Development and Performance Analysis of a Class of Intelligent Target Recognition Algorithms

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Abstract

This paper develops and compares two fuzzy logic based and a traditional rule-based pattern recognition system, which perform target recognition with data from a typical range and doppler resolving radar. The parameters used by the pattern recognition systems are target altitude, velocity, range from nearest base, and radar cross section. The pattern recognition systems identify four classes of aircraft: fighter/interceptors, large bombers, rotary craft, and vertical take off and landing (VTOL) combat aircraft. The first fuzzy based pattern recognition method classifies targets by selecting the aircraft with the maximum summed amount of membership, giving a classification accuracy of 94% (average). The second approach classifies targets by selecting the aircraft through a max-min fuzzy decision system. This results in a 99% average accurate classification. The traditional rule-based method implements an expert system and correctly classifies 75% (average) of the targets.

Introduction

Radar target recognition is a critical aspect of modern radar system theory. Most target classification applications in the past have applied high resolution radars to extract features from the target aircraft which form the basis for the target recognition [1]. In the absence of the high resolution radar, many systems have relied on man-in-the-loop for target classification. However, in an environment with a large number of hostile aircraft “utility can become compromised due to temporal requirements associated with modern” scenarios [2]. For this reason an efficient computer-based algorithm which uses parameters available from a typical low resolution, range-resolving radar is preferred for target classification. Fuzzy logic based pattern recognition systems provide a viable alternative to traditional methods.

Approach

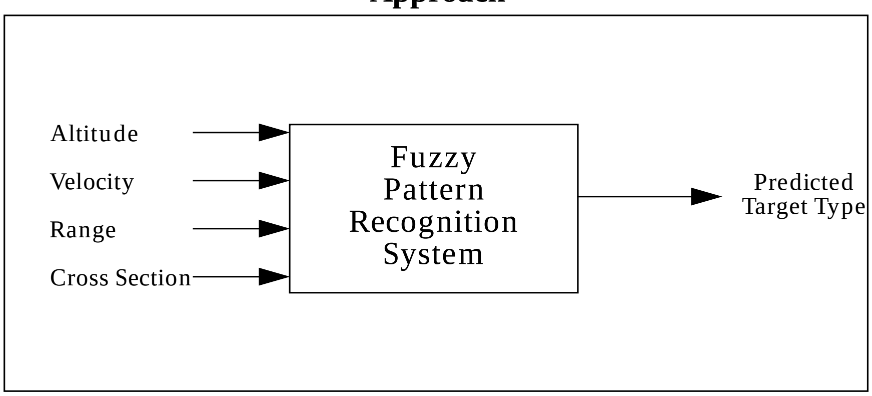

Figure 1. Block Diagram for Pattern Recognition System

Before membership functions can be generated for each of the target classes, information about the targets must be obtained. For the purposes of this paper, four different aircraft were used to generate the membership functions. These include a Mi-24 HIND Soviet Attack Helicopter, a TU-95 Bear Soviet long range bomber, a SU-27 Flanker Soviet fighter/interceptor, and a YAK-38 VTOL combat aircraft. Data for these aircraft were obtained from [3]. A mathematical approximation for target radar cross section was performed to generate the data for the pattern recognition system. The approximation is based upon summation of cross sections for simple geometric shapes [4].

