Target Detection by Fuzzy Gustafson-Kessel Algorithm

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Abstract

Many commercially available radar systems offer a range of filter options but the problem of clutter rejection for target detection is still present in a number of situations. Rejection of clutter and detection of targets from radar captured data is a challenging task. Raw data captured by radar are not always scaled. A normalization technique has been proposed which transforms the radar captured data into 8 bit. As 8 bit data is easy to analyze and visualize. A modification on Fuzzy c-means has been done by developing Fuzzy Gustafson–Kessel (FGK) algorithm and the result shows robustness of this proposed method.

Keywords: Target Detection, Clutter Rejection, Data Normalization, Fuzzy Clustering, Fuzzy Gustafson-Kessel (FGK).

1. INTRODUCTION

Detection of targets from radar data is a desired task in automatic target recognition (ATR). Interaction of electro-magnetic scattering between the target of interest and the rough surface makes target detection more challenging. Clutter rejection and target detection is of interest in recent years because of the need for object detection on the sea surface, remote sensing of vegetation for crop production assessment, and many other applications. There are several existing method has already been proposed for radar target detection [1-4].

In ISAR (Inverse Synthetic aperture Radar), the target rotates and the radar is stationary. Target images can be obtained by transmitting wideband signals, and high cross range resolution is obtained by coherently accumulating number of echoes from different aspect angles [5]. The goal of radar imaging system is to detect the targets particularly for surveillance. Clutter is the major problem for radar operations. Clutter refers to radio frequency (RF) echoes returned from targets which are uninteresting to the radar operators. The nature of clutter varies with application and radar parameters [6] because of many users and the over-crowding of the spectrum; electromagnetic interference is a common occurrence with current communication and electronic equipments. Hence, analysis performed to either avoid or eliminate such interference, which is termed as clutter. There are several works has been carried out with fuzzy c-means clustering [7] [8] but none of them has been able to reject clutter from the data. Lejiang et al[9] has proposed a fuzzy c-means clustering for duplicate data cleaning. Fuzzy Gustafson-kessel has been used by Niladri et al[10] for remote sensing change detection. Our method fuzzy Gustafson-kessel not only detects targets but reject clutter.

The main task of a radar signal processor is to make decisions whether a target present or not. After a signal has been transmitted, the receiver starts receiving return signals, with those originating from near objects arriving first because time of arrival translates into target range. The signal processor places a raster of range bins over the whole period of time, and now it has to make a decision for each of the range bins as to whether it contains an object or not. This decision-making is severely hampered by noise. Atmospheric noise enters into the system through the antenna, and all the electronics in the radar signal path produces noise too. In this paper a data scaling method has been proposed. Radar captured data even if used as a form of images but these images do not normally resemblance to those produced by conventional imaging system. The large volume of image data would overwhelm the available image analysis capabilities so scaling of captured data is becoming popular for target detection and other image analysis task [11] [12]. The raw data captured by the radar are all complex in nature and are not scaled. For an unscaled matrix, retrieving information is a very difficult task. In this proposed approach first we have used a method to normalize the captured data by dividing each data with its mean value. The matrix is scaled in such a way that the pixel ranges from 0 to 255, as this is the range generally used for gray level image processing. Scaling of the radar data is able to reject small portion of clutters. Fuzzy clustering has been done on the scaled matrix by considering that the targets and the clutters are distinguishable significantly.

Fuzzy c-means clustering generally employs Euclidean norm to measure the dissimilarity between patterns and cluster centers. Only spherical clusters can be detected properly using it. Fuzzy Gustafson and Kessel introduced [13] adaptive distance norm to measure the distance between clusters using fuzzy covariance matrix (a fuzzy equivalent of the classical covariance) - a representation of cluster centers along with data points. Using FGK [13] clusters with any shape can be detected. In case of radar captured data targets are not always in spherical structure. And so by normal fuzzy c-means clustering detection of targets are not always possible. To overcome from this drawback in this paper we proposed fuzzy Gustafson-Kessel for target detection on scaled data.

