Intelligent Approach to Determine the Type of Objects with Low Effective Reflective Surface, Built with Stealth Technology

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Abstract: A system with a module for statistical processing and a module based on fuzzy logic is developed to analyse the scattering field of complex objects with low effective reflectivity, built with Stealth technology. One of the tasks of the system is to determine the type of surface of the observed object (plane B2) by analyzing emulative data obtained under certain laboratory conditions and parameters of probed signal. Data is manipulated for statistical processing, where every angle of azimuth, at a fixed angle position corresponds to a certain level of signal within the field of dispersion.

Key Words: emulative data, amplitude, cubic spline, fuzzy logic, effective reflective surface, smooth and double-reflective surfaces.

1. Introduction

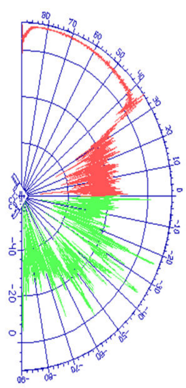
The main objective of radiolocation is to determine the type of the observed object. This can be achieved by analyzing the effective reflective surface (ERS) and also by restoring the image of the objective [3]. The great variety of objects according to ERS poses challenges for professionals working in this area. These challenges are greater in objects with low effective reflectivity due to the use of composite materials and technology, causing emergence of new physical properties and phenomena [4].

The application of "intelligent" modeling increases the efficiency of modern radiolocation [7]. The current available data sources show, that the use of an intelligent approach to modeling is primarily for processing of radiolocation data from objects with high radiolocation visibility. Using various forms of artificial intelligence in separate modules of radiolocation stations increases its efficiency and defense from cyber attacks [2].

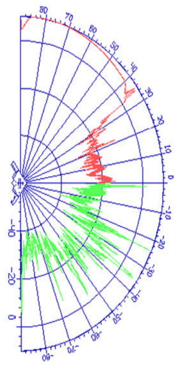
2. Problem Formulation

To analyze the scattering field of complex objects a mathematical model and software application system is developed to determine the type of concrete object of Stealth technology – plane B2, by using emulative data from the characteristics of the field of dispersion (Fig.1). Data were collected under laboratory conditions in a polar coordinate system at a fixed angle position $\varepsilon = 15\,\text{deg}$, varying .azimuth angle $\beta \in [0,90]\,\text{deg}$, wavelength $\lambda = 3$ cm (X range) and vertical polarization AV [1]. They are transformed into Cartesian coordinates, where every angle of azimuth at a fixed angle position corresponds to a certain level of signal of the total picture of the field of dispersion and are presented in Table 1÷ Table 4.

The system consists of two parallel operating modules: module for statistical processing and module based on fuzzy logic. One of the tasks of the system is to determine the type of surface of the observed object (plane B2).



a) (1)



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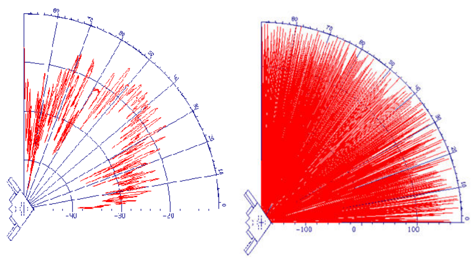


a) (3) b)

Fig.1.Graphical representation of emulative data for: a) amplitude of the field of dispersion a) (1) by object B2, a) (2) from the smooth surfaces of the object, a) (3) from double-reflected surfaces; b) phase change in the field of dispersion

Using the emulative data found in Table 1÷Table 4, system with two parallel operating modules is manipulated and software implemented to probability determine the type of object B2

- Statistical module

Statistical module includes regression models of the four characteristics of the field of dispersion, where the deviation of the modeles based on the experimental data,.to be minimal. These models can be adopted as standard (reference) when compared to real data to decide whether the object is B2 or not. Studies show, that the best method to create such models is cubic spline interpolation [11].

- Fuzzy logic classifier.

Studies show that in certain segments of the observation sector, there is a predominance of different types of surfaces [1]. A synthesized fuzzy classifier allows for the detection of the type of reflecting surface in a sector of observation, thus increases the probability of correct identification of the observed object.

The system decides if the analyzed object is B2 by classical logical conclusion (classical conjunction) (Fig.2).

Table 1. Amplitude of the field of dispersion of object B2

Azimuth angle [degree]	Amplitude [dB]	Azimuth angle [degree]	Amplitude [dB]
0	-11	46	+6
2	-12	48	+7
4	-13	50	+7
6	-15	52	+7
8	-12	54	+8
10	-14	56	+8
12	-14	58	+8
14	-11	60	+8
16	-14	62	+7
18	-20	64	+8
20	-18	66	+9
22	-11	68	+9
24	-11	70	+9
26	-14	72	+9
28	-11	74	+9,1
30	-14	76	+9,1
32	-9	78	+9,1
34	+2	80	+9,1
36	+4	82	+9,2
38	+6	84	+9,2
40	+6	86	+9
42	+7	88	+4
44	+6	90	+8

Table 2. Amplitude of the field of dispersion from smooth surfaces of the object B2

