INFORMATION MEDICAL FUZZY-EXPERT SYSTEM FOR THE ASSESSMENT OF THE DIABETIC KETOACIDOSIS SEVERITY ON THE BASE OF THE BLOOD GASES INDICES

[1]Zorina NIZHYNSKA-ASTAPENKO, [2]Sergiy PAVLOV, [1]Oleg VLASENKO, [3]Waldemar WOJCIK, [1]Maryna VLASENKO, [1]Olga CHAIKOVSKA, [2]Volodymyr PAVLOV, [4]Ainur ORAZAYEVA, [2]Katerina SHEVCHUK, [1]Tetiana VUZH

[1]Vinnytsia National Medical University named M. Pirogov
[2]Vinnytsia National Technical University
[3]Lubelska Polytechnika, Poland
[4]L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan

Abstract. Main directions of the application of the mathematical methods in medical diagnosis are analyzed, their drawbacks are evaluated , principles of diagnosis, based on fuzzy logic are formulated. Mathematical models and algorithms, formalizing the process of diagnostic decisions making on the base of fuzzy logic at quantitative and qualitative parameters of the patient state are developed; mathematical models of the membership functions, formalizing the presentation of quantitative and qualitative parameters of the patients state in the form of the fuzzy sets, used in the models and algorithms of diagnosis and determining the diagnosis in case of diabetic ketoacidosis are developed.
Aim of the study is realization of the computer-based expert system for the solution of the problems, dealing with medical diagnosis on the base of fuzzy logic in case of Diabetic Ketoacidosis.

Key words: *information expert system, control-method of fuzzy sets, sensors, medical diagnostics, diabetic ketoacidosis.*

INTRODUCTION

Diabetes – is one of the growing problems of the public health service in XXI century. According to the data of the 9th edition of the Diabetes Altas of IDF (The International Diabetes Federation) for a year 2019 the amount of diabetic patients among the adult population in the world is on average 9.3 % (from 6 to 11 % in different regions). In absolute terms this is approximately 463 million persons, among them more than 1.1 million of diabetes cases of the first type is among children [11].

Diabetic ketoacidosis(DKA) is an acute decompensation of the diabetes as a result of poor control of glycemia, that is characterized by the sharp increase of the glucose level and Ketone bodies in the blood, emergence of the ketone bodies in the urine and metabolic acidosis, that may cause death as a result of brain edema [1, 2]. Acute complication of diabetes results in considerable financial loading both on the health care system and the patient. The amount of expenses may reach approximately 26566 USD per patient for the period of the hospitalization in the USA [3]. Main standard approach to the stratification of the patient by the degree of Diabetic Ketoacidosis severity is the assessment and distribution according to the level of blood pH (for the arterial blood DKA I 7.21 - 7.34, DKA II 7.10 - 7.20, DKA III<7.1) [4, 5]. Additional criteria of the severity assessment in some countries are level of bicarbonates and beta-y-hydroxybutyrate.

Until recently the lethal index on account of DKA decreased with the increase of the frequency of hospitalization (Benoit SR, Zhang Y, Geiss LS, Gregg EW, Albright A., 2018). However, with the emergence of the coronaviral disease 2019 (COVID-19) considerable growth of the death rate was recorded in different age groups as compared with DKA patients but without COVID-19 (Pasquel FJ, Messler J, Booth R, et al., 2021).

Approaches to treatment were gradually changing, that enabled to reduce considerably the death rate as a result of Diabetic Ketoacidosis in different regions of the world, in the precovid period and the death rate in the majority of the countries was reduced to the level of less than 1 % [6, 7].

Main approaches to DKA treatment are written in the recommendations of ADA 2019 and ISPAD 2018 [8, 9, 10]. But their updating and revision remains actual in order to improve the efficiency of treatment on the base of the obtained experience.

Fifteenth International Conference on Correlation Optics, edited by Oleg V. Angelsky, Proc. of SPIE Vol. 12126, 1212626
 · doi: 10.1117/12.2616675

For the solution of the problems of medical diagnostics mathematical methods, based on the Bayesian approach, theory of the experiment planning, images recognition and logic programming got widespread use . Main difficulties in the application of these methods in the process of development and practical application of the automated systems of medical diagnostics are connected with the need to collect large arrays of the experimental data, complexity of statistic processing and interpretation in terms of the decision-making. regarding the particular diagnosis [1]. Besides, the known methods do not allow to describe cause-effect relations between the parameters of the patient`s state and his diagnosis, assessing the stage of severity of Diabetic Ketoacidosis in natural language, modeling the logic of diagnostician thinking, involving non-numerical (fuzzy) information about such parameters as pH, partial pressure of carbon dioxide pCO_2, total content of the carbon dioxide in the blood - tCO_2 and partial pressure of oxygen - pO_2.
In the given research the authors propose to widen the spectrum of indices for DKA diagnosis including the additional criteria – level of gases of the arterial blood, partial pressure of carbon dioxide - pCO_2, total content of carbon dioxide in the blood - tCO_2 and partial pressure of oxygen - pO_2 and use modeling on the base of fuzzy sets theory for the creation of the automated expert system for the determination of the DKA severity degree. The results regarding further development of the method on the base of fuzzy sets and automated expert system for the solution of the problems of medical diagnostics on the base of fuzzy logic are proposed. This method is the interconnected set of mathematical models, algorithms and software for determining the diagnosis of Diabetic Ketoacidosis at the assigned values of the parameters of the patient`s state.

