Fuzzy Clustering Methods in Multispectral Satellite Image Segmentation

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Abstract. Segmentation method for subject processing the multispectral satellite images based on fuzzy clustering and preliminary non-linear filtering is represented. Three fuzzy clustering algorithms, namely Fuzzy C-means, Gustafson-Kessel, and Gath-Geva have been utilized. The experimental results obtained using these algorithms with and without preliminary nonlinear filtering to segment multispectral Landsat images have approved that segmentation based on fuzzy clustering provides good-looking discrimination of different land cover types. Implementations of Fuzzy C-means, Gustafson-Kessel, and Gath-Geva algorithms have got linear computational complexity depending on initial cluster amount and image size for single iteration step. They assume internal parallel implementation. The preliminary processing of source channels with nonlinear filter provides more clear cluster discrimination and has as a consequence more clear segment outlining.

1 Introduction

It is known that forests and wetland are the main factors preventing the decline in biodiversity on the Earth in aggressive conditions of human activity. The main problem is agricultural expansion and deforestation. Deforestation is the consequence of two main reasons – agricultural expansion and accidental events. But forestry and agriculture are inseparable and condemned to work hand in hand. Significant part of forest is damaged by fire, pests, irrational agricultural politics leading to change of ground water level and as result leads to sickness and wreck. At now it is possible to discriminate forest areas on early stage of damaging using multispectral images of high spatial resolution received from satellites. That technology started about 40 years ago to monitor Earth surface at now is the effective instrument of ecological and agricultural monitoring such the regions as forests and wetland and preventing any accidents. Multispectral satellite images are able to bring us information in both visible and invisible spectral bands about vegetation, water temperature and land cover.

Multi-dimensional cluster analysis and segmentation are base procedures in thematic processing the multispectral images received from remote sensing satellites. There are lot of clustering and segmentation methods which have different benefits and imperfections. The special class of such the methods is represented by fuzzy clustering ones.

2 Method Description

Three clustering algorithms based on fuzzy methods where developed and utilized as part of segmentation software. There are fuzzy c-means[1] (FCM) and its variants – Gustafson-Kessel clustering algorithm [2, 3] and Gath-Geva one [4].

FCM is a method of data clustering which allows one data objects to be a member of two or more clusters. This method developed by [5] and improved by [6] is based on minimization of the following objective function:

$$J = \sum_{i=1}^{N} \sum_{j=1}^{C} \mu_{ij}^{m} \parallel x_i - s_j \parallel, \tag{1}$$

where m is real number ≥ 0, μ_{ij} – degree of membership of x_i in cluster s_j, x_i is the multi-dimensional data object, s_j is the multi-dimensional center of the cluster, and $\parallel \cdot \parallel$ is any norm expressing the similarity between any measured data and the cluster center.

Fuzzy clustering is carried out through an iterative optimization of the J_m with the update of membership matrix μ_{ij} and the cluster centers s_j using folowing algorithm:

1. The data set $X = (x_j) = (x_{j1}, x_{j2} \ldots, x_{jp})^T$ given. We choose the number of clusters $1 < c < n$, where p – dimension of data set.
2. Initialize the partition matrix μ_{ij} using random number genetrator in range [0, 1]:

$$\sum_{i=1}^{c} \mu_{ij} = 1, \tag{2}$$

3. Calculate the cluster centers $s_i = (s_{i1}, s_{i2}, \ldots, s_{ip})^T$ $(i = 1, 2, ..., c)$:

$$s_i = \sum_{j=1}^{n} \mu_{ij}^2 x_j \left/ \sum_{j=1}^{n} \mu_{ij}^2, \right. \tag{3}$$

4. Calculate the error:

$$E = \sum_{i=1}^{c} \sum_{j=1}^{n} \mu_{ij}^2 (s_i - x_j)^T (s_i - x_j). \tag{4}$$

If error is small enough, then stop iterations, else go to item 5.

5. Calculate the "new" partition matrix μ_{ij}:

$$\mu_{ij} = \left(\sum_{m=1}^{n} d_{ij}^2 / d_{mj}^2 \right)^{-\frac{1}{2}} \tag{5}$$

and then go to step 3.

where d_{mj}^2 is similarity measure $\| \cdot \|$.

Fuzzy c-means, Gustafson-Kessel, and Gath-Geva clustering algorithms are distinguished in the definition of distance function between the objects to be classified: Fuzzy C-means:

$$d_{ij}^2 = (s_i - x_j)^T (s_i - x_j), \tag{6}$$

Simple euclidean distance provides hyper-spherical form of clusters.