Azimuth angle [degree]	Amplitude [dB]	Azimuth angle [degree]	Amplitude [dB]
0	22	46	7,3
2	-15	48	7,8
4	-28	50	8
6	-26	52	9
8	-22	54	9,2
10	-20	56	9,4
12	-21	58	9,5
14	-20	60	9,6
16	-21	62	9,8
18	-19	64	9,9
20	-32	66	10
22	-22	68	10,1
24	-10	70	9,9
26	-20	72	9,8
28	-18	74	9,9
30	-28	76	10
32	-19	78	9,9
34	5	80	10
36	2	82	9,9
38	4	84	9,6
40	6	86	8,2
42	7	88	8
44	7,1	90	7,9

Table 3 Amplitude of the field by double-interacting elements of B2

Azimuth angle [degree]	Amplitude [dB]	Azimuth angle [degree]	Amplitude [dB]
0	-39	0	-39
2	-30	2	-30
4	-28	4	-28
6	-24	6	-24
8	-34	8	-34
10	-33	10	-33
12	-22	12	-22
14	-26	14	-26
16	-22	16	-22
18	-34	18	-34
20	-23	20	-23
22	-24	22	-24
24	-20	24	-20
26	-34	26	-34
28	-20	28	-20
30	-16	30	-16
32	-26	32	-26
34	-17	34	-17
36	-16	36	-16
38	-20	38	-20
40	-17	40	-17
42	-22	42	-22
44	-18	44	-18

Table 4. Relative phase change of the field of dispersion of object B2

Azimuth angle [degree]	Phase [degree]	Azimuth angle [degree]	Phase [degree]
0	150	0	150
2	40	2	40
4	150	4	150
6	161	6	161
8	176	8	176
10	130	10	130
12	153	12	153
14	122	14	122
16	178	16	178
18	155	18	155
20	120	20	120
22	142	22	142
24	178	24	178
26	171	26	171
28	178	28	178
30	170	30	170
32	155	32	155
34	170	34	170
36	155	36	155
38	130	38	130
40	165	40	165
42	145	42	145
44	140	44	140

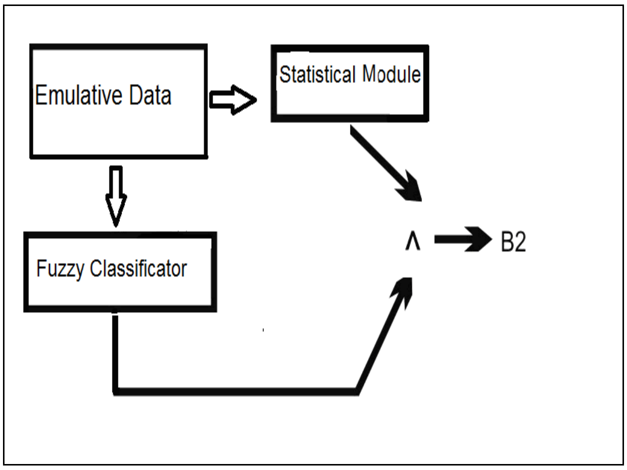


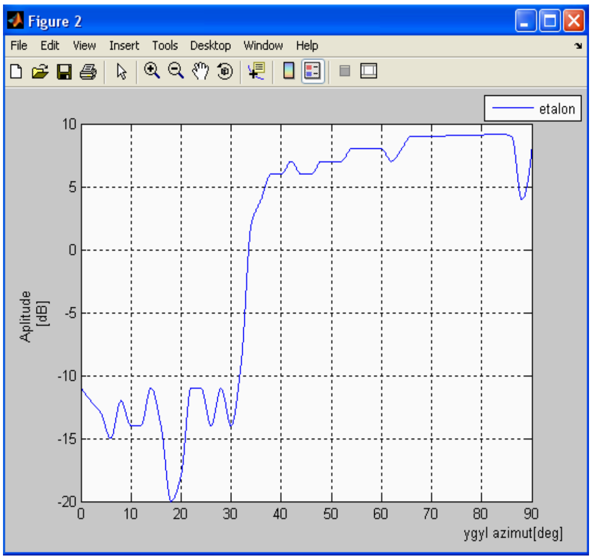
Fig.2. System to determine object B2

3. System for probable identification of the type of object B2

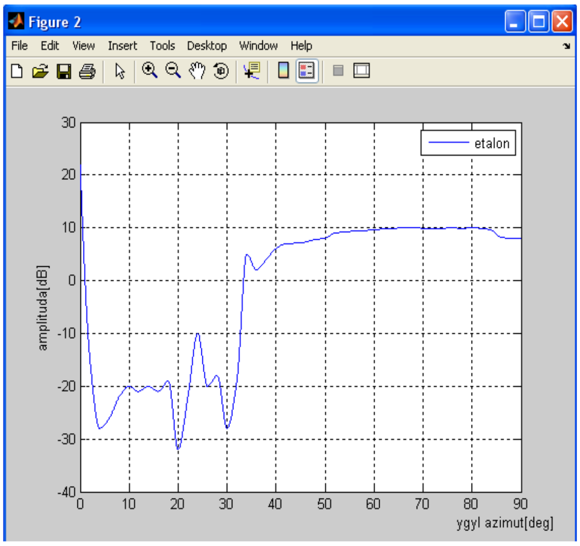
3.1 Statistical method to determine the probability an observed object is B2.

