Contemporary Engineering Sciences, Vol. 8, 2015, no. 19, 885 - 900
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2015.57217

Objects Hyperspectral Features Identification on the Base of Fuzzy Linear Regression and Fuzzy Similarity Measures

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Abstract

The classification process support algorithms of shooting hyperspectral data, realizing objects' identification of the Earth's surface by means of their hyperspectral features' analysis, received from the processed space images with application of various similarity measures, are considered. Identification algorithms on the base of Euclidean distance similarity measure, angular similarity measure and fuzzy similarity measure are considered. The use expediency of fuzzy linear regression in the algorithm of objects' hyperspectral features' identification is shown. Results of hyperspectral information processing with using of the offered algorithms are presented.

Keywords: identification algorithm, hyperspectral feature, coefficient of spectral reflection, coefficient of spectral brightness, Euclidean distance similarity measure, angular similarity measure, fuzzy similarity measure, fuzzy linear regression, consolidation

1 Introduction

The problem of processing and analysis of hyperspectral information formed on the base of hyperspectral images of the Earth's surface presented by a big set of pictures of the same scene in the narrow adjoining spectral ranges received from a board of the spacecraft is one of the actual tasks solved by systems of Earth remote sensing. So, in particular, the Russian space crafts «Resource-P» No. 1 and «Resource-P» No. 2 with the hyperspectral equipment (HSE) onboard started respectively on June 25, 2013 and on December 26, 2014 give out sets of pictures in 130 narrow adjoining ranges of visible area of spectrum which form a hyperspectral image (HSI). When processing GSI much attention is paid to questions of objects' identification of the Earth's surface, using their hyperspectral features (HSF).

Object's HSF in a graphic form can be presented as display of interrelation between the wavelength and values as spectral brightness coefficient (SBC), and spectral reflection coefficient (SRC) of the analyzed object. However at the solution of a problem of object's identification on its HSF use of SRC dependence on wavelength is more preferable as this brightness characteristic doesn't depend on shooting conditions in such degree as SBC. Besides, unlike SBC, for obtaining SRC values the standard reflecting surface in sight of the analyzed object isn't necessary.

Object's identification on its HSF can be carried out by means of comparison with application of some similarity measures of the analyzed object's HSF with some standard HSFs united in special spectral libraries [1–3]. Thus the analyzed and standard HSFs must have identical units of measure, spectral range and permission of data [4].

The analysis of works [5–9] testifies that for the problem solution of objects' identification of the Earth's surface on their HSFs the following approaches are most often used: algorithms on the base of similarity measures; method of a spectral corner; artificial neural networks; algorithm of k-averages; method of maximum likelihood.

The materials of experimental studies, received with application of the above approaches testify that we haven't algorithms which provide the demanded quality of objects' identification on their HSF in the prevailing majority of cases. Thus, the development problem of identification's algorithms of objects' HSF of the Earth's surface with application of various reasonably chosen similarity measures, and also of consolidation algorithm of identification's private results of objects' HSF received when using several identification's private algorithms of objects' HSF is actual [10–14].

For the solution of identification's problem of objects on its HSFs it is offered to use at the same time four algorithms of HSF identification based on Euclidean distance similarity measure, angular similarity measure and two fuzzy similarity measures for the purpose of the subsequent consolidation of identification's private results of objects' HSF.

The choice of Euclidean distance similarity measure can be proved by high efficiency of application of the given measure at the solution of various applied problems of identification (classification), including problems of identification when processing space images. The choice of angular similarity measure assuming realization of spectral corner method (Spectral Angle Mapper – SAM), can be proved by that this measure provides good identification's results of objects' HSF having similar values of points' brightness of the image in all spectral ranges even when on initial images effects of a flare are observed. This fact is explained by that the spectral corner method doesn't consider brightness values of image points. Application expediency of fuzzy similarity measures [5, 6] can be proved by that the analyzed HSF of object can belong at the same time to different classes of objects while algorithms of «rigid» identification which are algorithm on the base of Euclidean distance similarity measure and algorithm on the base of angular similarity measure, will unambiguously carry the analyzed object's HSF to any one unambiguously certain class that can be not always true. Algorithms of «soft» identification based on application of fuzzy similarity measures will allow to solve flexibly a problem of object's identification using HSFs.

2 Identification of object's hyperspectral characteristics on the base of Euclidean distance similarity measure

Identification of object's HSF on the base of Euclidean distance similarity measure realizes identification of HSF with use of well known Euclidean metrics for calculation of distance between two points in the J-dimensional space [14]:

$$E = \left(\sum_{\mathrm{j}=1}^{J} (y_{\mathrm{j}}^{\mathrm{A}} - y_j^S)^2 \right)^{0,5}, \tag{1}$$

where y_j^A is the SRC value of the analyzed HSF for the j-th hyperspectrometer channel; y_j^S is the SRC value of the standard HSF for the j-th hyperspectrometer channel; $j = \overline{1, J}$; J is the hyperspectrometer channel's number, equal to points' number (measurements) for HSF (for example, $J = 96$).
Wavelength λ_j for j-th hyperspectrometer channel ($j = \overline{1, J}$) is considered as well known value. The SRC values of the analyzed and standard HSFs are put in compliance to wavelengths.