The pattern recognition schemes presented in this paper use a membership function based upon a probability density function (pdf) to predict a target type. These membership functions are used to measure the possibility of a certain set of radar parameters belonging to a specific class of aircraft. In other words, given an altitude, velocity, range, and radar cross section, we determine the degree of association between those parameters and an actual target class (See Fig. 1). Certain design parameters must be considered when selecting the pdf's used in the membership function. For the purposes of this paper the following three conditions are considered: 1) the membership functions must be zero for any values which exceed the capability of the aircraft; 2) the membership functions should be maximum at typical values for the aircraft; and 3) the membership functions must produce a nonzero quantity for values which are below typical but still possible for the aircraft. For example, the rotary class aircraft should have zero output from the membership function for altitudes greater than its maximum ceiling, maximum values at its cruising altitude, and a nonzero membership for altitudes between cruising and zero. In order to fulfill all of these conditions, a modified Rayleigh pdf was selected as the basis for the membership function. To arrive at the membership function and obtain these characteristics it was necessary to flip, skew, and normalize the Rayleigh pdf. The peak of the pdf is set at the typical values for each respective target, and the other parameters are selected such that zero probability occurs beyond the maximum capability of the aircraft. Equations (1-3) were used to generate the pdf's which are then modified to form the membership functions. They show the Rayleigh probability density function, its mean, and variance, respectively. The Rayleigh pdf's used to generate the membership function are shown in Figs. 2, 3, 4, and 5.

$$f(x > 0) = \frac{x}{a^2} \exp\left(-\frac{x^2}{2a^2}\right) \quad \textbf{(1)}$$

$$\bar{X} = a\sqrt{\frac{\pi}{2}} \quad \textbf{(2)}$$

$$\sigma_x^2 = \left(2 - \frac{\pi}{2}\right)a^2 \quad \textbf{(3)}$$

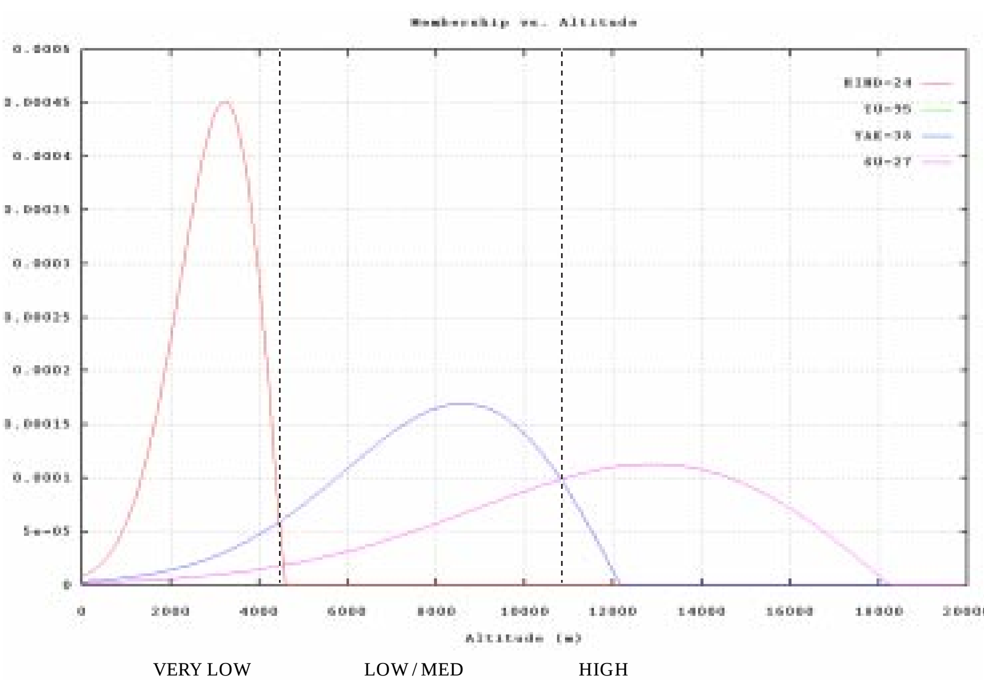

Figure 2. Rayleigh Probability Density Functions for Altitude

With the membership functions generated, we are ready to input a set of parameters into the pattern recognition system. The technique in this paper requires the radar to be capable of measuring range and calculating a signal to noise ratio. The parameters to be input into the pattern recognition system (altitude, velocity, range from nearest base, and radar cross section) can be obtained by Eqs. (4-7). Equation 4 is used to determine velocity from two separate range measurements.