In given experimental data ($(x_i, \varphi(x_i))$, there are various algorithms for setting how much exactly a function $F(x_i)$ approximates the experimental data. One of them is MNMK [11], where the function $F(x_i)$ is defined so that the sum of the squared differences $\sum_{i=1}^{m}(F(x_i)-\varphi(x_i))^2 \rightarrow \min$.

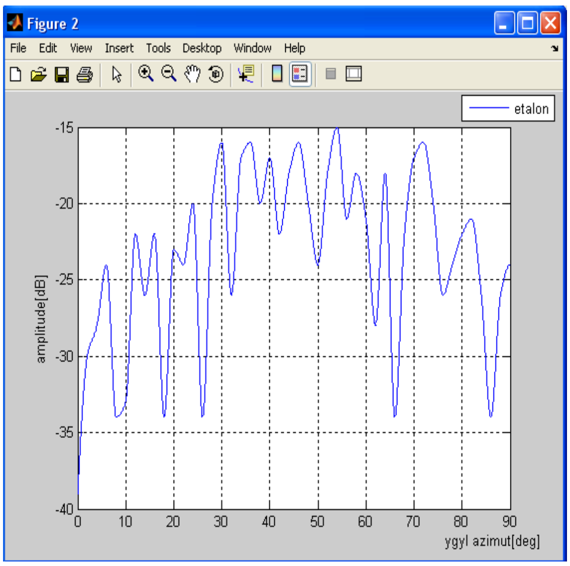
Interpolation is performed in a Matlab environment, which produces smooth interpolation curves (continuous and twice differentiable) by cubic spline of emulative data found in Table 1÷Table 2. These curves graphically describe the modification of the field of dispersion, (amplitude and phase of the reflected signal from the object as a whole, amplitude of the signal reflected from smooth and double-reflective surfaces) on the basis of the azimuth angle at a fixed angle position. The results are presented on Fig.3.



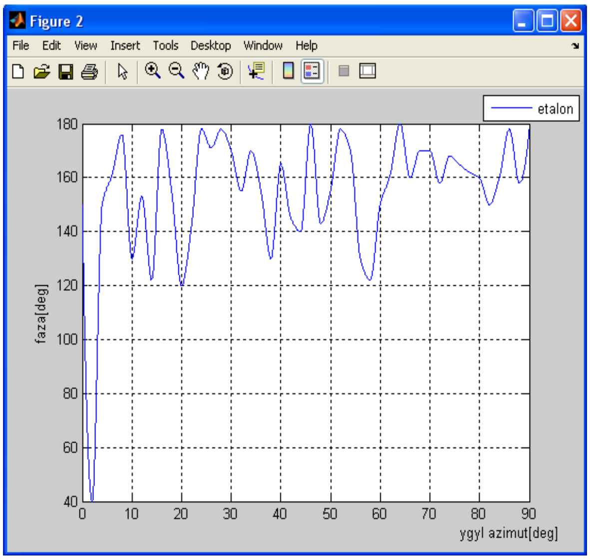
a)



b)



c)



d)

Fig.3. Modification of the characteristics of the field of dispersion: amplitude of the signal reflected from smooth surfaces (a), from double-reflecting surfaces (b); from the object as a whole(c); phase of the signal reflected from the object as a whole (d).

The resulting curves are adopted as standard. They allow for any azimuth angle in the area of observation (0÷90 deg) to determine the relevant characteristics of the field according to experimental data. If a real signal comes in X diapason (band) at a fixed angle position $\varepsilon = 15\,\text{deg}$ and a corresponding azimuth angle, the system reports a value of the characteristic. A method is developed to determine the probability the observed object to be B2.

Since there are no data from real experiments on possible deviations of the values of the characteristics of the field from the standard, simulation experiments were conducted in Matlab environment. It is assumed that for the statistical processing of the observed object, data were collected at 20 azimuth angles and each angle data fluctuate around the value of the reference curve at random under a normal distribution law with zero mathematical expectation and dispersion of 0.3. For each value of the azimuth angle 100 values of the relevant characteristics are generated using random numbers. The mean square deviation is determined for each attempt at each azimuth angle of the experiment. To obtain the threshold level for determining the type of the observed object, errors are summed for each trial and divided by the number of attempts (an average arithmetic error). The resulting number is considered a threshold level and is given a probabilistic nature by fractional-linear transformation. For probability over 50% it is assumed that the observed object is B2, and for probability less than 50% that it is another object. For the realization of experiments and determining the probability an object is B2 a program is created in a Matlab environment. In Fig. 4 ÷ Fig. 7 represent the standard and test curve of the relevant characteristics of the field of dispersion and the probability the observed object is B2.

