of the UAV in the system, etc.).

Information that the RSC must transmit to the UAV:

1) Current map of air routes and zones above the city on request.

2) The optimal flight route on air routes (specific coordinates, speed limits, etc.).

3) Information in the dynamics about the presence of other UAVs in the vicinity, speed and vectors of their movement.

4) Information about a possible collision and commands/recommendations on how to avoid.

5) The command to intercept the control and the command of this control itself (and it is possible, taking into account how a person previously controlled this particular UAV, with some optimal control strategy for this model. The data transmitted from the UAV to the RSC precisely allows such a strategy to be developed).

6) Various text, audio, photo, video messages for the case when the UAV is controlled by a person. And with the ability to transmit the coordinates of the message in space, three-dimensional objects to create the effect of augmented reality.

7) Photos and video streams that have been post-processed to replace what the UAV cameras show (for example, looking out the windows and suddenly seeing a blurry picture...)

8) Corrective information about the flight (for example, clarification of coordinates based on express analysis of images from cameras).

9) General information about the flight, UAV, weather, etc.

In order to register a UAV with the RSC, information about it is required. An approximate list of it is given below.

1) The characteristics are related to the form of ownership, owner, type of UAV and other formalities.

2) Complete weight and size properties.

3) Full flight characteristics (speed, maneuverability, etc.).

4) Full battery and power consumption specs.

5) Characteristics of sound and photo-video recording devices.

6) Characteristics of manipulators and cargo unloading systems.

7) Characteristics of the UAV control device and modules providing communication.

8) Characteristics of the sensors installed on the UAV.

9) Characteristics of the software installed on the UAV, its autonomous flight capabilities.

Figure 2 shows a prototype of the interface of the described system (the program client part)

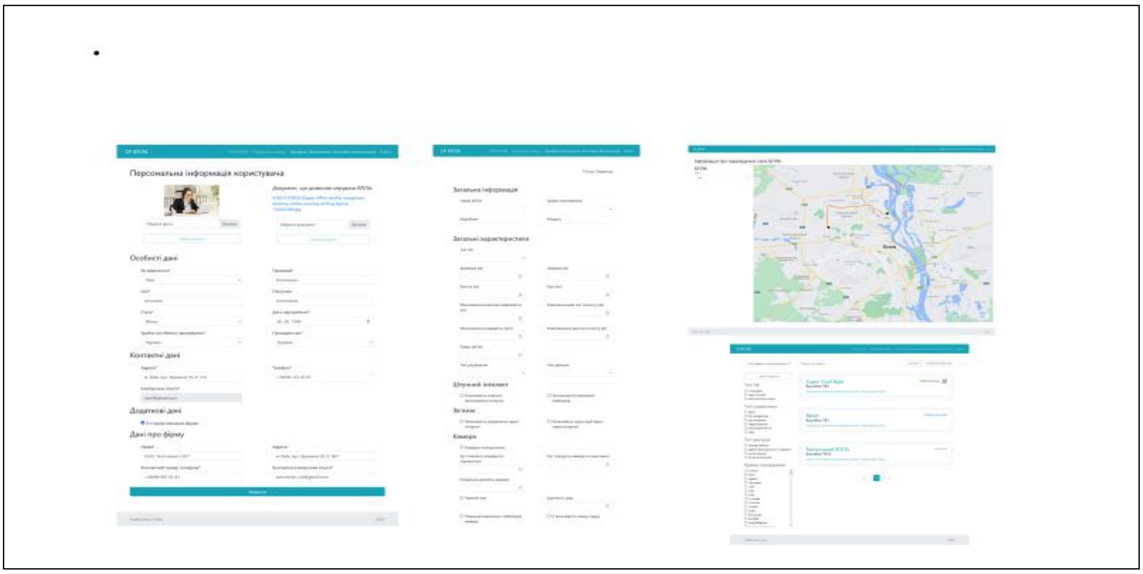

Fig. 2 The prototype of the described system interface

Laboratory stand:

At the moment, the authors are working on promoting the professional training of future UAV operators [5,6].

To update the approach to professional training today, one of the main tasks is to create interactive mock-up training systems in real physical space. The principles of building a basic laboratory stand, its equipment and the control system of a mobile modular robot, which helps to master the basic functions of a UAV or mobile operation of a ground base, are under development.

Fig. 3, 4. Working moments of training teenagers - future UAV management specialists and designers of robotic devices on courses initiated by scientists from the National Technical University of Ukraine "Ihor Sikorsky Kyiv Polytechnic Institute"

The creation of such educational complexes is preceded by the development of models and methods for solving the tasks of 4D surveying of the location by a mobile robot and synthesis of information, which bring the educational complexes as close as possible to real installations, ensure the unification of disparate audiovisual information, and allow system users to acquire correct and stable skills [6]. The charter of the sports federation of unmanned aviation of the sports and engineering direction has been developed. Relevant proposals were submitted to the draft Decision of the Verkhovna Rada of Ukraine on the state of readiness of the education system to counter and overcome real and potential threats to the national security and national interests of Ukraine in conditions of external and internal challenges.

Conclusion

By design, the situation centers described in the article should first of all be engaged in tracking UAVs in the city, preventing the commission of illegal actions with their help, developing and informing users and devices about the permitted areas for flights over the city, about airways, and controlling their use. The described system should deal with the certification of UAVs and placing them on the state register with the entry of the necessary information about them into the relevant databases. Well, and further operating with the described information, this system should become part of a smart city, which is responsible for the maximum effects of the use of UAVs.

Within the framework of this work, an analysis of possible ways of implementing the idea of creating an RSC in practice was carried out, the problems that would arise in this case were described, and possible ways of solving them were outlined.

The information that will have to be operated is described, in particular the information that the RSC should exchange with the UAV, it is analyzed how the RSC should control the space above the city, and the general vision is specified.

The authors are constantly working on promoting the professional training of UAV operators and robotics specialists, they have experience in this. The approach to the development of a special laboratory stand is described [5,6].

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