$$\frac{dx}{dt} = (x_{new} - x_{old}) / (\Delta t) = \dot{x} \quad \textbf{(4)}$$

where

x_{new} - current range of the target (meters)

x_{old} - range of the target for the previous measurement (meters)

Δt - time between range measurements (seconds)

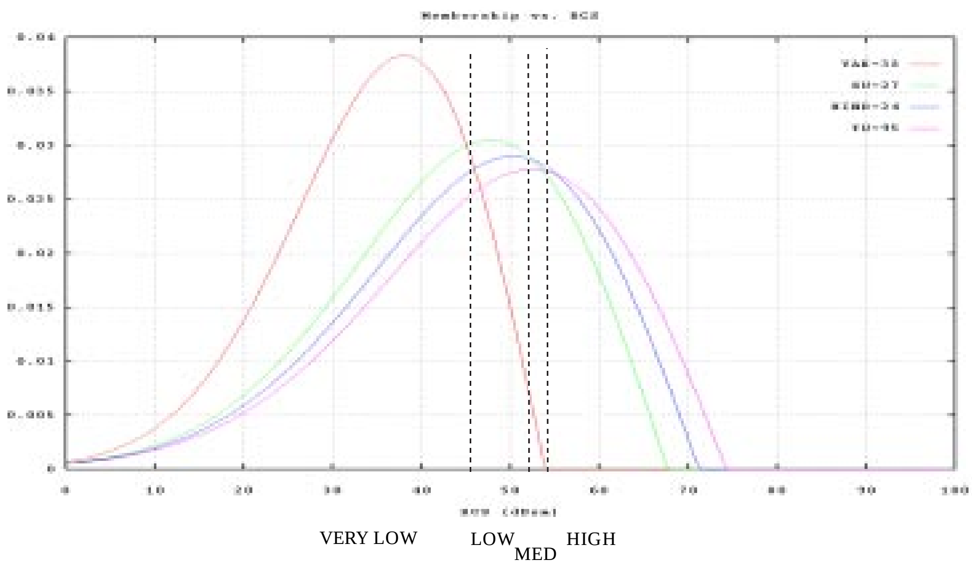

Figure 3. Rayleigh Probability Density Functions for Target Radar Cross Section

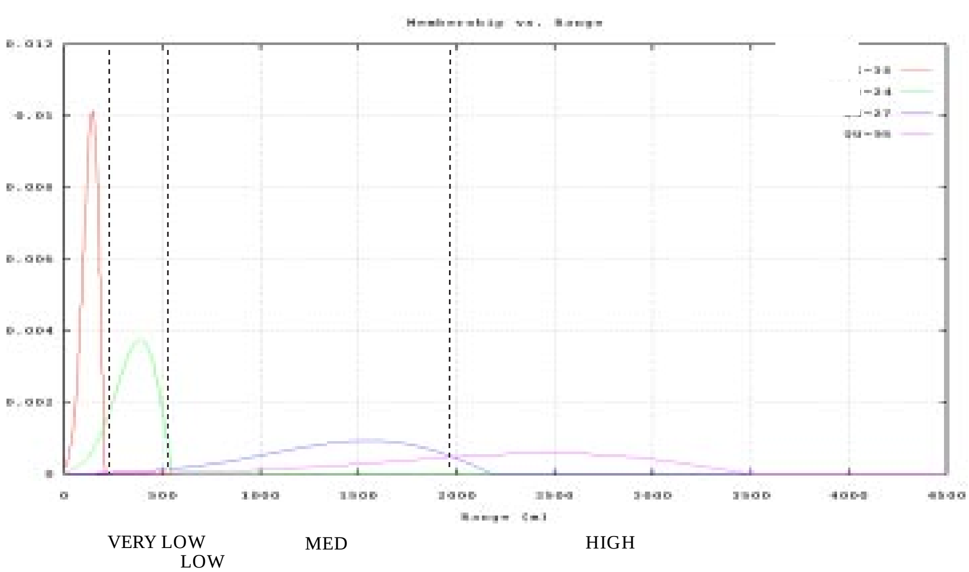

Figure 4. Rayleigh Probability Density Functions for Target Range

Range from nearest base can be determined by taking the magnitude of the difference between the position vector of the target and the position vector of the nearest airbase capable of supporting the aircraft.