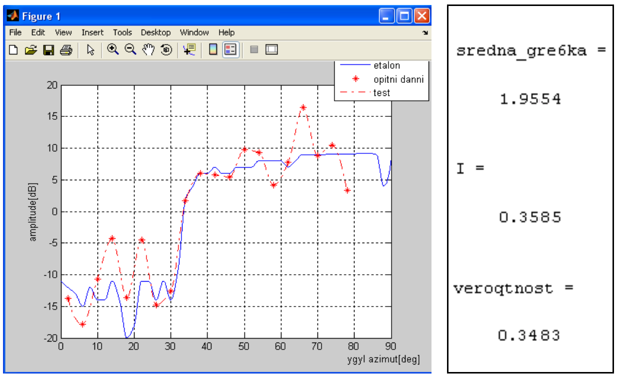


Fig. 4. Reference (standard) and test curve of the amplitude of the field of dispersion and the probability the object is B2

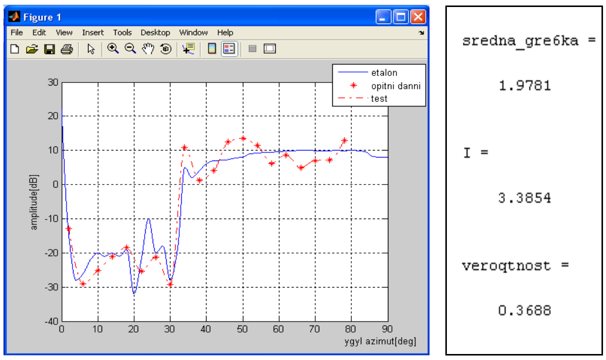


Fig. 5. Reference and test curve of the amplitude of the field of dispersion from smooth surfaces and the probability the object is B2

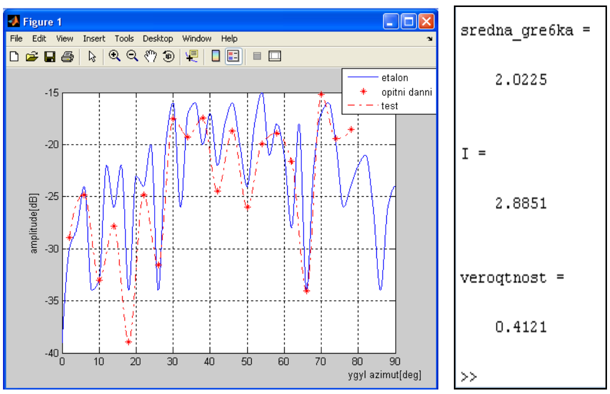


Fig. 6. Reference and test curve of the amplitude of the field of dispersion from double-reflecting surfaces and the probability the object is B2

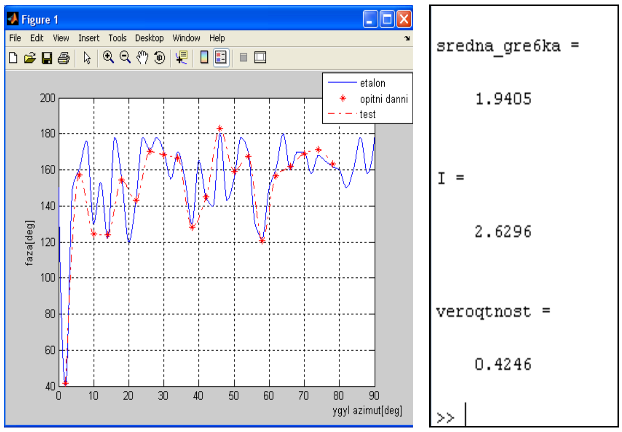


Fig. 7. Reference and test curve of the phase change and the probability the object is B2

The probability the observed object is B2 could be increased by analyzing emulative data for the type of dominant reflective elements in different areas of the observation sector of $(0^\circ \div 90^\circ)$. This method requires tools for determining the nature of the reflecting surface at a certain amplitude of the reflected signal to a given azimuth angle.

3.2. Increasing the probability of correct recognition of object with Stealth technologies (aircraft B2) with application of fuzzy logic conclusion

Fuzzy logic classifier is created using fuzzy logic conclusion, which classifies the reflective surfaces of an object B2 in two classes: smooth and double-reflective, by amplitude and ratio of amplitudes.

The ratios of the amplitudes are defined of vertically polarized signals in the smooth and double-reflective surfaces to the amplitude of the signal of the whole object in azimuth angles, varying from 0÷90 deg and $\lambda = 3$ cm. Table 5 presents the relations of the amplitudes of the signals, reflected from surfaces in a sector $(0^\circ \div 90^\circ)$.

The ratios are included as part of the input data of fuzzy logic classifier, working on the method of Mamdani [9]. Two input attributes are introduced: „Amplitude" (AM) and „Relation (Ratio) of Amplitudes" (OT). The synthesis of the classifier requires informative survey of defined attributes [5].

Table 5. Relations of amplitudes of smooth and double-reflective surfaces to the amplitudes of signals from the whole object

Azimuth angle	Smooth	Azimuth angle	Double-reflective
0	2	0	3,54
2	1,25	2	2,5
4	2,15	4	2,15
6	1,73	6	1,6
8	1,83	8	2,83
10	1,42	10	8,36
12	1,50	12	1,57
14	1,80	14	2,36
16	1,50	16	1,57
18	0,95	18	1,7
20	1,78	20	1,28
22	2	22	2,18
24	0,90	24	1,82
26	1,43	26	2,43
28	1,64	28	1,82
30	2,00	30	1,14
32	2,11	32	2,89
34	2,50	34	8,5
36	0,50	36	4
38	0,66	38	3,33
40	1,00	40	2,83
42	1,00	42	6,50
44	1,18	44	3,00
46	1,2	46	2,67
48	1,1	48	2,85
50	1,14	50	3,43
52	1,28	52	2,57
54	1,15	54	1,87
56	1,18	56	2,62
58	1,18	58	2,25
60	1,2	60	2,62
62	1,4	62	4,00
64	1,25	64	2,25
66	1,12	66	3,77
68	1,1	68	2,44
70	1,1	70	1,89
72	1,1	72	1,78
74	1,09	74	2,22
76	1,1	76	2,89
78	1,1	78	2,67
80	1,1	80	2,44
82	1	82	2,33
84	0,9	84	2,88
86	0,9	86	3,77
88	2	88	6,50
90	0,98	90	3,00