AIM AND TASKS OF THE RESEARCH

Aim of the research is the realization of the automated expert system for the solution of the problems of medical diagnostics, on the base of fuzzy logic in case of Diabetic Ketoacidosis.
The given paper analyses main directions of the application of the mathematic methods in medical diagnostics, the drawbacks of these method are analyzed, principles of diagnostics, based on fuzzy logic are formulated, mathematical models and algorithms, which formalize the diagnostic decisions making process on the base of fuzzy logic at quantitative and qualitative parameters of the patient`s state are developed, mathematical models of the membership functions, formalizing the presentation of quantitative parameters of the patient`s state in the form of fuzzy sets, used in the models and algorithms of Diabetic Ketoacidosis diagnostics are elaborated.

USAGE OF MATHEMATIC TOOLS OF FUZZY LOGIC FOR THE PROCESSING OF THE DIAGNOSTIC INFORMATION

Taking into account the fact that in the process of the clinic studies there often appears the need to use not only clear digital criteria but also certain linguistic characteristics of indices (terms) changes, the authors performed the analysis of the part of them by means of mathematical tools of fuzzy logic. Such approach enables to obtain single-valued digital expression for the criteria, which have the descriptive characteristics and, correspondingly, qualitative content, for instance: VL – very low, L – low, LA – lower that average, A – average, HA – higher than average, H – high [1, 2, 3]. Each of these terms is a fuzzy set, assigned by means of special membership functions and can be presented by a certain interval, which has its digital degrees from 0 to 1. Absolute non- membership to the set is shown by 0, absolute membership – by 1.
Application of the mathematical tool of fuzzy logic can be important in case when it is necessary to determine the probability of the interconnection of the pathological states, which have different clinical characteristics. In our case fuzzy logic tool is applied to assess the severity level of Diabetic Ketoacidosis.
From clinical point of view three serial stages of DKA are distinguished: I – moderate ketoacidosis, II – precoma or noncompensated ketoacidosis, III – coma stage. (Kravchun N. A. et al., 2010; Dedov I. I. et al., 2014)
Symptoms, characteristic for DKA of the 1st stage are: thirst, polyuria, loss of the body mass, dry skin and xerosis, weakness, headache, sleepiness, dehydration degree not more than 5 %, smell of acetone in the air, hyporexia and nausea, short breath is observed at minor physical loads, moderate tachycardia, arterial blood pressure is normal or elevated.
In case of precoma development (DKA of the 2nd stage) the symptoms of decompensation of diabetes (thirst, polyuria, loss of the body mass, dry skin and xerosis, general weakness) are prevailed by the symptoms of intoxication: sluggishness, sleepiness, loginess, headache, absence of appetite, multiple vomiting. In the process of the objective examination passive position in the bed are determined , extremities motions are sluggish and slow, low muscular tonus, low T-reflexes, hollow eyes, skin is dry, cold in the section of the extremities, nose. Kussmaul breathing in the rest state, with the participation of the auxiliary muscles, respiration rate is 20-28/min, severe tachycardia is determined, rhythm

disturbances may occur, hypotension, pulse of poor volume. While examining the digestive system – the tongue is dry, covered with brown coat, tender abdomen in epigastric section and right hypochondrium, palpation of the abdomen is painful , palpation of the intestinal segments is painful, patients react on the examination by moan and facial dolorosa. In the process of auscultation of the lungs the breathing is harsh, auscultation of heart – the heart tones are weakened, loud second heart sound above pulmonary trunk, auscultation of abdomen – motility is sharply decreased and may be absent. Diuresis as a result of osmotic stimulation even at dehydration of 5-10 % is saved.

8 The development of Diabetic Ketoacidosis coma (DKA III stage) is characterized by the loss of consciousness, its depth is evaluated by Glasgow coma scale. Position of the patient in the bed is passive, movements are not present, sharp decrease of muscles tonus, decrease to complete absence of T-reflexes, emergence of pathological reflexes. The examination shows that the skin is dry with cutis marmorata, cold on touch or hot if the accompanying infection is connected, skin tightness and elasticity of the skin are drastically reduced, hollow eyes, soft, in case of brain edema they become dense, smell of the acetone in the expired air, Kussmaul breathing with the participation of the auxiliary muscles, respiration rate is 30-40/min. By auscultation the respiration is harsh, sonorous rhonchi, weakened heart tones, loud second heart sound above pulmonary trunk. Low arterial blood pressure , pulse is frequent, very fine and scarcely perceptible. Tongue is dry, covered with the crusts of deep brown color. By percussion, the size of the liver is increased, motility is absent. Natural urination is impossible, urine passes along urinary catheter with normal or reduced to oligoanuria daily diuresis.

However in greater part of modern protocols it is recommended to use the objective laboratory criteria, based on determination of certain laboratory indices.