Using range and elevation angle the altitude can be calculated by equation 6.

$$z = x\sin(\phi) \qquad \textbf{(5)}$$

where

ϕ - the elevation angle from the surface of the earth (deg or rad)

x - current range of the target(meters)

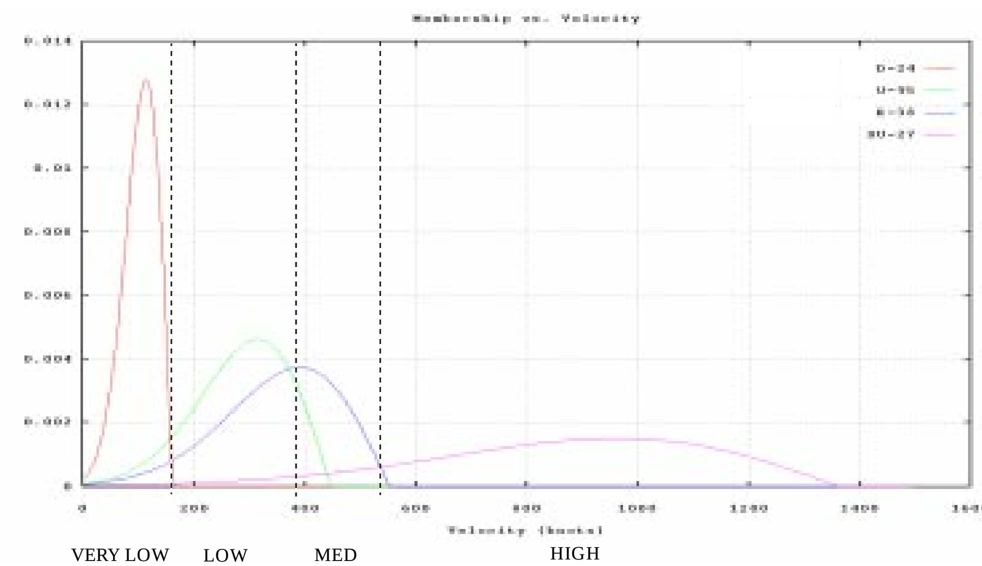

Figure 5. Rayleigh Probability Density Functions for Target Velocity

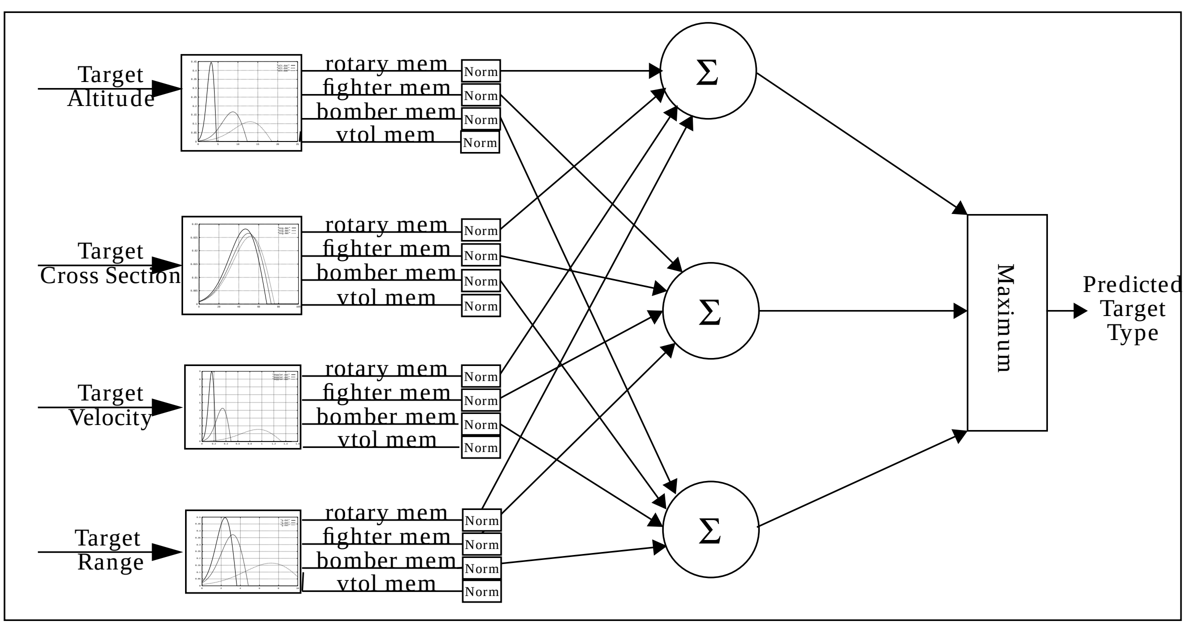

Figure 6. Fuzzy Maximum Summed Membership Approach to Pattern Recognition System

The equation for target radar cross section can be derived through manipulation of the radar range equation as follows in Eq. 6:

$$\sigma_T = \frac{\left(\frac{S}{N}(4\pi)^3 R^4 k T_o B_n F_n L_T L_R\right)}{(P_T G_T G_R \lambda^2)} \quad \textbf{(6)}$$

S/N - signal to noise ratio
R - target range(meters)
k - Boltzmann's constant
T_o - noise temperature (degrees K)
B_n - effective noise bandwidth(Hz)
F_n - noise figure(ratio)
L_T - total transmission loss(ratio)
L_R - total receive loss(ratio)
P_T - peak power transmitted(watts)
G_T - transmit antenna gain(ratio)
G_R - receive antenna gain(ratio)
λ - wavelength of the transmitted signal(meters)

Fuzzy Maximum Summed Membership Approach

The fuzzy maximum summed approach to the pattern recognition system consists of two steps: 1) determine the membership for each parameter across all targets (altitude, rcs, velocity, and range) by evaluating in the corresponding membership functions, and 2) sum the membership for each target class for all parameters. The target class which has the largest summed membership is selected as the predicted target type. This approach proved to be 94% accurate over 100 test cases of real data. Figure 6 shows a block diagram for this pattern recognition system.

Fuzzy Min-Max Approach