3.2.1. Informative approach to assess defined attributes

A commonly used approach for assessing informative attributes is to determine the intervals, which contain $P.100\%$ of all elements of the general aggregate with probability γ. The boundaries (lower U_D and upper U_G) of these intervals are defined as practical limits of dispersion (PLD). They are calculated by the following formulas [11]:

$$U_D = \overline{X} - k.s, \qquad U_G = \overline{X} + k.s \qquad (1)$$

The value of the coefficient κ depends on the trusty probability γ, from the magnitude P (0<P<1) and the sample size n and is taken from tables. The value of s is the assessment of the mean square deviation.

Criteria for informative attributes

The assessment of informative attributes in a dynamic object is completed by the practical limits U_D and U_G. For each attribute in formula (1) U_D and U_G are calculated.

Criteria for informativeness are introduced as follows:

- Intervals determined by the practical limits for the corresponding classes, have no common points
- Intervals determined by the practical limits have common points, but no interval is a subset of another and the respective probabilities $P(U_{D2} < X < x_0)$ and $P(x_0 < X < U_{G1})$, which are provisionally called „probability for incorrect classification" (P_{GK}), are less than 30% [6].

x_0 is marked the abscissa at the intersection of f $(x_1; a_1; b_1)$ and f (x_2, a_2, b_2). For determining of x_0 it is used, that the closed-end interval with length 6σ[X] and middle with the same average value as $E[X]$, contain practically all possible values of the distributed by normal law random variable X [11].

If practical limits of dispersion are calculated on the base of experimental data we can determine the approximate value of $\sigma[X]$.

$$\sigma[X] \approx \frac{1}{6}(U_G - U_D) \qquad (2)$$

When a given random variable X is distributed by normal law, it has a density distribution as follows:

$$f(x;a;b) = \frac{1}{\sqrt{2\pi}b} e^{-\frac{(x-a)^2}{2b^2}} \quad (3)$$

Where $a = E[X]$ и $b = \sigma(X)$ are parameters of the distribution.

One of the main tasks in any dispersion is determining the probability of a random variable emerging in a given interval (x_1, x_2). For the random variable X distributed by normal law this probability is

$$P(x_1 < X < x_2) = \int_{x_1}^{x_2} f(x)dx = \Phi(t_1) - \Phi(t_2) \quad (4)$$

$$\text{Where } t_1 = \frac{x_1 - E[X]}{\sigma[X]}, t_2 = \frac{x_2 - E[X]}{\sigma[X]};$$

$$\Phi(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{t^2}{2}} dt \quad (5)$$

The value of Φ (t) is taken from tables [11] and the densities of distribution of class 1 and class 2 are given by the following formulas:

$$f(X_1, a_1; b_1) = \frac{1}{\sqrt{2\pi}b_1} \cdot e^{-\frac{(x-a_1)^2}{2b_1^2}} \quad (6)$$

$$f(X_2, a_2, b_2) = \frac{1}{\sqrt{2\pi}b_2} \cdot e^{-\frac{(x-a_2)^2}{2b_2^2}} \quad (7)$$

Class 1 is the class for which U_G is greater. The probability of incorrect classification can be defined for each class by the formula (4), as follows:

For class1

$$\Rightarrow t_1 = \frac{x_0 - E[X_1]}{\sigma[X_1]}; t_2 = \frac{U_{G1} - E[X_1]}{\sigma[X_1]} \quad (8)$$

For class 2

$$\Rightarrow t_1 = \frac{U_{D2} - E[X_2]}{\sigma[X_2]}; \; t_2 = \frac{x_0 - E[X_2]}{\sigma[X_2]},$$

Table 6 and Table 7 provide the statistical characteristics of the attributes and their practical limits of dispersion for the corresponding classes for $\gamma = 0{,}95$ and P=0, 99 [11].

Table 6. Practical limits for sign ”Amplitude”

Type of surface	**n**	$\bar{x}$	**S**	**k**	**Practical limits**
Smooth	46	13,2	7,2	2,408	-4,1÷30,5
Double-reflective	46	23,3	6,1	2,408	8,9÷37,9

Table 7. Practical limits for attribute ”Ratio”

Type of surface	**n**	$\bar{x}$	**S**	**k**	**Practical limits**
Smooth	46	1,5	0,6	2,408	0,13 ÷2,9
Double-reflective	46	2,9	1,1	2,408	0,2÷5,5

The percentage of probability for “incorrent” classification for AM and OT is determined”. For this purpose we prepared the graphs of the functions of density distribution of AM and OT, presented respectively on Fig. 8 and Fig. 9