2. DATA CAPTURING

A MATLAB simulated environment has been created where four points scattarer has been designed in the model. Where the left and right point scattarer is rotating with an angular step of 0.3˚ about a central axis the fourth one is the rear point scattarer. The rear side point scattarer is placed 17m behind the middle point scattarer and at a 0.9m cross range distance with respect to the right side point scattarer. The cross range distance between left and middle point is 0.5m. Similarly the middle and right points are separated in cross range by 0.5m. By this model the captured matrix is of size 21 x 724. As the point scattarer assembly is rotated starting from 23.5˚ to 29.5˚ with a step of 0.3˚. In this way we have generated 21 row vectors each with size 1 x 4. So, for a single Radio Frequency, a data matrix will be generated having the dimension of 21 x 4. The numbers of relative frequencies (i.e., RF) are taken as 181 because the RF sweep range is 1.7GHz to 2.6GHz with a step size of 5MHz. Finally 181 number of 21 x 4 data matrix has been generated through the simulation model and the resulting data matrix on which the work has been carried out is with dimension [21 x (181 x 4)] i.e., 21 x 724.

3. SCALING OF DATA

Constructing an ISAR image requires data collection in both frequency and angular dimensions. ISAR imaging systems produce electromagnetic images of targets in the range-Doppler domain. If the data are evenly sampled and the sampling rate is dense enough and if the total angular looks on the target is small then an ISAR can be obtained by using a 2 dimensional FFT algorithm. The data captured through ISAR are always having long float values. In this paper we have converted the captured value first into short floating point value by dividing each pixel with its mean value. And the scaling operation has been done by using the following criteria;

```
If max (pixel_value)>255
then new_pixel=max(pixel_value)-255
else
new_pixel=255-max
end
```

4. FUZZY GUSTAFSON-KESSEL ALGORITHM (FGK)

Fuzzy cluster analysis allows gradual memberships of data points to clusters measured as degrees in [0,1]. This gives the flexibility to express that data points can belong to more than one cluster. These membership degrees offer a much finer degree of detail of the data model. Aside from assigning a data point to clusters in shares, membership degrees can also express how a data point should belong to a cluster. The concept of these membership degrees is substantiated by the definition and interpretation of fuzzy sets. A fuzzy cluster model of a given data-set X into c clusters is defined to be optimal when it minimizes the objective function;

$$J_f(X, U_f, C) = \sum_{i=1}^{c} \sum_{j=1}^{n} u_{ij}^m d_{ij}^2 \qquad (1)$$

Where $X = \{x_1, x_2, ..., x_n\}$ be the set of pixels and c is the number of clusters $(1 < c < n)$ represented by fuzzy sets μ_{Γ_i} and $i = 1,2,......c$. U_f is the partition of X if it satisfy the following;

$$\sum_{j=1}^{n} u_{ij} > 0 \quad \forall i \in 1,2,.......c \text{ and}$$

$$\sum_{i=1}^{c} u_{ij} = 1 \quad \forall j \in 1,2,........n$$

'd' is the Euclidean distance between cluster centers and the data points. But this distance only makes it possible to identify spherical clusters.

The Gustafson–Kessel algorithm [13] replaces the Euclidean distance by a cluster-specific Mahalanobis distance, so as to adapt to various sizes and forms of the clusters. The Gustafson–Kessel algorithm tries to extract much more information from the data than the algorithms based on the Euclidean distance. In the Gustafson–Kessel algorithms the clusters are parameterized by the mean (center) and the distance norm matrix (related to the covariance matrix of the cluster). The Gustafson–Kessel algorithm tries to extract much more information from the data than the algorithms based on the Euclidean distance. It is more sensitive to initialization, therefore it is recommended to initialize it using a few iterations of FCM depending on the considered partition type. The Fuzzy Gustafson–Kessel algorithm exhibits higher computational demands due to the matrix inversions.

For a cluster *i*, its associated Mahalanobis distance is defined as;

$$d^2(x_j, C_i) = (x_j - c_i)^T \sum_i^{-1} (x_j - c_i)$$

Where $\sum_i$ is the covariance matrix of the cluster.

5. RESULTS

The raw data captured by the radar is complex values. Where the minimum value is 9.8868e-08 and the maximum value is -6.8941e-04. Data has been scaled by using the proposed scaling method which is described in algorithm 1.