In the given study such laboratory indices of the arterial blood were determined, blood pH, partial pressure of carbon dioxide - pCO_2, total content of carbon dioxide in the blood - tCO_2 and partial pressure of oxygen - pO_2. All the patients were taken blood tests regarding the gas composition and indices of acid-base balance. Blood sample was taken mainly from the radial artery of the nondominant hand in the place of the palpatory determination of the best pulsation of the vessel in the heparinized syringe of 2 ml of volume during the hospitalization. Prior Allan's test was taken. Blood samples were taken to the laboratory during 1-2 min for the immediate laboratory study. If necessary, the corrective indices of Hв, body temperature, oxygen concentration in the mixture, taken by the patient were input into "Easy Blood Gas" (USA, 2008). Gas analysis of the blood was determined by the method of the potentiometric measurement, by means of ion-selective electrodes, using automatic analyzer "Easy Blood Gas" (USA, 2008).

Table 1 contains the data base of laboratory indices for the assessment of the severity level in case of Diabetic Ketoacidosis (Expert Data Base ARTERIA).

Table 1. Assessment of the probability of the severity level in case of Diabetic Ketoacidosis (ExpertDataBaseARTERIA)

Diagnosis	pH	pCO_2, mmHg	tCO_2, mmHg	pO_2, mmHg
Ketosis	7.35 ÷ 7.45	44.75 ÷ 52.2	27.20 ÷ 30.75	75.5 ÷ 109.5
Diabetic Ketoacidosis I	7.21 ÷ 7.34	19.80 ÷ 27.80	10.70 ÷ 15.10	94.0 ÷ 113.00
Diabetic Ketoacidosis II	7.10 ÷ 7.20	14.45 ÷ 19.85	6.25 ÷ 10.25	94.00 ÷ 119.00
Diabetic Ketoacidosis III	6.90 ÷ 7.09	12.55 ÷ 21.65	4.05 ÷ 5.85	115.00 ÷ 42.50

On the base of Table 1 data base for the assessment of the severity level in case of Diabetic is formed on the base of fuzzy terms (Table 2).

Table 2.Data base for the assessment of the severity level in case of Diabetic Ketoacidosis on the base of fuzzy terms (ExpertDataBaseARTERIA)

Diagnosis	**pH (X_1)**	**pCO_2, mmHg (X_2)**	**tCO_2, mmHg (X_3)**	**pO_2, mmHg (X_4)**
Ketosis (d_{1a})	HA	HA	HA	L
	HA	HA	HA	LA
	HA	HA	HA	A
	H	HA	HA	LA
Diabetic Ketoacidosis I (d_{2a})	A	LA	LA	LA

	A	LA	LA	A
	HA	LA	LA	LA
	HA	LA	LA	A
Diabetic Ketoacidosis II (d_{3a})	A	L	LA	LA
	A	L	LA	A
	A	LA	LA	LA
	A	LA	LA	A
Diabetic Ketoacidosis III (d_{4a})	L	L	L	A
	LA	L	L	A
	LA	LA	L	HA

For each index from the data base for the formalization of indices the corresponding membership functions are determined.

That is why, mathematical models for the assessment of the severity level of Diabetic Ketoacidosis (Expert Data Base ARTERIA) have the following form (1 – 4):

$$\begin{aligned}&\mu^{d1A}(X_1,X_2,X_3,X_4)=\mu^{HA}(X_1)\cdot\mu^{HA}(X_2)\cdot\mu^{HA}(X_3)\cdot\mu^{L}(X_4)\cdot\cup\\&\mu^{HA}(X_1)\cdot\mu^{HA}(X_2)\cdot\mu^{HA}(X_3)\cdot\mu^{LA}(X_4)\cup\mu^{HA}(X_1)\cdot\mu^{HA}(X_2)\cdot\mu^{HA}(X_3)\cdot\mu^{A}(X_4)\cup\\&\mu^{H}(X_1)\cdot\mu^{HA}(X_2)\cdot\mu^{HA}(X_3)\cdot\mu^{LA}(X_4);\end{aligned}\tag{1}$$

$$\begin{aligned}&\mu^{d2A}(X_1,X_2,X_3,X_4)=\mu^{A}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{LA}(X_4)\cdot\cup\\&\mu^{A}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{A}(X_4)\cup\mu^{HA}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{LA}(X_4)\cup\\&\mu^{HA}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{A}(X_4);\end{aligned}\tag{2}$$

$$\begin{aligned}&\mu^{d3A}(X_1,X_2,X_3,X_4)=\mu^{A}(X_1)\cdot\mu^{L}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{LA}(X_4)\cdot\cup\\&\mu^{A}(X_1)\cdot\mu^{L}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{A}(X_4)\cup\mu^{A}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{LA}(X_4)\cup\\&\mu^{A}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{LA}(X_3)\cdot\mu^{A}(X_4);\end{aligned}\tag{3}$$

$$\begin{aligned}&\mu^{d4A}(X_1,X_2,X_3,X_4)=\mu^{L}(X_1)\cdot\mu^{L}(X_2)\cdot\mu^{L}(X_3)\cdot\mu^{A}(X_4)\cdot\cup\\&\mu^{LA}(X_1)\cdot\mu^{L}(X_2)\cdot\mu^{L}(X_3)\cdot\mu^{A}(X_4)\cup\mu^{LA}(X_1)\cdot\mu^{LA}(X_2)\cdot\mu^{L}(X_3)\cdot\mu^{HA}(X_4);\end{aligned}\tag{4}$$

For the construction of the equations it is necessary to determine membership functions $\mu^j(x_i)$ of all fuzzy terms j (H, HA, A, LA, L, VL) for all factors x_i (in the given case j – is the value of the symmetry coefficient, *i* – is the investigation interval: $i=\overline{1,4}$). If the high level is considered as a variant of a norm, then the construction of the equations must be performed for five fuzzy terms (L, LA, A, HA, A).

