A Modification of the FCM-CV-algorithm and Its Application for Radar Portraits Classification

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Abstract: *The note presents a modification of the FCM-CV-algorithm is able to detect a fuzzy partition into optimal number of fuzzy clusters. A plan of the modification is presented. An illustrative example of algorithm applied to radar portrait classification problems is described. Some preliminary conclusions are made.*

Keywords: *fuzzy clustering, cluster validity, degree of fuzziness, radar portraits*

I. INTRODUCTION

The methods of fuzzy clustering are widely used for solving various problems of pattern recognition due to their high accuracy and efficient handling of the classification results. The methods of fuzzy clustering are successfully used for space photographs analysis, in medicine, geoinformatics and military sciences.

By convention the methods of fuzzy clustering are divided into optimization, heuristic and hierarchical. Optimization procedures are the most common [1]. All optimization algorithms require number of classes as a parameter, which can be not predefined. Different cluster validity indexes are used to determine the adequate number of classes in the desired partition. The procedure that makes it possible to find fuzzy partition into the optimum number of classes is introduced in [2]. This procedure was called FCM-CV- algorithm. It combines well known FCM-algorithm of Bezdek and Dunn [3] with the calculation of cluster validity indexes.

This article introduces the modification of FCM-CV-algorithm. It uses a calculation of two cluster validity indexes with the variation of classification fuzziness index. The effectiveness of the proposed modification is demonstrated on the illustrative example of the classification of the range radar portraits of the aerospace attack arms of USAF - United States Air force.

II. A NEW VERSION OF THE FCM-CV-ALGORITHM

The optimization methods of fuzzy clustering give a solution of classification problem as the fuzzy partition $P^* = \{A^1,\ldots,A^c\}$ into the given number c of fuzzy classes. Let $A^l, l = 1,\ldots,c$ be the fuzzy sets with the corresponding membership functions $\mu_{li}, l = 1,\ldots,c, i = 1,\ldots,n$ defined on the investigated objects' set $X = \{x_1,\ldots,x_n\}$. If condition $\sum_{l=1}^{c}\mu_{li} = 1$ is satisfied for each object $x_i \in X$ then the fuzzy sets $A^l, l = 1,\ldots,c$ form the fuzzy partition $P = \{A^1,\ldots,A^c\}$ which is described by matrix $P_{c\times n} = [\mu_{li}]$, where μ_{li} is a grade of membership of element $x_i \in X$ to the certain fuzzy cluster $A^l \in \{A^1,\ldots,A^c\}$, n is an element number of the set $X = \{x_1,\ldots,x_n\}$ being classified, and c is the number of fuzzy clusters in the desired fuzzy partition P^*. The task of fuzzy clustering using optimization methods stands for evolution of the extremum of the certain functional $Q(P)$ on the set of all fuzzy partitions, which is described by formula

$$Q(P) \to \underset{P\in\Pi}{extr}, \tag{1}$$

where Π is a set of all possible fuzzy partitions P of the set of objects X being classified.

Bezdek and Dunn functional [3] is as follows:

$$Q(P) = \sum_{l=1}^{c}\sum_{i=1}^{n}\mu_{li}^{\gamma}\left\|x_i - \tau^l\right\|^2, \tag{2}$$

where γ is a fuzziness index of classification, $1 < \gamma < \infty$.

The classification problem can be solved as follows:

$$P^* = \arg\min_{P}\left\{\begin{array}{l} Q(P): P = (A^1,\ldots,A^c),\ A^l = (\mu_{l1},\ldots,\mu_{ln}), \\ \quad 0 \le \mu_{li} \le 1, \\ \sum_{l=1}^{c}\mu_{li} = 1,\ \sum_{i=1}^{n}\mu_{li} > 0, \\ \quad i = 1,\ldots,n, l = 1,\ldots,c \end{array}\right\} \tag{3}$$

Algorithm of the criterion (2) minimization is introduced in [3]. It is named FCM-algorithm (fuzzy c-means).