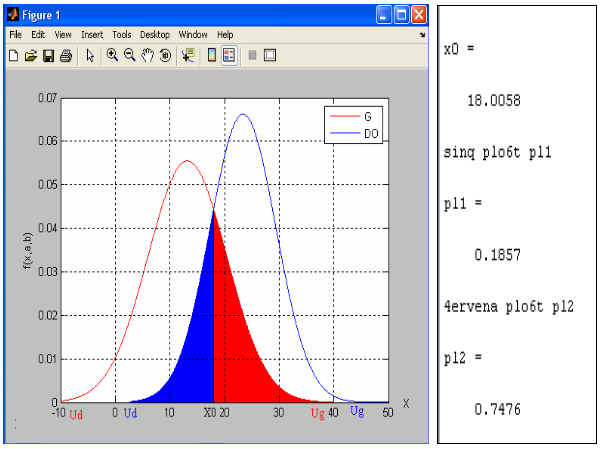


Fig.8. Graphs of the functions of the density distribution of attribute „Amplitude”

The constants „**a**” and „**в**” in the densities of distribution of class ”Smooth” and class ”double-reflective”, the values of $X_0 \Rightarrow f_1(x, a_1, b_1) = f_2(x, a_2, b_2)$ and the probability for „incorrect” classification P_{GK} in % for each attribute are given in Table 8, Table 9.

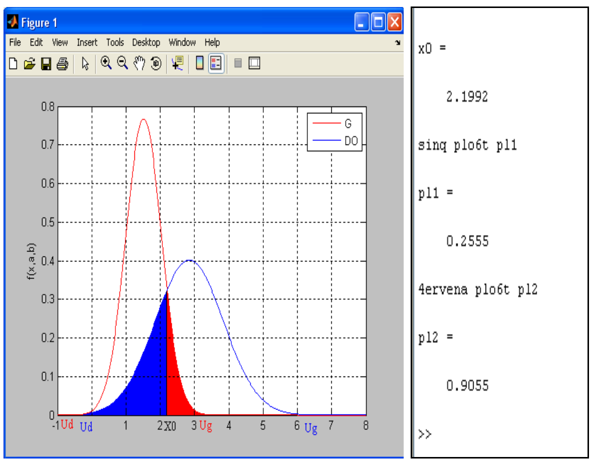


Fig.9 Graphs of the functions of the density distribution of the attribute „Relation”

Table 8. Parameters of the density distribution, X_0, P_{GK} for attribute Amplitude

Class surface	Parameters of the density on the basis of Amplitude		X_0	P_{GK} %
Smooth	$a_1 = 13{,}2$	$b_1 = 7{,}2$	18	25
Double-reflective	$a_2 = 23{,}4$	$b_2 = 6{,}1$		18

Table 9. Parameters of the density distribution, $X_0, P_{\max}^{GK}$ for attribute Relation

Class surface	Parameters of the density on the basis of Relation		X_0	P_{GK} %
Smooth	$a_1 = 1{,}5$	$b_1 = 0{,}5$	2,2	25
Double-reflective	$a_2 = 2{,}9$	$b_2 = 0{,}9$		10

Analysis of the outcomes based on the criteria for informativity shows that both attributes Amplitude and Relation are informative.

3.2.2. Synthesis of classifier of reflecting surfaces with application of fuzzy logic conclusion by the method of Mamdani

The fuzzy logic conclusion (Fuzzy logic inference) is approximation of the dependence $y = f(x_{1,}x_{2,}...x_n)$ with the help of fuzzy knowledge base and operations over fuzzy sets. The main methods of fuzzy logic inference are based on the algorithms of Mamdani, Sugeno, Larsen, and Tsukamoto [8]. The Mamdani model for small training sample, gives better accuracy and simpler but meaningful interpretation of its parameters in comparison with the other approaches. [9]

In a specific task the classifier, based on fuzzy logic has 2 inputs, determined by the number of informative attributes and two outputs – corresponding to the number of classes.

The description of the range of variation of input and output variables is with triangular membership functions. The transformation of input variables into output variables is performed by the algorithm of Mamdani (Fig. 10).

The limit values of input variables of both classes and the parameters of the membership function of the input data for each attribute are given in Table 10 ÷ Table 12

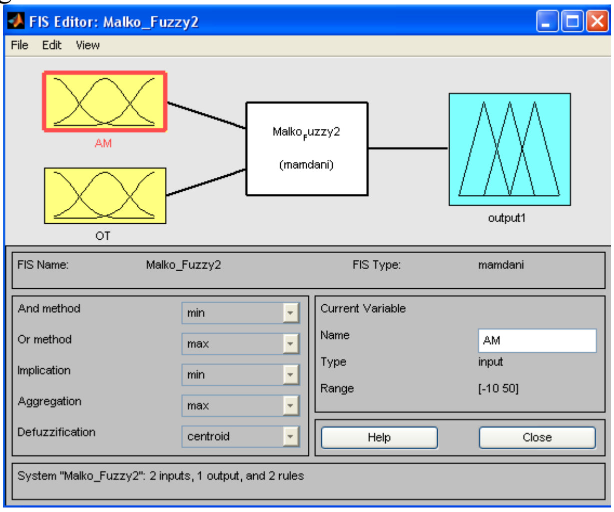


Fig.10. Fuzzy logical conclusion by the method of Mamdani

Table 10. Limit values for attributes for different types of surfaces

Attribute	Type of aircraft	Limit values of the attribute	
		min	max
Amplitude	Smooth	-4,1	30,5
	Double-reflective	8,9	37,9
Relation	Smooth	0,1	2,9
	Double-reflective	0,2	5,5

Table 11. Parameters of membership function for input variables for attribute Amplitude

Input variables	Min	Mean	Max
AMg	-4,1	13,2	30,5
AMd	8,9	23,4	37,9

Table 12. Parameters of the membership function of input variable of attribute Relation

Input variables	Min	Mean	Max
OTg	0,12	1,6	2,9
OTd	0,20	2,8	5,5

The membership functions of the input variables „Amplitude” are given in Fig.11

The output variables are presented on (Table 13). An output variable is determined by discrete levels 1 and 2, which are responsible for the corresponding class of surfaces.