Each factor x_i must correspond its five membership functions. For simplification of the modelling certain actions must be taken: Let $\underline{x_i}$ and $\overline{x_i}$ – be low and upper boundary of the range of factor x_i changes. We express interval [$\underline{x_i}$, $\overline{x_i}$] on the interval U=[0, 4] where membership functions $\widetilde{\mu}^j(u)$, $u\in U$ are set for fuzzy terms j=HA, A, LA, L and VL.

Graphic form of the membership functions is shown in Fig. 1. The selection of the similar curves is stipulated by the fact that they are piecewise linear approximations of the expert membership functions $\mu^j(x_i)$, obtained for the factors $x_1 \div x_4$ by the method of paired comparisons [16].

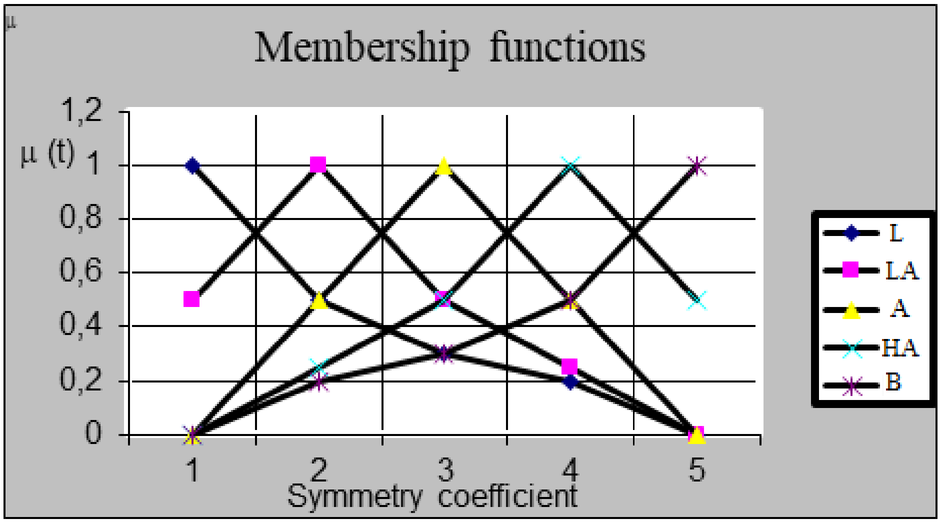

Fig. 1 Membership functions of fuzzy terms

Transition from $\tilde{\mu}^j(u)$ function to the required functions $\mu^j(x_i)$ is realized in the following way:

$$u_i = 4\frac{x_n - \underline{x_n}}{\overline{x_n} - \underline{x_n}}, \; \tilde{\mu}^j(u_n) = \mu^j(x_n) \qquad (5)$$

Analytical expressions of the functions $\mu^j(x_1)$ from the value X_1 (pHARTERIA), if $PH = \overline{6{,}9; 7{,}45}$

$$\tilde{\mu}^L(X_1) = \begin{cases} \frac{3{,}575 - 0{,}5x_1}{0{,}12}, x_1 \in [6{,}9; 7{,}03] \\ \frac{3{,}725 - 0{,}5x_1}{0{,}42}, x_1 \in [7{,}03; 7{,}45] \end{cases} ; \quad \tilde{\mu}^{LA}(X_1) = \begin{cases} \frac{0{,}5x_1 - 3{,}385}{0{,}13}, x_1 \in [6{,}9; 7{,}03] \\ \frac{3{,}655 - 0{,}5x_1}{0{,}14}, x_1 \in [7{,}03; 7{,}17] \\ \frac{3{,}725 - 0{,}5x_1}{0{,}28}, x_1 \in [7{,}17; 7{,}45] \end{cases} ;$$

$$\tilde{\mu}^A(X_1) = \begin{cases} \frac{x_1 - 6{,}9}{0{,}27}, x_1 \in [6{,}9; 7{,}17] \\ \frac{7{,}45 - x_1}{0{,}28}, x_1 \in [7{,}17; 7{,}45] \end{cases} ; \quad \tilde{\mu}^{HA}(X_1) = \begin{cases} \frac{0{,}5x_1 - 3{,}45}{0{,}27}, x_1 \in [6{,}9; 7{,}17] \\ \frac{0{,}5x_1 - 3{,}515}{0{,}14}, x_1 \in [7{,}17; 7{,}31] \\ \frac{3{,}795 - 0{,}5x_1}{0{,}14}, x_1 \in [7{,}31; 7{,}45] \end{cases} ; \quad \tilde{\mu}^H(X_1) = \begin{cases} \frac{0{,}5x_1 - 3{,}45}{0{,}4}, x_1 \in [6{,}9; 7{,}31] \\ \frac{0{,}5x_1 - 3{,}58}{0{,}14}, x_1 \in [7{,}31; 7{,}45] \end{cases} .$$