Gustafson-Kessel:

$$d_{ij}^2 = (s_i - x_j)^T (det(F_i)^{\frac{1}{2}} F_i^{-1})(s_i - x_j), \tag{7}$$

Gath-Geva:

$$d_{ij}^2 = \frac{det(F_i)^{\frac{1}{2}}}{\alpha_i} \exp(\frac{1}{2}(s_i - x_j)^T (F_i^{-1})(s_i - x_j)), \tag{8}$$

where F_i is covariance matrix, that provides ellipsoidal form of clusters and more comprehensive partitioning the multi-dimensional data, α_i is calculated in following manner:

$$\alpha_i = \frac{1}{n} \sum_{j=1}^{n} \mu_{ij}. \tag{9}$$

Covariance matrix is used to form non-spherical clusters which are more suitable for multi-dimensional data partitioning. That also leads to visible difference in algorithm convergence, effectivity and performance of processing the multispectral images.

Distance function for Gustafson-Kessel and Gath-Geva algorithms uses covariance matrix to take into account different metrics (scales) in different dimensions. The large images to be processed might be the reason of weak covariance matrix conditionality that results in heavy losses of aptitude for discrimination for Gustafson-Kessel and overflows for Gath-Geva when fixed digit capacity arithmetics based on atomic numerical types is used. To keep of that problems standard normalization methods and arbitrary (multi-precision) arithmetics are the sufficient efforts. When d_{ij}^2 becomes small the overflow may occure. To prevent that case the distant function is confined from below by some smallest value d_{min}.

Due to source signal noise the some spatial segment granularity occurs. To reduce that granularity the weak nonlinear filtering using algorithm [7] was applied to source channels. That algorithm may be used both for edges extraction and for nonlinear filtering. It does not lower the sharpness of transitions of channel brightness the boundaries of cover types remain clear. As a result the boundaries of spatial segments after clustering process also remain legible. Algorithm works with values of brightness and pixels' coordinates simultaneously. To form the homogeneous areas or search the edges on the gray-scale image a round mask is used. Usually the mask's radius is 3.4 pixels which
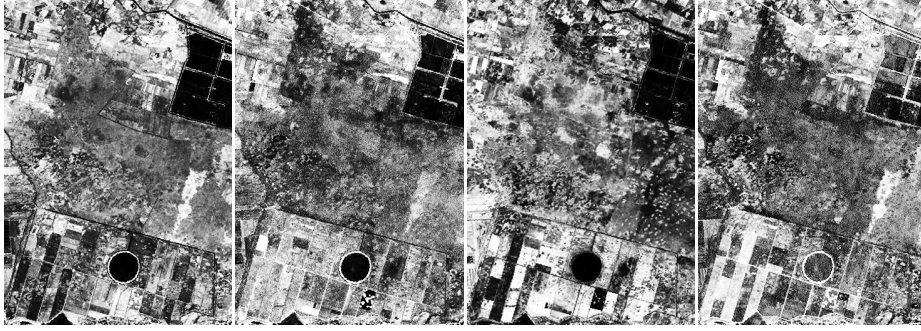
Fig. 1. Channels 2-5 of multispectral Landsat image to be processed with fuzzy clustering algorithm.

gives mask of 37 pixels size. The mask is placed at each point of the image and the brightness of each pixel of the mask is compared with the brightness of the mask central pixel.

$$c(\mathbf{r}, \mathbf{r}_0) = \begin{cases} 1, I(\mathbf{r}) - I(\mathbf{r}_0) \leq t \\ 0, I(\mathbf{r}) - I(\mathbf{r}_0) > t, \end{cases} \quad (10)$$

where $I(\mathbf{r}_0)$ – the brightness value of the mask's center, $I(\mathbf{r})$ – the brightness value of the mask pixel, t specific threshold.

The result of the comparisons is sum:

$$n(\mathbf{r}_0) = \sum_{\mathbf{r}} c(\mathbf{r}, \mathbf{r}_0). \quad (11)$$

where n is the quantity of pixels in the USAN (Univalue Segment Assimilating Nucleus). Then that sum should be minimized, so the algorithm is called SUSAN (Smallest USAN). Parameter t means the maximum of ignored noise. Then n is compared with it's thresholding value g, which is $3n_{max}/4$, where n_{max} – maximum value which could be assigned to n.