The fuzzy min-max approach to the pattern recognition system consists of two steps: 1) determine the membership for each parameter across all targets (altitude, rcs, velocity, and range) in the normalized, modified pdf's (which are serving as our membership functions) and 2) for each target class find the minimum membership across all its parameters. The target class with the largest minimum membership is selected as the predicted target type. For example, if the fighter class scored a 0.2 membership for altitude, a 0.75 membership for rcs, a 0.34 membership for velocity, and a 0.82 membership for range the minimum would be 0.2. If, after repeating this for all the different target classes, the maximum from the set of all targets minimum parameter membership is 0.2 then the predicted target type would be the fighter class. The advantage of this method is that it eliminates targets which have exceeded their maximum capabilities, since this situation would result in a membership of zero. Recall this is a requirement for development of the membership functions. This approach proved to be 99% accurate over 100 test cases of real data. Figure 7 shows a block diagram for this pattern recognition system.

Rule Based Approach

The crisp rule based approach to the pattern recognition system divides the pdfs into four separate regions: very low, low, medium, and high. The transition point between the regions are the crossing points on the membership functions. For example, the very low to low transition point will be where the membership function with the lowest mean crosses the membership function with the next highest mean. Figures 2,3,4 and 5 show the threshold selections used for this pattern recognition system. After dividing all of the memberships into a very low, low medium, and high region, a series of rules are generated which take the following form (as an example):
if (**altitude is medium**) and (**velocity is high**) and (**target cross section is low**) and (**range is low**) then the (**predicted target type is fighter**).