Algorithm of HSF identification on the base of Euclidean distance similarity measure assumes: calculation of Euclidean distance similarity measures (1) for the analyzed HSF and standard HSFs, stored in the database; ordering on increase of the calculated values of Euclidean distance similarity measures; choice as required that standard HSF for which value of Euclidean distance similarity measures (1) is minimum.

3 Identification of object's hyperspectral characteristics on the base of angular similarity measure

Identification of object's HSF on the base of angular similarity measure assumes use of spectral corner method (Spectral Angle Mapper – SAM) realizing an assessment of similarity of the analyzed and standard HSF, considered as vectors which dimension is equal to number of hyperspectrometer channels, by means of corner's calculation between them [4]:

$$\alpha = arccos\frac{G \cdot G'}{|G| \cdot |G'|} = arccos\frac{\sum_{j=1}^{J} g_j \cdot g'_j}{\left(\sum_{j=1}^{J} g_j^2\right)^{0,5} \cdot \left(\sum_{j=1}^{J} (g')^2\right)^{0,5}} \qquad (2)$$

where G and G' are the spectrums of the analyzed and standard HSFs respectively; g_j and g' are the SRC values of the analyzed and standard HSFs respectively for wavelength's value λ_j ($j = \overline{1, J}$); J is the hyperspectrometer channel's number.

Algorithm of HSF identification on the base of angular distance similarity measure assumes: calculation of angular similarity measures (2) for the analyzed HSF and standard HSFs, stored in the database; ordering on increase of the calculated values of angular distance similarity measures; choice as required that standard HSF for which value of angular distance similarity measures (2) is minimum.

Often because of errors of HSE, resulting in inaccuracy of information on the about the analyzed object's HSF and also because of almost total absence of the «pure» analyzed HSF and existence in most cases of the analyzed HSF representing mix from several basic classes [5], it is expedient to consider some standard HSFs having the smallest values of Euclidean distance similarity measure (1) and angular similarity measure (2) as the potentially required. However, despite use at identification of a large number of the standard HSFs, results of identification with application of Euclidean distance similarity measure or angular similarity measure can be unsatisfactory.

In this regard it is expedient to carry out confirmation of identification's result, which, in particular, can be received by means of application of other identification's algorithms of object's HSF with the subsequent consolidation of identification's private results. As show experimental studies, the good consolidating identification's result provides sharing of HSF identification's algorithms on the base of Euclidean distance similarity measure, on the base of angular similarity measure and on the base of fuzzy similarity measures.

4 Identification of object's hyperspectral characteristics on the base of fuzzy similarity measures

Identification of object's HSF can be executed on the base of classical linear regression's equation (CLR) by means of the problem's solution of equation parameters' selection (k and b) for the analyzed HSF and standard HSF (for example, according to method of least squares):

$$y = k \cdot x + b \qquad (3)$$

with the subsequent calculation of root-mean-square deviation (RMSD) for the analyzed HSF and standard HSF, which can be used as the characteristics of uniqueness at HSF identification.

If for object’s HSF identification we use only one characteristic of uniqueness – such as RMSD, in some cases objects’ HSF, having approximately equal values of RMSD, can be carried to one class in spite of the fact that the form of curve for objects’ HSF will be various. In this regard for identification of object’s HSF it is offered to use additional characteristics of uniqueness which can be received on the base of fuzzy linear regression (FLR) equation. These characteristics can be used for calculation of fuzzy similarity measures.

In [6] it is shown that is most expedient to use FLR equation with asymmetric fuzzy parameters as it (unlike FLR equation with symmetric fuzzy parameters) provides calculation of the uniqueness characteristic’s value – RMSD, which is equal or close to the value received by means of CLR equation:

$$Y(x) = A_1 \cdot x + A_0 , \tag{4}$$

where $A_1 = (a_1, c_1, d_1)$ and $A_0 = (a_0, c_0, d_0)$ – triangular fuzzy numbers (TFN), corresponding to parameters k и b of CLR equation (3), represented by means of the triangular membership functions, and considered as the asymmetric fuzzy parameters of FLR equation (4).

When algorithms’ developing of object’s HSF identification on the base of fuzzy measures various fuzzy similarity measures [5] can be used. Thus identification algorithms will have identical stages of realization.