Two management rules are developed (see Table 14). The parameters of the membership function for the output function are given respectively in Table 15.

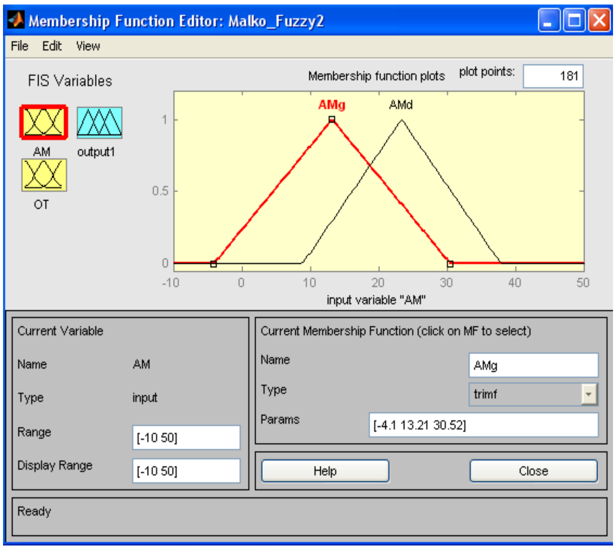


Fig.11 Membership function of input variables „A”

Table 13. Indication of the output variable

Class	Indication
Class 1 Smooth	Gladki
Class 2 - Double-reflective	Dwukratni

Table 14. Management rules (logical conclusion)

1. if (AM is AMg) and (OT is OTg) then (output 1 is Gladki)
2. if (AM is AMd) and (OT isOTd) then (output 2 is Dwukratni)

Table 15. Parameters of the membership function for the output variable

Class	Min	Mean	Max
Smooth	0,00	0,25	0,50
Double-reflective	0,50	0,75	1,00

These data are used in the synthesis of the classifier. The rules for logical inference and the parameters of the membership function of the output variable are set in the Fuzzy Logic editor of Matlab.

Training samples are input vectors formed by the values of the attributes for the corresponding classes. The Fuzzy classifier is trained in a given input vector to compare a corresponding output vector, defined by a logical rule. The result from the training can be visualized through the window shown in Fig.12. With input data of AM (Amplitude) =27.2 and OT (Relation) = 0.633, the Fuzzy classifier gives result with a value greater than 0.5, which according to the parameters of the membership function of the output variable mean for double-reflective surface.

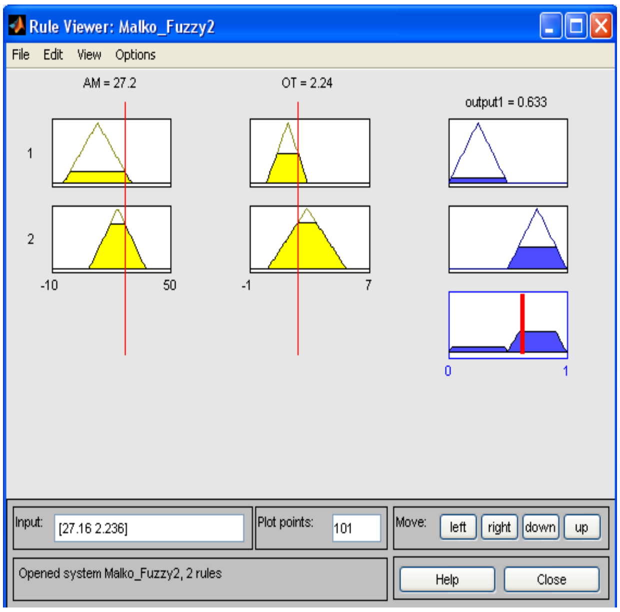


Fig.12 Visualization of the result from the work of the Fuzzy classifier

A graphic user interface (GUI) is designed in the programming environment of Matlab 7.0 to ease research [10].