Analytical expressions of the functions $\mu^j(x_2)$ from the value X_2 (pCO_2, mmHgARTERIA), if $pCO_2 = \overline{10; 60}$

$$\tilde{\mu}^{L}(X_2)=\begin{cases}\frac{17{,}5-0{,}5x_2}{12{,}5}, x_2\in[10;22{,}5]\\ \frac{30-0{,}5x_2}{37{,}5}, x_2\in[22{,}5;60]\end{cases}\quad \tilde{\mu}^{LA}(X_2)=\begin{cases}\frac{1{,}25+0{,}5x_2}{12{,}5}, x_2\in[10;22{,}5]\\ \frac{23{,}75-0{,}5x_2}{12{,}5}, x_2\in[22{,}5;35]\\ \frac{30-0{,}5x_2}{25}, x_2\in[35;60]\end{cases}\quad \tilde{\mu}^{A}(X_2)=\begin{cases}\frac{x_2-10}{25}, x_2\in[10;35]\\ \frac{60-x_2}{25}, x_2\in[35;60]\end{cases}$$

$$\tilde{\mu}^{HA}(X_2)=\begin{cases}\frac{0{,}5x_2-5}{25}, x_2\in[10;35]\\ \frac{0{,}5x_2-11{,}25}{12{,}5}, x_2\in[35;47{,}5]\\ \frac{60-x_2}{12{,}5}, x_2\in[47{,}5;60]\end{cases}\quad \tilde{\mu}^{H}(X_2)=\begin{cases}\frac{0{,}5x_2-5}{37{,}5}, x_2\in[10;47{,}5]\\ \frac{30-0{,}5x_2}{12{,}5}, x_2\in[47{,}5;60]\end{cases}$$

Analytical expressions of the functions $\mu^j(x_3)$ from the value X_3 (TCO_2, mmHgARTERIA), if $TCO_2 = \overline{2;40}$

$$\tilde{\mu}^{L}(X_3)=\begin{cases}\frac{10{,}5-0{,}5x_3}{9{,}5}, x_3\in[2;11{,}5]\\ \frac{20-0{,}5x_3}{28{,}5}, x_3\in[11{,}5;40]\end{cases}\quad \tilde{\mu}^{LA}(X_3)=\begin{cases}\frac{3{,}75+0{,}5x_3}{9{,}5}, x_3\in[2;11{,}5]\\ \frac{15{,}25-0{,}5x_3}{9{,}5}, x_3\in[11{,}5;21]\\ \frac{20-0{,}5x_3}{19}, x_3\in[21;40]\end{cases}\quad \tilde{\mu}^{A}(X_3)=\begin{cases}\frac{x_3-2}{19}, x_3\in[2;21]\\ \frac{40-x_3}{19}, x_3\in[21;40]\end{cases}$$

$$\tilde{\mu}^{HA}(X_3)=\begin{cases}\frac{0{,}5x_3-1}{19}, x_3\in[2;21]\\ \frac{0{,}5x_3-5{,}75}{9{,}5}, x_3\in[21;30{,}5]\\ \frac{24{,}75-0{,}5x_3}{9{,}5}, x_3\in[30{,}5;40]\end{cases}\quad \tilde{\mu}^{H}(X_3)=\begin{cases}\frac{0{,}5x_3-1}{28{,}5}, x_3\in[2;30{,}5]\\ \frac{0{,}5x_3-10{,}5}{9{,}5}, x_3\in[30{,}5;40]\end{cases}$$

Analytical expressions of the functions $\mu^j(x_4)$ from the value X_4 (TCO_2, mmHgARTERIA), if $pO_2 = \overline{70;150}$

$$\tilde{\mu}^{L}(X_4)=\begin{cases}\frac{55-0{,}5x_4}{20}, x_4\in[70;90]\\ \frac{75-0{,}5x_4}{60}, x_4\in[90;150]\end{cases}\quad \tilde{\mu}^{LA}(X_4)=\begin{cases}\frac{0{,}5x_4-25}{20}, x_4\in[70;90]\\ \frac{65-0{,}5x_4}{20}, x_4\in[90;110]\\ \frac{75-0{,}5x_4}{40}, x_4\in[110;150]\end{cases}\quad \tilde{\mu}^{A}(X_4)=\begin{cases}\frac{x_4-70}{40}, x_4\in[70;110]\\ \frac{150-x_4}{40}, x_4\in[110;150]\end{cases}$$

$$\tilde{\mu}^{HA}(X_4)=\begin{cases}\frac{0{,}5x_4-35}{40}, x_4\in[70;110]\\ \frac{0{,}5x_4-45}{20}, x_4\in[110;130]\\ \frac{85-0{,}5x_4}{20}, x_4\in[130;150]\end{cases}\quad \tilde{\mu}^{H}(X_3)=\begin{cases}\frac{0{,}5x_4-35}{60}, x_4\in[70;130]\\ \frac{0{,}5x_4-55}{20}, x_4\in[130;150]\end{cases}$$