At the first stage of algorithm parameters (namely TFN) the FLR equation of the analyzed HSF are defined. Therefore the problem of square programming (PSP) formulated as follows [6] is solved:

$$\begin{aligned} F_{\text{ЗКП}} &= k_1 \cdot \sum_{j=1}^{J} (y_j - \sum_{i=0}^{n} a_i \cdot x_{ji})^2 + \\ &+ k_2 \cdot (1-\alpha) \cdot \sum_{j=1}^{J} \sum_{i=0}^{n} (c_i + d_i) \cdot x_{ji} + \xi \cdot \sum_{i=0}^{n} (c_i^2 + d_i^2) \to \min_{a,c,d} \end{aligned} \tag{5}$$

and

$$\sum_{i=0}^{n} a_i \cdot x_{ji} + (1-\alpha) \cdot \sum_{i=0}^{n} d_i \cdot x_{ji} \ge y_j , \tag{6}$$

$$\sum_{i=0}^{n} a_i \cdot x_{ji} - (1-\alpha) \cdot \sum_{i=0}^{n} c_i \cdot x_{ji} \le y_j , \tag{7}$$

$$c_i \ge 0; d_i \ge 0 \ (j = \overline{1, J};\ i = \overline{0, n};\ n = 1), \tag{8}$$

where j is the ordinal number of hyperspectrometer channel ($j = \overline{1,J}$); J is the hyperspectrometer channel’s number; i is the ordinal number of TFN (if $n = 1$ then $i = \overline{0,1}$); $x_{j0} = 1$ ($j = \overline{1,J}$) – parameter b of CLR equation (2); x_{j1} – wavelength value for the j-th hyperspectrometer channel; y_j is the SRC value for wavelength x_{j1} ($x_{j1} = \lambda_j$); α is a value of TFN level, characterizing FLR corridor’s width ($\alpha \in [0,1]$); k_1, k_2 are the weight coefficients characterizing a contribution of the first and second items in the objective function (5); ξ is a small positive number such that $k_1, k_2 \gg \xi$ (the third item is entered into criterion function in order that it had a square type and that at the search of TFN values could formulate the PSP [15]).

At the solution of PSP (5)–(8) it is supposed that $k_1 = k_2 = 1$ (in [6] it is shown that the choice of parameters' values k_1, k_2 has no strong impact on the problem solution); $\xi = 0{,}001$.

Let $a_0 = z_1; c_0 = z_2; d_0 = z_3; a_1 = z_4; c_1 = z_5$; $d_1 = z_6; x_{j1} = \lambda_j; y_j = g_j$. Then PSP (5) – (8) can be written as:

$$F_{ЗКП} = \sum_{j=1}^{J} (g_j - z_1 - z_4 \cdot \lambda_j)^2 + \\ + \sum_{j=1}^{J} (z_2 + z_5 \cdot \lambda_j + z_6 \cdot \lambda_j) + 0,001 \cdot (z_2^2 + z_3^2 + z_5^2 + z_6^2) \rightarrow \min_{z_1,\ldots,z_6} \tag{9}$$

and

$$\begin{cases} z_1 + z_3 + z_4 \cdot \lambda_j + z_6 \cdot \lambda_j \geq g_j; \\ z_1 - z_2 + z_4 \cdot \lambda_j - z_5 \cdot \lambda_j \leq g_j; \\ z_2 \geq 0; \\ z_3 \geq 0; \\ z_5 \geq 0; \\ z_6 \geq 0. \end{cases} \tag{10}$$

For the solution of PSP in the form of (8) at restrictions (9) the method of Lagrange uncertain multipliers can be used. In view of the fact that the solution of PSP by this method is very labor-consuming problem, use of the existing mathematical packages allowing to solve minimization problems with restrictions is expedient. In particular, can be solved in system of engineering and scientific calculations of MATLAB with application of the built-in function «quadprog» [16].

FLR equation (3) for the analyzed object's HSF is formed on the base of PSP solution (9) – (10). Thus on the base of the calculated TFNs $A_1 = (a_1, c_1, d_1)$ и $A_0 = (a_0, c_0, d_0)$ of FLR equation (4) for values of waves' lengths $x = \lambda_j$ ($j = \overline{1, J}$) characteristic points of the CLR equation $Y_{FLR}^{CLR}(\lambda_j)$ is defined:

$$Y_{\text{FLR}}^{CLR}(\lambda_j) = a_0 + a_1 \cdot \lambda_j . \tag{11}$$

Also the equations of the upper $Y_{FLR}^{UP}(\lambda_j)$ and lower $Y_{FLR}^{LOW}(\lambda_j)$ borders of FLR corridor of the analyzed characteristic are defined:

$$Y_{FLR}^{UP}(\lambda_j) = a_0 + d_0 + (a_1 + d_1) \cdot \lambda_j , \tag{12}$$

$$Y_{FLR}^{LOW}(\lambda_j) = a_0 - c_0 + (a_1 - c_1) \cdot \lambda_j . \tag{13}$$

The FLR equation (3) for the standard HSF, and also the CLR equation, the upper $Y^{UP}_{FLR}(\lambda_j)$ and lower $Y^{LOW}_{FLR}(\lambda_j)$ borders of FLR corridor, defined according to (11), (12) and (13), are formed similarly. Thus all calculated values of FLR for the standard HSF are stored in the database.