3.2.3. Graphic user interface (GUI) of a software application for recognition of dynamic object B2 by attributes „Amplitude” and „Ratio”

The input window of the interface is given in Fig. 13. The work of the Fuzzy classfier can be tested through the interface by ordered pairs from a database, for which the outcome of the classifier is known (Fig.14, Fig.15) It can also be analyzedfor data outside the practical limits of the attributes (Fig. 16), and to determine the type of the reflecting surface in a random data. Fig.17

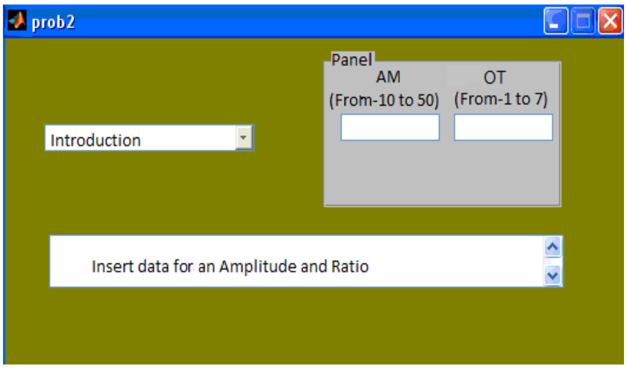


Fig. 13. Input window of the interface for determining the type of reflecting surface

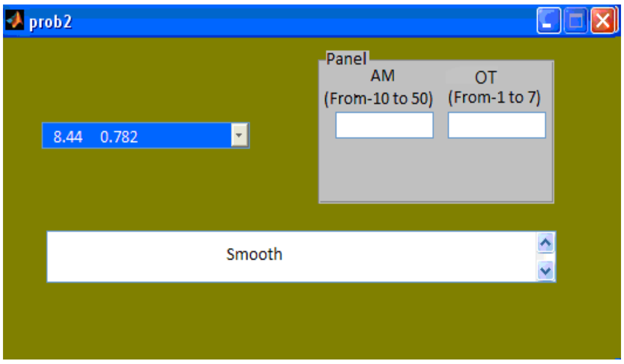


Fig. 14. Testing the classifier for smooth surfaces from object B2

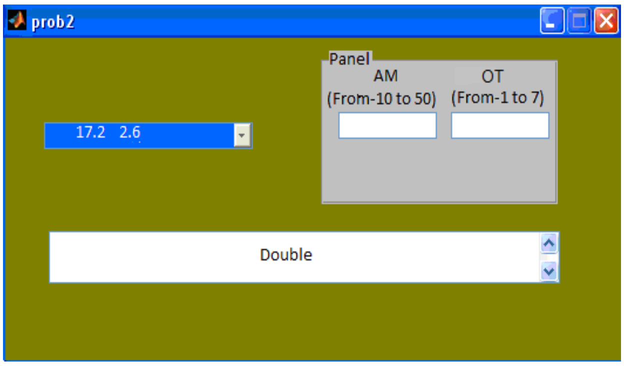


Fig. 15 Testing the classifier for double-reflective surfaces

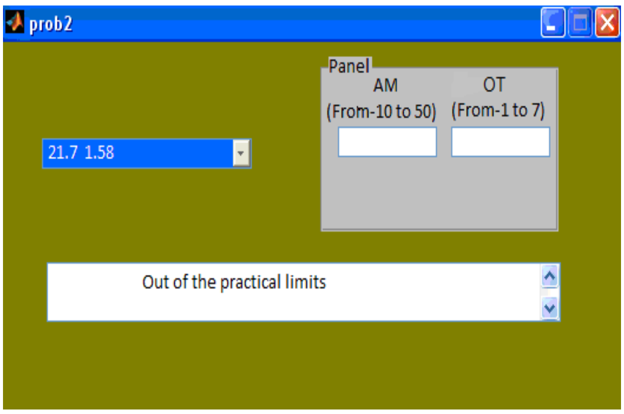


Fig. 16. Testing the classifier on data outside the practical limits of attributes for object B2

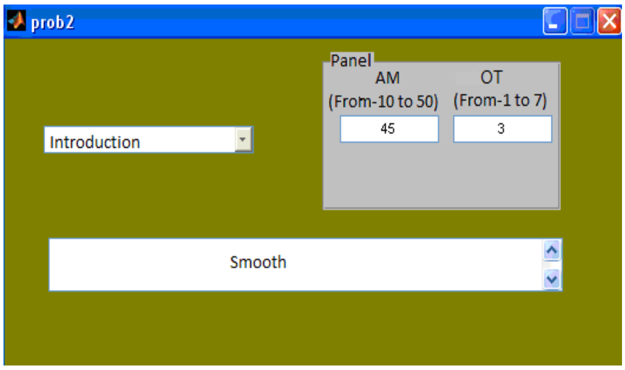


Fig. 17. Determining the type of the reflecting surface in a random data of the attributes

The developed statistical methods for detecting object B2 can be incorporated into a recognition system, which works on a conjunctive principle. The decision is taken based on the classic logical inference:

IF

the likelihood of criteria amplitude from the whole object is greater than 50% $\wedge$

the likelihood of criteria amplitude from smooth surfaces is greater than 50% $\wedge$

the likelihood of criteria amplitude from double-reflective surfaces is greater than 50% $\wedge$

the likelihood of criteria relative phase shift is greater than 50% $\wedge$

met criteria for dominant type of reflecting surface in a corresponding sector of observation

THEN the object is B2

Conclusions

1. Statistical processing of emulative data for object B2, allows for the design of models of the field of dispersion (amplitude-phase) from the object as a whole, as well as from its individual parts (smooth and double-reflective surfaces).

2. The analysis of the field of dispersion from the object and its segments, enables the identification of components of that field in a given sector of observation through intelligent modelling.

3. The developed „intelligent" system is open-ended and allows implementation of new modules for analysis of the field of dispersion of a wider class of objects.

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