One of the major issues of optimization methods is a determination of the «true» number c of fuzzy clusters to which the investigated totality «is split», or in other words the most nagging problem of cluster validity arises out of the situation when the investigator doesn't have any information about number of clusters c. This problem is described by different factors, which characterize obtained fuzzy partition $P^* = \{A^1, \ldots, A^c\}$ using appropriate algorithm. In particular searching for fuzzy partition by means of FCM-algorithm different researchers also proposed a number of:

partition coefficient [4]:

$$V_{pc}(P) = \frac{1}{n}\sum_{l=1}^{c}\sum_{i=1}^{n}\mu_{li}^2 \, , \qquad (4)$$

partition entropy [5]:

$$V_{pe}(P) = -\frac{1}{n}\sum_{l=1}^{c}\sum_{i=1}^{n}\left|\mu_{li} \cdot \ln \mu_{li}\right| , \qquad (5)$$

Fukuyama-Sugano factor [6]:

$$V_{FS}(P) = \sum_{l=1}^{c}\sum_{i=1}^{n}\mu_{li}^2\left(\left\|x_i - \tau^l\right\|^2 - \left\|\tau^l - \overline{\tau}\right\|^2\right) \qquad (6)$$

$FCM-CV$-algorithm combining traditional FCM-algorithm with the calculation of any cluster validity indexes in the interval $[c_*, c^*]$, where c_* and c^* are the least and the largest possible numbers of clusters c in the desired fuzzy c-partition, is a highly effective procedure of solving classification problems, and specifically the problem of outliers identification in the investigated set of objects [7]. At the same time, different cluster validity indexes in the desired fuzzy c-partition in some cases reveal different number c of clusters as optimal.

This circumstance is caused by the high sensitivity of some factors $V_c(P)$ to the data structure and also by the fact that the initial partition in the FCM-algorithm is determined randomly, which draws insignificant changes of the membership values in the matrix of fuzzy c-partition. Considering this, it is assumed to be expedient to include into the proposed in [2] scheme of $FCM-CV$-algorithm calculation of not one, but two $V_c(P)$ factors and the rules in accordance with which fuzzy c-partition will be selected as the solution of classification problem only when the numbers of clusters c are equal for both factors $V_c(P)$. To ensure the procedure convergence it is offered to vary index γ with a certain step $\Delta\gamma$. This idea was outlined in the [7].

Thus, with the use of partition coefficient $V_{pc}(P)$ and partition entropy $V_{pe}(P)$ as the factors $V_c(P)$ the overall diagram of the $FCM-CV$-algorithm modification proposed will is as follows:

If values of c_* and c^* are given,

then $c_1 := c_*$ and $c_p := c^*$,

else $c_1 := 2$ and $c_p := n-1$ **and** the number of classes c in the desired fuzzy partition are ordered as follows: $2 \le c_1 < \ldots < c_\ell < \ldots < c_p \le n-1$; set the iteration bound γ^* of the fuzziness index of classification γ, $\gamma \in (1, \gamma^*]$; iteration step $\Delta\gamma$; $b := 1$ and $\gamma^* := \gamma_{(b)}$;

it is assumed $\ell := 1$;

calculate

3.1. using FCM–algorithm $P(c_\ell)$ partition into c_ℓ classes is calculated;

3.2. factor $V_{pc}(P)$ for the obtained partition $P(c_\ell)$ is calculated;

3.3. factor $V_{pe}(P)$ for the obtained partition $P(c_\ell)$ is calculated;

if $\ell < p$

then $\ell := \ell + 1$ and passage to step 3 is realized,

else passage to step 5 is realized;

set of $\Pi(c_*, c^*) = \{P(c_\ell) \mid \ell = 1, \ldots, p\}$ possible decisions is formed

condition is checked: **if** $\gamma_{(b)} > 1$ for a certain fuzzy partition $P(c_\ell) \in \Pi(c^*, c_*)$ on c classes $\max_c (V_{pc}(P))$ **and** $\min_c (V_{pe}(P))$ is carried out for a certain number of classes $\breve{c} \in [c_*, c^*]$, **then** this fuzzy partition on $\breve{c}$ classes is selected as the solution P^*, **else** is assumed that $\gamma_{(b+1)} := \gamma_{(b)} - \Delta\gamma$, $b := b + 1$ and passage to step 2 is realized.

III. EXPERIMENTAL RESULTS

The data about the range radar portraits of the aerospace attack arms of the U.S. Air Force: strategic bomber B-52H "Stratofortress", tactical fighter F-15A "Eagle" and the strategic cruise missile of the air basing ALCM was used for the computational experiment. It was modelled with different foreshortening angles.

The data is presented in Table 1.

Table 1. Angle of targets rotations

Number of a portrait	Target type	Angle of rotation in degrees
1	B-52	0^0
2	F-15	0^0
3		120^0
4		240^0
5	ALCM	0^0
6		60^0
7		120^0
8		180^0
9		240^0
10		300^0

Range radar portraits are depicted in figure 1.