FLR corridors of the analyzed HSF and standard HSF are asymmetric (fig. 1) because of TFN's $A_1 = (a_1, c_1, d_1)$ and $A_0 = (a_0, c_0, d_0)$ asymmetry.

In this regard HSF points can be broken into 2 subsets: a subset of the points lying in the upper part of FLR corridor (between the line of upper bound of FLR corridor and the CLR line, determined respectively by the equations (12) and (11)), and a subset of the points lying in the lower part of FLR corridor (between the line of the lower bound of FLR corridor and the CLR line, determined respectively by the equations (13) and (11)).

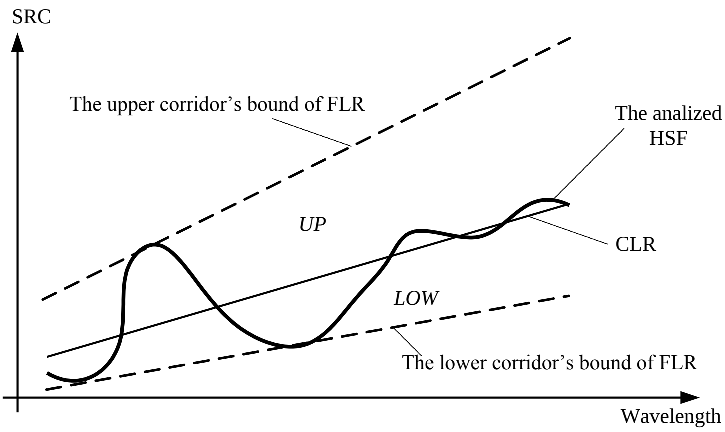

Fig. 1. HSF representation in FLR corridor

At the second stage of algorithm for the points of the analyzed HSF and each standard HSF lying in the upper UP and lower LOW parts of FLR corridors we calculate values of fuzzy similarity measures F^{UP} and F^{LOW}, using one of two fuzzy similarity measures [5]:

$$f_1 = 1 - \frac{\sum_{j=1}^{J} |u_A(\lambda_j, g'_j) - u_S(\lambda_j, g''_j)|}{\sum_{j=1}^{J} (u_A(\lambda_j, g'_j) + u_S(\lambda_j, g''_j))}, \tag{14}$$

$$f_2 = \frac{1}{J} \cdot \sum_{j=1}^{J} \frac{min(u_A(\lambda_j, g'_j), u_S(\lambda_j, g''_j))}{max(u_A(\lambda_j, g'_j), u_S(\lambda_j, g''_j))}, \tag{15}$$

where $u_A(\lambda_j, g'_j)$ is a value of membership function of fuzzy set A of the analyzed HSF to the FLR equation of this HSF for SRC value g'_j, corresponding to wavelength λ_j ($j = \overline{1, J}$); $u_S(\lambda_j, g''_j)$ is a value of membership function of fuzzy set S of the standard HSF to the FLR equation of this HSF for SRC value g''_j, corresponding to wavelength λ_j ($j=\overline{1,J}$); J is the channels' number of hyperspectrometer equal to points' number in the analyzed (standard) HSF.

These similarity measures were chosen from a set of known fuzzy similarity measures, because they showed the highest quality of identification results for the test data sets described by means of FLR equations.

Value of membership function of some HSF point (λ_j, g_j) to the FLR equation of this HSF can be defined as [6]:

$$u(\lambda_j, g_j) = \begin{cases} 1 - \dfrac{a_0 + a_1 \cdot \lambda_j - g_j}{c_0 + c_1 \cdot \lambda_j}, \text{if } a_0 + a_1 \cdot \lambda_j - c_0 - c_1 \cdot \lambda_j \le g_j \le a_0 + a_1 \cdot \lambda_j; \\ 1 - \dfrac{g_j - a_0 - a_1 \cdot \lambda_j}{d_0 + d_1 \cdot \lambda_j}, \text{if } a_0 + a_1 \cdot \lambda_j \le g_j \le a_0 + a_1 \cdot \lambda_j + d_0 + d_1 \cdot \lambda_j; \\ 0, \text{otherwise}; \end{cases} \quad (16)$$

where $a_0, c_0, d_0, a_1, c_1, d_1$ are the TFN's parameters calculated at the solution of PSP (9) – (10).

At the finishing third stage of algorithm for the analyzed HSF and each standard HSF at first calculation of the resultant fuzzy similarity measure, defined as minimum of fuzzy similarity measures F^{UP} and F^{LOW}, is carried out:

$$\mathrm{F} = min(F^{UP}, F^{LOW}). \quad (17)$$

Then all standard HSFs are ordered on decrease of fuzzy similarity measures' values. Thus as the required we choose that standard HSF, for which fuzzy similarity measures' value (17) is maximum.