3 Experimental Results

To test the fuzzy clustering algorithms the multispectral Landsat images have been used. Fig. 1 shows channels 2-5 which were chosen for processing. Landsat channels shown on fig.1 have different dispersion and were equalized using `netpbm` utilities to make them visible more clearly. The channel data to be fed into clustering software remain untouched because of clustering algorithm takes in to account real distribution of channel signal level on one's own.

Raw output data of developed segmentation software is 2-d vector field over R^N, where N is a number of clusters. Each component of that field is strictly increasing function of probability for pixel to be member of one of N clusters.

On presented images one can see some well discriminated land cover types. There are open water, forests, wetlands, bushes and agriculture areas. Results of segmentation on 15 clusters using fuzzy C-means without any preliminary filtering show that there

also are fuzzy boundaries of segments on the cluster map going on to sand in some places. To diminish such the phenomena one can use filter which will smooth slightly changing areas rather blur clearly discriminated land cover type edges. Most appropriate filter having got such the behavior is the non-linear one described in [7]. The fig. 2 demonstrates smoothing properties of that filter when brightness threshold was choosed be equal to 7, 15, and 20. Besides the brightness threshold parameter the filter has spatial one – distance threshold which was set into default value corresponding to radius equal to about 3.4 and was not changed across experiments. As one can see, smooth-

| (a) | (b) | (c) | (d) |

Fig. 2. Nonlinear filtering samples: (a) original image, (b) brightness threshold = 7, (c) brightness threshold = 15, (d) brightness threshold = 20.

ing property of that filter increases with brightness threshold grows. At the same time some part of edges remains sharp. Amount of sharp edges and consequently cluster granularity depend on brightness threshold. Thus we get additional degree of freedom in segmentation process control that could dramatically improve the segmentation results. Nonlinear filtering lowers intraclass covariance but practically doesn't touches

interclass ones, so cluster discrimination doesn't suffer. Smoothing the channels before segmentation allows to eliminate fine granularity of output segment map and to merge the small cluster with large ones. In reality this means disappearance of some real small objects, for example, bushes in wetland areas. Nevertheless, sometimes it is necessary to get generalized segment map. The SUSAN filter allows to fulfil nonlinear processing variyng the threshold in wide region achieveing the smoothing results from neglible small up to very strong.

Fig. 3-6 demonstrate examples of segmentation using non-linear filtering with different brightness threshold for Gustafson-Kessel and Gath-Geva clustering algorithms. The cluster number was choosen taking into account real diversity of land covers for territory being ivestigated. Actually a lot of experiments with different cluster number were fulfiled. As soon as segmentation become to look stable cluster number was stated.

Obtained results have transformed into scalar field using simple maximal probability solver to get the possibility of visual evaluation and have presented as colour map of spatial partitions. As a result every pixel became a member of one cluster. All pixels of same colour are members of same cluster. No any intelligent algorithm was used to colourize segment map so the same areas on different pictures have different colours.