When a complete set of rules is generated such that all possibilities are exhausted (i.e. an answer for every question) an expert system has been created. The rule based system was approximately 75% accurate over 100 test cases.

Conclusion

In this paper, two fuzzy based and one traditional rule based approach to the problem of target class prediction have been discussed. The fuzzy based algorithms have the following advantages: 1) they are one pass procedures which can easily be implemented in an embedded computer for a radar, or in a computer simulation with very little impact on run-time performance, 2) the system proves to be extremely accurate, and 3) the system does not require a great deal of knowledge of the targets to be predicted. Each approach only requires average and maximum values of altitude, velocity, range from nearest base, and radar cross section to generate a successful pattern recognition system. The rule based approach would be more accurate than the fuzzy based approach if the membership functions did not overlap. However, the difficulty with target recognition is that the target can obtain any value up to the maximum with nonzero probability. This provides for a great deal of overlap in the membership functions. Furthermore, the rule based approach assumes that when a characteristic falls within a particular region, that it is 100% within that region and 0% within any other region (crisp set logic). Since fuzzy logic accounts for partial membership within several regions, the fuzzy based approaches were more accurate then the traditional rule based approach.

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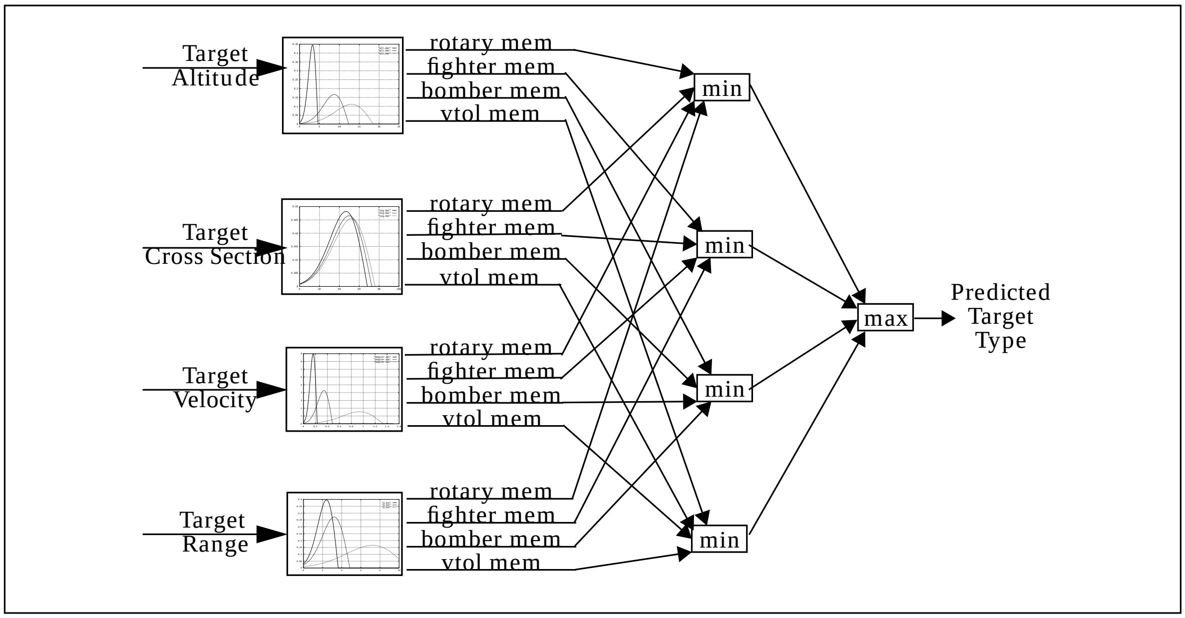

Figure 7. Fuzzy Maximum Minimum Approach to Pattern Recognition System

References

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