Taking into account the stages described above it is possible to tell that HSF's identification algorithm on the base of fuzzy similarity measure assumes:

- finding of FLR equation for the analyzed HSF;
- extraction from the database of the calculated FLR values for the standard HSFs and calculation of fuzzy similarity measures' values F^{UP} and F^{LOW} according to (14) or (15) for the analyzed and standard HSFs;
- calculation of fuzzy similarity measures' values (17) for the analyzed and standard HSFs and a choice as required that standard HSF for which value of fuzzy similarity measures' value (17) is maximum.

5 The consolidation algorithm of identification's private results of object's HSF

As it was already noted, for improvement of identification's quality of the analyzed object's HSF the consolidation realization of identification's private results (in one way or another) is necessary.

At application of four identification's algorithms to the analyzed HSF and some standard HSFs four values are calculated: value of Euclidean distance similarity measure E (1); value of angular similarity measure α (2); two values of fuzzy similarity measures and, the formulas (14), (15) F_1 and F_2 (17) calculated according to (14), (15) и (17).

During the work with the database containing information on the standard HSFs for the analyzed object's HSF the four identifying sets will be received. Each set is the application's result of one of four HSF identification's algorithms and contains K values (according to number of the standard HSFs in the database).

Each such identifying set can be ordered on decrease (increase) of values of the used similarity measure. As a result some rating estimates will be appropriated to the standard HSFs in the database (ordinal numbers in a rating): than value of Euclidean distance similarity measure and angular similarity measure are higher and values of fuzzy similarity measures are lower, the number in a rating is less. Let R_E^k is the rating assessment of the k-th standard HSF for the identification's algorithm on the base of Euclidean distance similarity measure E; R_α^k is the rating assessment of the k-th standard HSF for the identification's algorithm on the base of angular similarity measure α; $R_{F_1}^k$ is the rating assessment of the k-th standard HSF for the identification's algorithm on the base of fuzzy similarity measure F_1; $R_{F_2}^k$ is the rating assessment of the k-th standard HSF for the identification's algorithm on the base of fuzzy similarity measure F_2 ($k=\overline{1,K}$).

The consolidation algorithm of identification's private results of object's HSF assumes:

– the consolidation of identification's private results received with application of Euclidean distance similarity measure E, angular similarity measure α and two fuzzy similarity measures F_1 and F_2 by means of formula:

$$\overline{R}^k = (R_E^k + R_\alpha^k + R_{F_1}^k + R_{F_2}^k)/4; \quad (18)$$

– the ordering of the standard HSFs from the database on increase of average values of the rating assessments $\overline{R}^k$ ($k=\overline{1,K}$).

Let the consolidating rating assessments R_{ord}^k are defined as numbers in a rating for the average assessments $\overline{R}^k$ ($k=\overline{1,K}$). It is obvious that for the further analysis it is expedient to use the insignificant part of the best standard HSFs from the database (from 5 to 10 standard HSFs) having the smallest values (ordering numbers) of the consolidating rating assessments R_{ord}^k.

After the visual comparative analysis of identification's results of the analyzed object's HSF by means of some best standard HSFs from the database received in the above way and presented both in text and in a graphic form, the software operator can make a final decision on compliance to the analyzed object's HSF of some standard HSFs from the database.

6 The experimental studies

The software developed on the base of the offered identification's algorithms was used at the solution of HSF identification's problem of various objects of the Earth's surface. In particular, HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013», taken from the processed hypespectral image of Sevastopol city, was analyzed. In the database at the time of implementation of this analysis there were about 100 standard HSFs received on the base of spectral library ASTER [2], hyper spectral images of such cities as St. Petersburg (Russia), Sevastopol (Russia) and Los Angeles (USA), received from spacecraft «Resource-P». At the solution of identification's problem of the analyzed HSF with application of four considered above identification's algorithms all standard HSFs from the database were used.

The five best identification's results of the analyzed HSF are presented in table 1. Thus the ordering numbers R^k_{ord} of the best standard HSFs determined by means of streamlining according to increasing of the consolidating rating assessments $\overline{R}^k$ ($k=\overline{1,K}$) of all standard HSFs, names of the best standard HSFs with the indication of their class and subclass, and also the ordering numbers of the standard HSFs defined at individual application of HSF identification's algorithms to HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013» on the base of Euclidean distance similarity measure, angular similarity measure and two fuzzy similarity measures are given.

In all presented tables including in the table 1, the ordering numbers of the three best HSFs, defined at individual application of HSF identification's algorithms and in consolidation's result of identification's private results of object's HSF, are highlighted in bold type. The fragments of the software's main window containing graphic interpretation of HSF identification's results are given in fig. 2 and 3. Thus are shown: the analyzed HSF, the CLR line, borders of FLR corridor and the standard HSF (chosen from the table of HSF identification's results). Points of the analyzed HSF are marked with the daggers markers, the interpolated points of the analyzed HSF are marked with the square markers, and points of the standard HSF are marked with the round markers. The analyzed HSF and standard HSF with ordering number 1 (table 1), corresponding to object's HSF «Deciduous trees, area of Sakskoye lake, suburb of Yevpatoria city. «Resource-P», August 3, 2013» are presented in fig. 2.