As one can see the growth of the threshold leads to raising the segment area when target number of clusters is fixed. However it should be pointed that general structure of segment arrangement and its structure in relation with land cover types is not significantly changed.
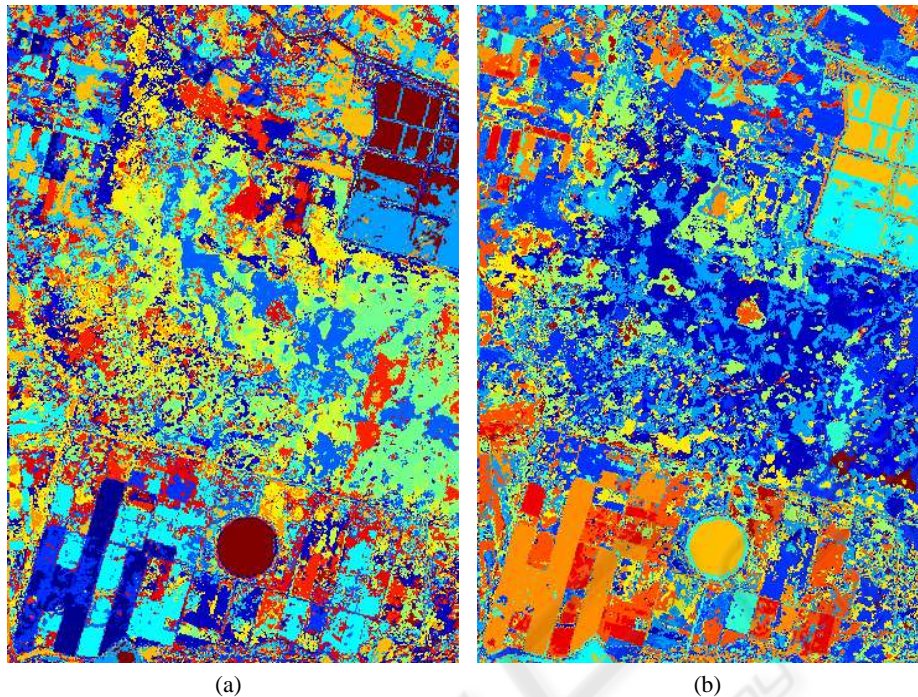
(a)   (b)
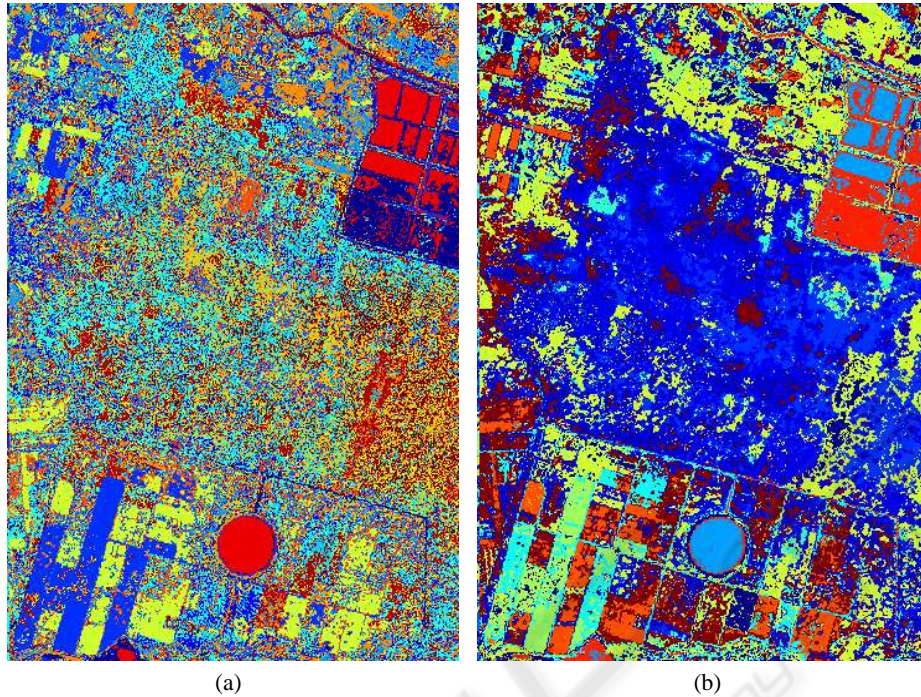
Fig. 3. Segmentation results using Gustafson-Kessel (a) and Gath-Geva (b) algorithms at 20 clusters without any filtering.

4   Conclusion

Segmentation results of multispectral Landsat images obtained using fuzzy clustering methods such as Fuzzy C-means, Gustafson-Kessel, and Gath-Geva with and without preliminary nonlinear filtering testify that segmentation using fuzzy clustering methods provides good-looking discrimination of land cover types that occurs in uch the complex cases as wetland, water-meadow, and bush areas. The discrimination quality of segmented images was tested and approoved by land-improvement specialists using data of land-based expedition. The non-linear filtering with guided smoothing is the convenient instrument of preliminary processing for semi-automatic segmentation of complex land covers.

Implementations of Fuzzy C-means and Gustafson-Kessel algorithms have got linear computational complexity depending on innitial cluster amount and image size for single iteration step. All the algorithms assume internal parallel implementation for MPP computer. The preliminary processing of source channels with nonlinear filter provides more clear cluster discrimination and has as a consequence more clear segment outlining and provides operated generalization of output segment maps.