Decision making regarding the severity degree of the disease can be made according to the following algorithm:

- Step 1: fix the values of the factors for the specific patient x_n($n=\overline{1,4}$);
- Step 2: by the formulas (1) – (4) the values of the membership functions $\mu^j(x_n)$ are determined at fixed values of factors x_n;
- Step 3: by means of logic equations membership functions $\mu^{d_i n}(x_1, x_2, ... x_n)$ are calculated for all degree of the disease severity d_n, $n=\overline{1,4}$. Operations I (·) and OR (V) over the membership functions μ(a) and μ(в) are changed for operations min and max:

$$\mu(a) \bullet \mu(в) = min[\mu(a), \mu(в)]; \tag{6}$$

$$\mu(a) V \mu(в) = max[\mu(a), \mu(в)]; \tag{7}$$

Step 4: Decision do is determined, for which

$$\mu^{d_0}(x_1, x_2, ... x_n) = \max[\mu^{d_n}(x_1, x_2, ... x_n)] \tag{8}$$

Necessary range will correspond to this decision, this range indicates the degree of the severity level in case of Diabetic Ketoacidosis.

PRACTICAL REALIZATION OF THE MEDICAL EXPERT SYSTEM FOR THE ASSESSMENT OF DIABETIC KETOACIDOSIS SEVERITY

For the realization of the operation of the blocks of adjustment, membership functions storage, fuzzy processing and output of the expert system principles of obtaining the valid diagnosis on the base of fuzzy logic were provided as the basis.

Basic ideology of the information medical expert system operation for the assessment of the Diabetic Ketoacidosis severity, on the base of the introduction of fuzzy logic blocks for the assessment of the severity stage in case of Diabetic Ketoacidosis is shown in Fig. 2 (to improve the reliability of the assessment it is planned to perform the assessment by the venous component).

The result of realization of the given blocks was the developed programming shell, in this case, the user is proposed after the launching of the program to introduce the value of the low and upper scale of values, that is in the data base of certain pathology, in our case, we introduce the values which are basic for the determination.

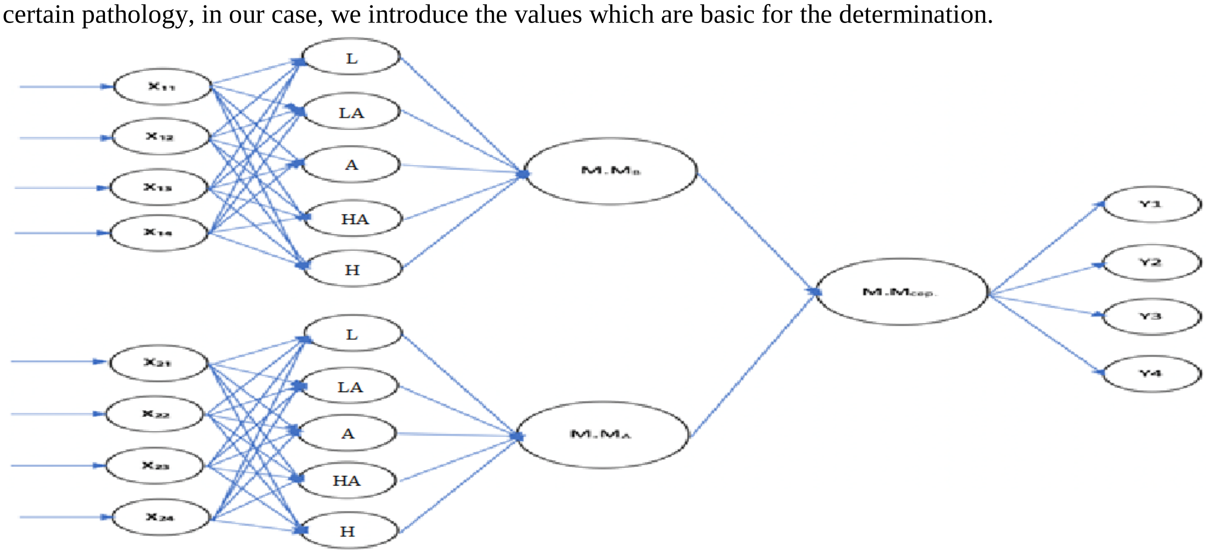

Fig 2. Fuzzy logic blocks for the assessment of the severity stage

Result of the realization of the given blocks was the programming shell that operates in the following way.
1. After the launching of the program the user is suggested to introduce the value of the upper and low scale of values, that is in the database on a certain, on the base of blood gases indices, pathology, in our case we introduce the values which are the basic for determination.
2. To continue the work with the program, after filling all the fields it is necessary to press «save», for the restoration of the previous data, which were input before, the user must press «retire».