Table 1. The best identification's results of HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013» (consolidation)

R^k_{ord}	Object's name with the standard HSF	Class	Subclass	$\overline{R}^k$	R_E	R_α	R_{F_1}	R_{F_2}
1	Deciduous trees, area of Sakskoye lake, suburb of Yevpatoria city. «Resource-P», August 3, 2013	Trees	Vegetation	**2,25**	**1**	**3**	**4**	**1**
2	Deciduous trees in a coastal zone of the island. St. Petersburg. July 17, 2013	Trees	Vegetation	**3,5**	5	**2**	**3**	**4**
3	Green grass in the field. Park of the 300 anniversary in St. Petersburg. «Resource-P», July 17, 2013	Forbs	Vegetation	**4,25**	**4**	**1**	5	7
4	Forest glade of fire-prevention strip (sand, trees). Suburb of St. Petersburg. «Resource-P»	Trees	Vegetation	4,5	6	7	**2**	**3**
5	Forest glade, grass and bushes. Suburb of St. Petersburg. «Resource-P», July 17, 2013	Trees	Vegetation	5	**3**	4	7	6

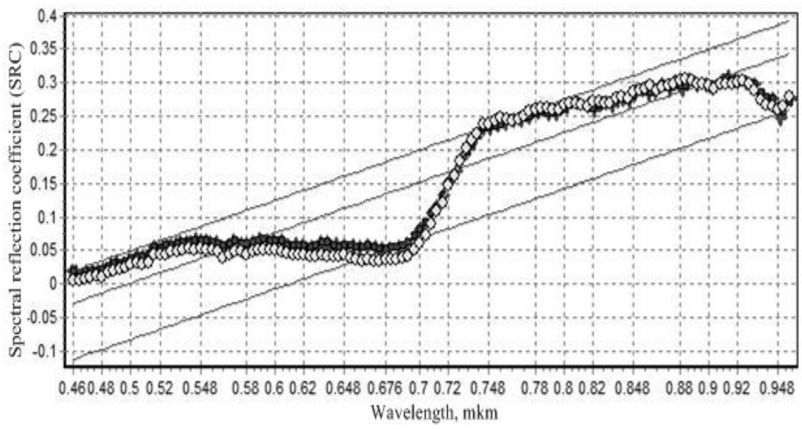

Fig. 2. Fragment of the software's main window with the identification's result presented in the graphic form (for the standard HSF with the general ordering number 1)

Thus the majority of points of the analyzed HSF coincides with points of the standard HSF. The analyzed HSF and standard HSF with ordering number 2 (table 1), corresponding to object's HSF « Deciduous trees in a coastal zone of the island. St. Petersburg. July 17, 2013» are presented in fig. 3. Thus a little bigger curves' difference of the analyzed and standard HSFs is observed.

Table 2. The best identification’s results of HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013» on the base of angular similarity measure (2)

R_α	Object’s name with the standard HSF	Class	Subclass	R_{ord}^k	$\overline{R}^k$	R_E	R_{F_1}	R_{F_2}
1	Green grass in the field. Park of the 300 anniversary in St. Petersburg. «Resource-P», July 17, 2013	Forbs	Vegetation	**3**	**4,25**	**4**	**5**	7
2	Deciduous trees in a coastal zone of the island. St. Petersburg. July 17, 2013	Trees	Vegetation	**2**	**3,5**	5	**3**	**4**
3	Deciduous trees, area of Sakskoye lake, suburb of Yevpatoria city. «Resource-P», August 3, 2013	Trees	Vegetation	**1**	**2,25**	**1**	**4**	**1**
4	Forest glade, grass and bushes. Suburb of St. Petersburg. «Resource-P», July 17, 2013	Trees	Vegetation	5	5	**3**	7	**6**
5	Rye field (green color). ASTER library, 2011	Trees	Vegetation	14	19	43	16	12

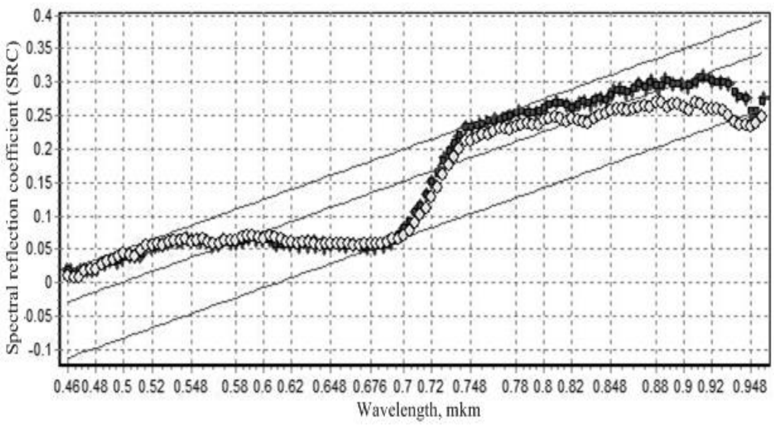

Fig. 3. Fragment of the software’s main window with the identification’s result presented in the graphic form (for the standard HSF with the general ordering number 2)