Really, segmentation software returns the results as 2-d vector field v_i, which is the strictly increasing function of probability p_i that pixel is a member of i-th cluster. When using more complex tool then simple maximal probability solver, for example, maximal
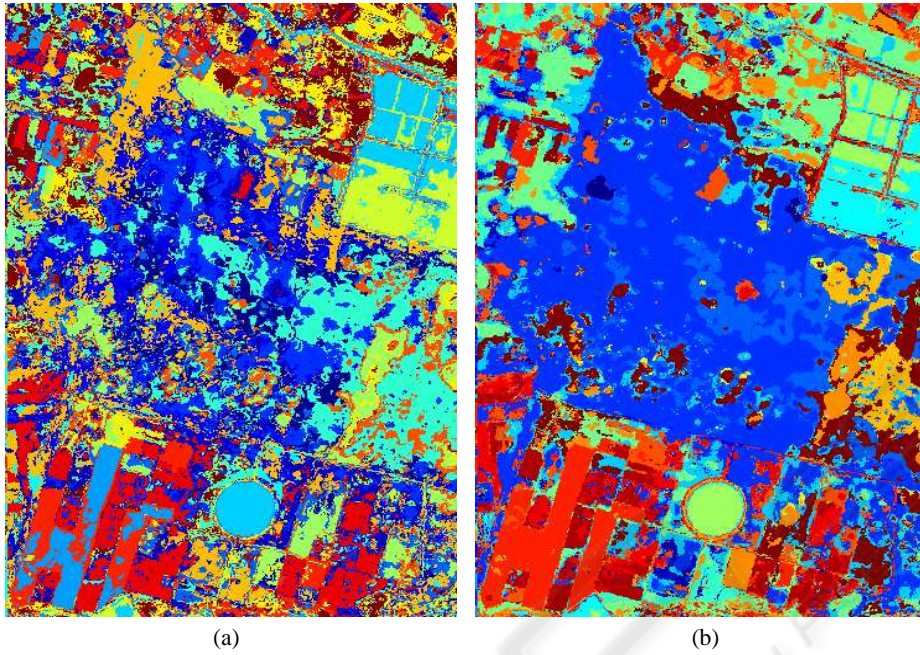
(a)   (b)

Fig. 4. Segmentation results using Gustafson-Kessel (a) and Gath-Geva (b) algorithms at 20 clusters using filtering with threshold = 7.

likehood one, it is possible to significantly improve the results of segmentation and to avoid large part of manual processing the multispectral data.

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<div align="center">(a)   (b)</div>

Fig. 5. Segmentation results using Gustafson-Kessel (a) and Gath-Geva (b) algorithms at 20 clusters using filtering with threshold = 15.

<div align="center">(a)   (b)</div>
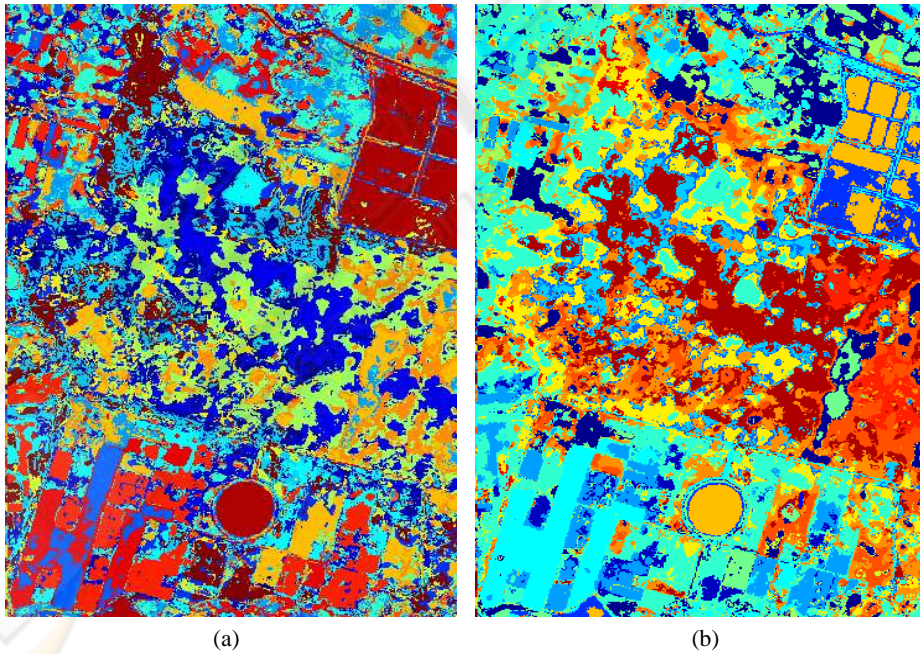
Fig. 6. Segmentation results using Gustafson-Kessel (a) and Gath-Geva (b) algorithms at 20 clusters using filtering with threshold = 20.