Table 3 Contains the results of clinical studies

pH arterious X1	**pCO_2 art X2**	**tCO_2 art X3**	**pO_2 art X4**		
7,224	**15,1**	**6,7**	**70**	**2**	**2,3**
7,273	**22,4**	**11**	**120**	**1**	**2**
7,188	**15,6**	**6,4**	**119**	**2**	**2**
7,345	**31,4**	**18,1**	**96**	**1**	**2**
7,163	**27,2**	**10,6**	**141**	**3**	**4**
7,098	**8,8**	**3**	**144**	**3**	**3**
7,293	**27,8**	**14,3**	**82**	**1**	**2**
7,379	**22,5**	**14**	**94**	**1**	**2**
7,08	**11**	**3,7**	**127**	**3**	**4**
7,27	**24,8**	**12,2**	**75**	**2**	**2**
7,05	**15,8**	**5,4**	**180**	**3**	**4**
6,93	**23,2**	**5,6**	**86**	**3**	**4**
7,232	**18,3**	**8,3**	**113**	**2**	**2**
7,374	**21,9**	**13,4**	**110**	**1**	**2**
7,154	**21,4**	**8,2**	**117**	**2**	**2**
6,98	**18,4**	**4,9**	**132**	**3**	**4**
7,227	**17,6**	**7,9**	**114**	**2**	**2**
7,17	**13,7**	**5,4**	**126**	**2**	**2**
7,031	**13,5**	**4**	**156**	**3**	**3**
7,25	**14,1**	**6,6**	**119**	**1**	**2**
7,067	**12,8**	**4,1**	**119**	**3**	**3**
7,12	**13,3**	**4,7**	**123**	**3**	**4**
7,315	**19,8**	**10,7**	**110**	**1**	**2**
7,221	**13,8**	**6,1**	**119**	**2**	**2**
7,346	**29,3**	**16,9**	**91**	**1**	**2**
7,129	**12,3**	**4,5**	**127**	**3**	**4**
7,342	**26,4**	**15,1**	**110**	**1**	**2**
7,04	**20,1**	**6,1**	**111**	**3**	**4**
7,347	**13**	**7,5**	**113**	**1**	**2**
7,123	**27,3**	**9,8**	**109**	**3**	**4**

On the base of the data the program for diagnosis of Diabetic Ketoacidosis was developed. The example of the dialog window in given in Fig. 2.

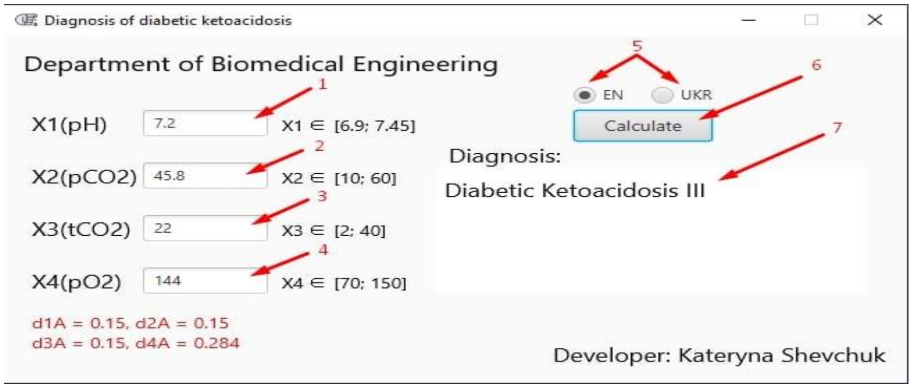

Fig. 3. Example of the dialog window of the program, where 1 – is text field of the parameter X1 (pH); 2 – is text field of the parameter X3 (pCO2); 3 – is text field of the parameter X4 (tCO2); 4 – is text field of the parameter X5 (pO2); 5 – selection of the language of the program application; 6 – is the button for the calculation of the result; 7 – result.

CONCLUSIONS

Method of the application of fuzzy sets for the realization of the information expert system for the solution of the problems of medical diagnostics, in particular for Diabetic Ketoacidosis diagnosis was further developed.

Main directions of mathematic methods application in medical diagnostics were analyzed, their drawbacks were evaluated, principles of diagnostics, based on fuzzy logic were formulated.

Basic scientific results: mathematical models and algorithms, formalizing the process of diagnostic decisions making on the base of fuzzy logic, taking into account quantitative and qualitative parameters of patient`s state were developed; mathematical models of the membership functions, formalizing the presentation of the quantitative and quantitative parameters of the patient`s state in the form of fuzzy sets, used in the models and algorithms of diagnostics and determining the diagnosis in case of Diabetic Ketoacidosis were developed.

The developed models and algorithms of medical diagnostics are based on the ideas and principles of artificial intelligence and knowledge engineering, theory of the experiments planning, theory of fuzzy sets and linguistic variables. Validation of the expert system is performed on real data.

Practical value of the research is the possibility of the application of the automated expert system for the solution of the problems of medical diagnostics on the base of fuzzy logic for the classification of the severity degree of Diabetic Ketoacidosis. Program shell on the base of fuzzy expert system is created. This shell can be used as a tool for the design of the object-oriented systems, necessary for the intelligent support of diagnostic decisions in different branches of medicine, including clinical practice and doctors training. Characteristic feature of the shell is that it enables to create expert diagnostic systems without special training in the sphere of programming and fuzzy sets.