It is visible from table 1, that the majority of the standard HSFs from the list of the best identification’s results belong to the same class («Trees»). Besides, all standard HSFs from the list of the best identification’s results belong to the same subclass («Vegetation»), as the analyzed HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013» (though all standard HSFs participating in identification are divided into 4 subclasses and 11 classes).

When using only of one HSF identification's algorithm the result of identification can be less exact. So, for example, from table 2, containing five best identification’s results of the analyzed HSF «Landing of deciduous trees around a reservoir of Andreevka village of Bakhchsarai area of Crimean peninsula. «Resource-P», August 4, 2013» by means of only one HSF identification’s algorithm on the base of angular similarity measure, it is visible, that the best result of identification has incorrectly certain class. At the same time consolidation of identification's private results received with application of four identification's algorithms allows to establish more exact rating assessments $\overline{R}^k$ of the standard HSF from the database and to avoid adoption of the false decision on identification's results of the analyzed HSF. Algorithms of HSF identification on the base of Euclidean distance similarity measure and fuzzy similarity measures also not always give the HSF identification's results accepted on accuracy. In particular, at identification of HSF «An asphalt-concrete covering of Ventura fwy Highway, Los Angeles, USA. «Resource-P», September 29, 2013» HSF identification's algorithm on the base of Euclidean distance similarity measure yielded less exact identification's results, than the consolidating algorithm of HSF identification (table 3).

Table 3. The best identification's results of HSF « An asphalt-concrete covering of Ventura Highway, Los Angeles, USA. «Resource-P», September 29, 2013» Euclidean distance similarity measure (1)

R_E	Object's name with the standard HSF	Class	Subclass	R_{ord}^k	$\overline{R}^k$	R_α	R_{F_1}	R_{F_2}
1	Construction cement of light brown color. ASTER library, 2011	Main constructional materials	Anthropogenous objects	11	18,75	**9**	34	31
2	An asphalt-concrete covering of Ventura fwy Highway, Los Angeles, USA. «Resource-P», September 29, 2013	Road asphalt and bitumen	Anthropogenous objects	**1**	**1,25**	**1**	**1**	**1**
3	Gray and the white removed runway concrete (with small compound display). ASTER library, 2011	Concrete	Anthropogenous objects	**8**	**15,75**	13	**24**	**23**
4	Construction concrete of the bridge with quartz impregnations. ASTER library, 2011	Concrete	Anthropogenous objects	12	19	17	30	25
5	Concrete covering of a runway, Los Angeles, USA. «Resource-P», on September 29, 2013	Concrete	Anthropogenous objects	**3**	**6,5**	**11**	**5**	**5**

The inaccuracies of identification, when using only of one algorithms on the base of fuzzy similarity measures (table 4), are visible on the identification's example of HSF «Coastal waters in the bay «Quarantine», Sevastopol city. «Resource-P», August 3, 2013». It is visible from tables 2–4 that the consolidating identification's result (values R_{ord}^k) often happens more exact, than identification's result of private algorithm on the base of one similarity measure (values R_α , R_E and R_{F_1} respectively in the first column of the tables).

In the reviewed examples for representation of object's HSF we use SRC. Similar results were received at application of SBC for representation of object's HSF. However, as it was already stated above, use of SRC at the solution of identification's problem of object's HSF is more preferable.

Table 4. The best identification's results of HSF «Coastal waters in the bay «Quarantine», Sevastopol city. «Resource-P», August 3, 2013» on the base of fuzzy similarity measure (14)

R_{F_1}	Object's name with the standard HSF	Class	Subclass	R_{ord}^k	$\overline{R}^k$	R_α	R_E	R_{F_2}
1	The burned-out grass, field near the presidential road, Sevastopol city. «Resource-P», August 3, 2013	Forbs	Vegetation	24	36,25	**75**	61	8
2	Asphalt highway to Kotlin Island, St. Petersburg. KA of «Resource-P», July 17, 2013	Road asphalt and bitumen	Anthropogenous objects	**16**	**31,25**	84	**34**	**5**
3	Water in the gulf Long Beach Harbor, Los Angeles, USA. «Resource-P», September 29, 2013	Water	Liquids	**4**	**13,75**	**35**	**16**	**1**
4	Sea water in the Sevastopol bay, Sevastopol. «Resource-P», August 3, 2013	Water	Liquids	**1**	**2,5**	**2**	**1**	**3**
5	The field «under the ferry» (without crops), the area of the presidential road, Sevastopol city. «Resource-P», August 3, 2013	Farmland	Anthropogenous objects	20	34,5	80	47	6

7 Conclusions

The results of experimental studies confirm expediency of further development of the offered approach to the solution of identification's problem of objects' HSF, based on consolidation of identification's private results objects' HSF, received with application of various reasonably chosen identification's algorithms for the purpose of reliability's increase of classification decision [11, 17]. Further researches can be directed on reasonable attraction of new similarity measures for the solution of identification's problem and improvement of consolidation algorithm of identification's private results of objects' HSF.