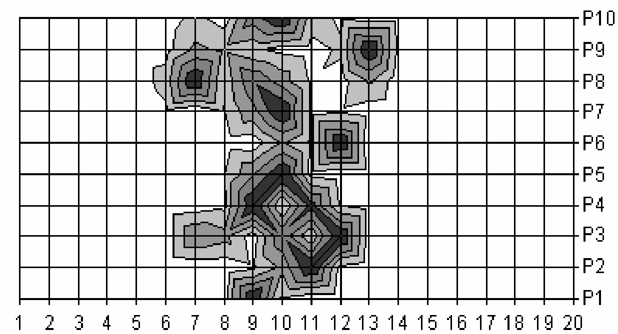

Fig. 1 - Example of radar portraits at different angle of rotations.

Computational experiments were conducted with the use as cluster validity indexes of fuzzy partition entropy determined by formula

$$V_{pe}(P) = -\frac{1}{n}\sum_{l=1}^{c}\sum_{i=1}^{n}\left|\mu_{li} \cdot \ln \mu_{li}\right|, \qquad (7)$$

with the use by which $\min_c \left(V_{pe}(P)\right)$ appears itself, and partition coefficient determined as follows

$$V_{pc}(P) = \frac{1}{n}\sum_{l=1}^{c}\sum_{i=1}^{n}\mu_{li}^2 , \qquad (8)$$

use of which requires execution of conditions $\max_c \left(V_{pc}(P)\right)$ for finding the optimum number of classes c.

Experiments were conducted with the variation of the fuzziness index γ in interval of $[\gamma_* = 1.5, \gamma^* = 4.0]$ with a step $\Delta\gamma = 0.5$, and in the interval of the number of classes $[c_* = 2, c^* = 4]$, where c_* – is the lowest and c^* – is the highest possible number of clusters in the desired (uknow) partition. In all experiments the number of classes in the obtained partition proved to be equal to three. The graphs of the behaviour of cluster validity indexes with $\gamma = 1.5$ are depicted in Fig. 2. and Fig. 3.

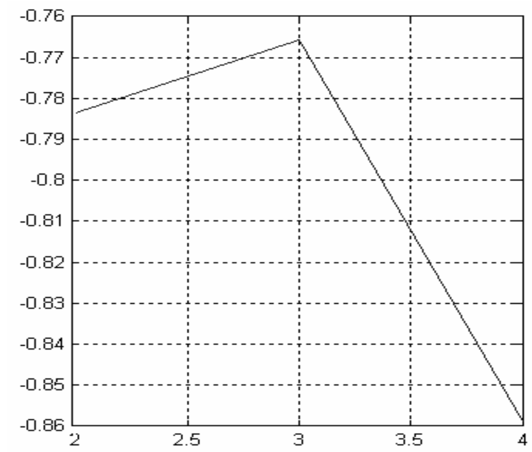

Fig. 2 - Values of cluster validity indexes (partition entropy $V_{pe}(P)$).

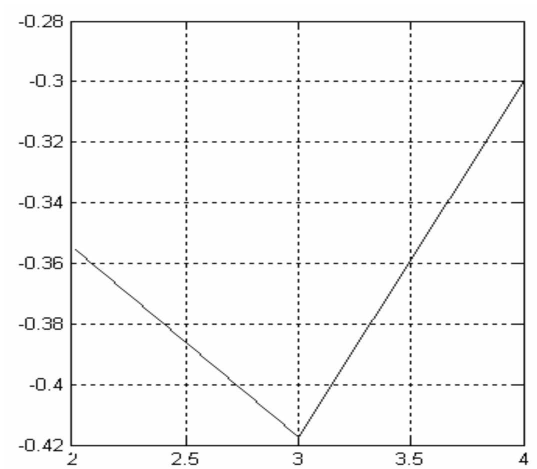

Fig. 3 - Values of cluster validity indexes (partition coefficient $V_{pc}(P)$).

Thus, the modification of $FCM - CV$-algorithm proposed and the procedure of its application make it possible to classify the range radar portraits of different arms of the aerospace attack of U.S. Air Force.

IV. CONCLUSIONS

It should be pointed out that in the procedure proposed other cluster validity indexes can be used and in this case procedure must be modified correspondingly at step 3 and step 6. Thus, the FCM-CV-algorithm modification proposed allows not only find optimum in the sense of criterion (2) fuzzy partition into the optimum number of classes as the previous version, but also to establish the number of classes with the higher accuracy or quantitatively to evaluate the spread of the structure of the totality of objects being investigated.

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