REFERENCES

[1] Khan, Vinshi, et al. "Incidence, Predictors and Outcomes of Cerebral Edema Among Patients With Diabetic Ketoacidosis (DKA) From Nationwide Inpatient Sample (NIS) 2002-2015: 2725." American Journal of Gastroenterology 113 (2018): S1519.

[2] Rotshtein A. Design and Tuning of Fussy IF – THEN Vuly for Medical Didicol Diagnosis. In Fuzzy and Neuro-Fuzzy Systems in Medicine (Eds: N. Teodovescu, A. Kandel, I. Lain.). – USA. CRC-Press, 1998, pp. 235–295.

[3] Valentina K. Serkova, Sergey V. Pavlov, Valentina A. Romanava, et al. Medical expert system for assessment of coronary heart disease destabilization based on the analysis of the level of soluble vascular adhesion molecules // Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017, 104453O; doi: 10.1117/12.2280984.

[4] Khan, Vinshi, et al. "Incidence, Predictors and Outcomes of Cerebral Edema Among Patients With Diabetic Ketoacidosis (DKA) From Nationwide Inpatient Sample (NIS) 2002-2015: 2725." American Journal of Gastroenterology 113 (2018): S1519.

[5] Desai, Dimpi, et al. "Health care utilization and burden of diabetic ketoacidosis in the US over the past decade: a nationwide analysis." Diabetes Care 41.8 (2018): 1631-1638.

[6] Nyenwe, Ebenezer A., and Abbas E. Kitabchi. "The evolution of diabetic ketoacidosis: an update of its etiology, pathogenesis and management." Metabolism 65.4 (2016): 507-521.

[7] Pavlov V.S. . Information Technology in Medical Diagnostics II // Wójcik, W., Pavlov, S., Kalimoldayev, M. (2019). London: Taylor & Francis Group, CRC Press, Balkema book. – 336.

[8] O.V. Katelyan, S.D. Himych, P.F. Kolesnic, A.S. Barylo, V.S. Pavlov, T.I. Kozlovska, M. Maciejewski & A. Kalizhanova. Study of the peripheral blood circulation of an abdominal wall using optoelectronic plethysmograph/ Information Technology in Medical Diagnostics II. CRC Press, Balkema book, 2019 Taylor & Francis Group, London, UK, PP. 119-125.

[9] 9.Tetyana I. Kozlovska; Sergii V. Sander; Sergii M. Zlepko; Valentina B. Vasilenko; Volodymyr S. Pavlov, et al. Device to determine the level of peripheral blood circulation and saturation, *Proc. SPIE* 10031, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2016, 100312Z (September 28, 2016); doi:10.1117/12.2249131.

[10] Wolfsdorf, Joseph I., et al. "ISPAD Clinical Practice Consensus Guidelines 2018: Diabetic ketoacidosis and the hyperglycemic hyperosmolar state." *Pediatric diabetes* 19 (2018): 155-177.

[11] International Diabetes Federation. IDF Diabetes Atlas, 8th edn. Brussels, Belgium:International Diabetes Federation, 2017.

[12] Taubayev, G., Bychkov, A.L., Murzin, F.A., Khairulin, S.S., Abdikerimova, G.B. Machine learning algorithms and classification of textures. Journal of Theoretical and Applied Information Technologythis link is disabled, 2020, 98(23), стр. 3854–3866.

[13] Abdikerimova, G.B., Murzin, F.A., Bychkov, A.L., Ryabchikova, E.I., Xinyu, W.E., Ayazbayev, T.The analysis of textural images on the basis of orthogonal transformations. Journal of Theoretical and Applied Information Technologythis link is disabled, 2019, 97(1), стр. 15–22

[14] Abdikerimova, G.B., Bychkov, A.L., Khayrulin, S.S.,F.A. Murzin, N.E. Russkikh, Ryabchikova, E.I., Xinyu, W. Analysis of images obtained by the transmission electronic microscopy. Materials Today: Proceedingsthis link is disabled, 2019, 12, стр. 90–92

[15] Ushenko, A.G. Laser Polarimetry of Polarization-Phase Statistical Moments of the Object Field of Optically Anisotropic Scattering Layers (2001) Optics and Spectroscopy (English translation of Optika i Spektroskopiya), 91 (2), pp. 313-316

[16] Ushenko, A.G., Burkovets, D.N., Ushenko, Yu.A. Polarization-Phase Mapping and Reconstruction of Biological Tissue Architectonics during Diagnosis of Pathological Lesions (2002) Optics and Spectroscopy (English translation of Optika i Spektroskopiya), 93 (3), pp. 449-456

[17] Abdikerimova, G.B., Murzin, F.A., Bychkov, A.L., Xinyu, W.E.I., Rybchikova, E.I. Software tools for cell walls segmentation in microphotography. Journal of Theoretical and Applied Information Technologythis link is disabled, 2018, 96(15), стр. 4783–479.

[18] Oleksandr Vasilevskyi, Volodymyr Didych, Anna Kravchenko, Maksym Yakovlev, Iryna Andrikevych, Dmytro Kompanets, Yevhen Danylyuk, Waldemar Wójcik, Askhat Nurmakhambetov, Method of evaluating the level of confidence based on metrological risks for determining the coverage factor in the concept of uncertainty, Proceedings Volume 10808, Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2018, 108082C.