Use of the offered approach for developing HSF identification's algorithms will allow to solve objects' identification's problem of the Earth's surface on allocated from the processed space images of spacecraft «Resource-P» HSF with the subsequent accumulation of the standard HSFs in the database that, in turn, will provide creation of actual domestic spectral library of standards HSFs which can be applied when monitoring a condition of agricultural grounds, forests, water resources, an ecological condition of soils, etc.

References

[1] USGS Spectroscopy Lab. http://speclab.cr.usgs.gov

[2] Jet Propulsion Laboratory, ASTER Spectral Library, NASA. http://speclab.jpl.nasa.gov

[3] A.M. Baldridge, S.J. Hook,, C.I. Grove,, G. Rivera, The ASTER spectral

library version 2.0, *Remoute Sensing of Environment*, **113** (2009), 711 - 715. http://dx.doi.org/10.1016/j.rse.2008.11.007

[4] C. Yang,, J H. Everitt,, J.M. Bradford, Yield estimation from hyperspectral imagery using spectral angle mapper (SAM), *American Society of Agricultural and Biological Engineers*, **51** (2008), 729 - 737. http://dx.doi.org/10.13031/2013.24370

[5] D. Van der Weken, M. Nachtegael,, E.E. Kerre, An overview of similarity measures for images, *Proceedings of ICASSP 2002 (IEEE Int. Conf. Acoustics, Speech and Signal Processing)*, **4** (2002), 3317 - 3320. http://dx.doi.org/10.1109/icassp.2002.5745363

[6] Lee Haekwan, Tanaka Hideo, Fuzzy approximations with non-symmetric fuzzy parameters in fuzzy regression analysis, *Journal of the Operations Research Society of Japan*, **42** (1999).

[7] J.D. Adams, M.O. Smith, P.E. Johnson, Spectral mixture modeling: A new analyst of rock and soil types at the Viking Lander 1 site, *Journal of Geophysical Research*, **91** (1996), 8090 - 8112. http://dx.doi.org/10.1029/jb091ib08p08098

[8] K. Michael, Su Griffin at al., Examples of EO-1 Hyperion Data Analysis, *Lincoln Laboratory Journal*, **15** (2005), 271 - 298.

[9] E.V. Nikulchev, Geometric method of reconstructing systems from experimental data, *Technical Physics Letters*, **33** (2007), 267 - 269. http://dx.doi.org/10.1134/s1063785007030248

[10] N.N. Astakhova, L.A. Demidova, E.V. Nikulchev, Forecasting Method for Grouped Time Series with the Use of k-Means Algorithm, *Applied Mathematical Sciences*, **9** (2015), 4813 - 4830. http://dx.doi.org/10.12988/ams.2015.55391

[11] L.A. Demidova, N.I. Nesterov, Fuzzy and possibilistic segmentation of earth surface images by means of intelligent information technologies, *Proceedings 2014 International Conference on Computer Technologies in Physical and Engineering Applications*, *ICCTPEA* (2014), 35 - 36. http://dx.doi.org/10.1109/ICCTPEA.2014.6893262

[12] L.A. Demidova, Genetic algorithm for optimal parameters search in the one-factor forecasting model based on continuous type-2 fuzzy sets, *Automation and Remote Control*, **74** (2013), 313 - 320. http://dx.doi.org/10.1134/s000511791302015x

[13] L.A. Demidova, S. V. Truhanov, Classification process support algorithms of shooting hyperspectral data, *Cloud of Science*, **2** (2015), 40 - 60.

(in Russian).

[14] J. Dattorro, *Convex Optimization & Euclidean Distance Geometry*, Meboo publishing USA (2005).

[15] D. M. Himmelblau, *Applied Nonlinear Programming*, The University of Texas, McGraw-Hill Book Company (1972).

[16] S. Attaway, *Matlab a Practical Introduction to Programming and Problem Solving*, Butterworth_Heinemann (2009).

[17] L. Demidova, E. Nikulchev, Yu. Sokolova, Use of Fuzzy Clustering Algorithms' Ensemble for SVM classifier Development, *International Review on Modelling and Simulations,* **8** (2015), to appear

Received: August 5, 2015; Published: September 12, 2015