Step 1: data= R ;
Step 2: m = mean(R);
Step 3: MAT1= $abs(\text{int}(R/m))$

Step 4: MAXIMUM= MAX (MAT1);
Step 5: if MAXIMUM $\geq$ 255 then
Step 6: VARIABLE1=MAXIMUM-255;
Step 7: if MAXIMUM $\leq$ 255 then
Step 8: VARIABLE1=255-MAXIMUM;
Step 9: FINAL_MATRIX= MAT1-VARIABLE1;
Step 10: if FINAL_MATRIX $\leq$ 0 then
Step 11: FINAL_MATRIX=0;

Algorithm 1: Proposed data scaling method

Figure 1(a) contains contour plot for the original complex data matrix. Figure 1 (b) is the generated contour plot after applying proposed algorithm. By which we can easily determine that there are three targets present in the environment.

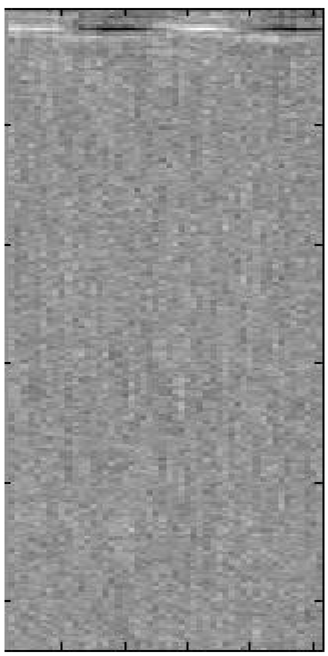

FIGURE 1(a)

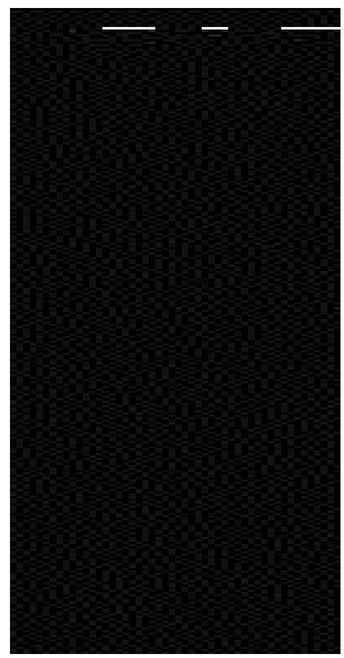

FIGURE 1(b)

All three targets are taken as flat plates for experiment with approximate dimensions (.56mX.56m) for left target, (.3mX.3m) for middle (.71mX.71m) for right target. The Gustafson–Kessel algorithm models each cluster Γ_i by both its center c_i and its covariance matrix $\sum_i$ where $i = 1,2,....c$. Thus cluster prototypes are tuples $C_i = (c_i, \sum_i)$ and both c_i and $\sum_i$ are to be learned. The eigen structure of the positive definite $p \times p$ matrix $\sum_i$ represents the shape of cluster *i*.

The cluster center c_i has been calculated by using the formula;

$$c_i = \frac{\sum_{j=1}^{n} u_{ij}^{m} x_j}{\sum_{j=1}^{n} u_{ij}^{m}}$$

The membership degree has been calculated by;

$$u_{ij} = \frac{d_{ij}^{-\frac{2}{m-1}}}{\sum_{l=1}^{c} d_{lj}^{\frac{2}{m-1}}}$$

The covariance matrix has been calculated by;

$$\sum_i = \frac{\sum_i *}{\sqrt[p]{\det(\sum_i *)}}$$

$$\text{Where } \sum_i * = \frac{\sum_{j=1}^{n} u_{ij}(x_j - c_i)(x_j - c_i)^T}{\sum_{j=1}^{n} u_{ij}}$$

6. CONCLUSION

This work describes a natural extension of Fuzzy c-means clustering with Gustafson-Kessel distance method.The new formulation should prove extremely beneficial to improving the performance of fuzzy clustering algorithms in the field of target detection and clutter rejection. Since the pixels differences between the clutter and target is very low so they are not separable by sharp boundaries (as they are highly overlapped), fuzzy Gustafson-Kessel algorithm seem to be more appropriate and realistic choice to separate them.

7. REFERENCES

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