NON-PARAMETRIC SERIAL DECISION FUSION

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The study of a distributed serial data fusion system for a network of several CFAR receivers is presented. Rank fusion rules and independent control of each receiver detection threshold have been used in order to obtain a CFAR operation of the network. A recursive algorithm has been formulated allowing to choose the optimum rank rule for a given network with the objective of maximize the global probability of detection. The results are compared to those obtained for a parallel configuration with a unique concentrated fusion center which is used as a reference.

1. Introduction

In radar surveillance often several spacially distributed sensors can detect a target with different probabilities of detection and false alarm rates, range, interference rejection, etc. By combining the detected signals in a fusion center better detection characteristics and interference rejection can be obtained. For example, a parallel concentrated fusion center can process the data from all the sensors of a network, as shown in fig.1.

An alternative is to use a distributed serial fusion configuration in which each sensor performs the fusion of its signals with the information of the preceding sensors. This architecture has several advantages:

- The amount of information that must be transmitted along the network is reduced, requiring narrower channel bandwiths

- The processing is simpler and fastest because is performed in multiple parallel processors

- Because the fusion is distributed, the network is more immune to malfunction or destruction of its parts.

However even a serial network must have a central control center performing the following tasks:

- Modify the detection thresholds of the the sensors

- Choose the best fusion rule according to the network status

- Reconfigure the network in case of malfunction or partial destruction

The present study assumes a network of Cell Averaging Constant False Alarm Rate (CA-CFAR) sensors with different characteristics of detection. A parallel concentrated fusion center has also been studied to be used as a reference. The global
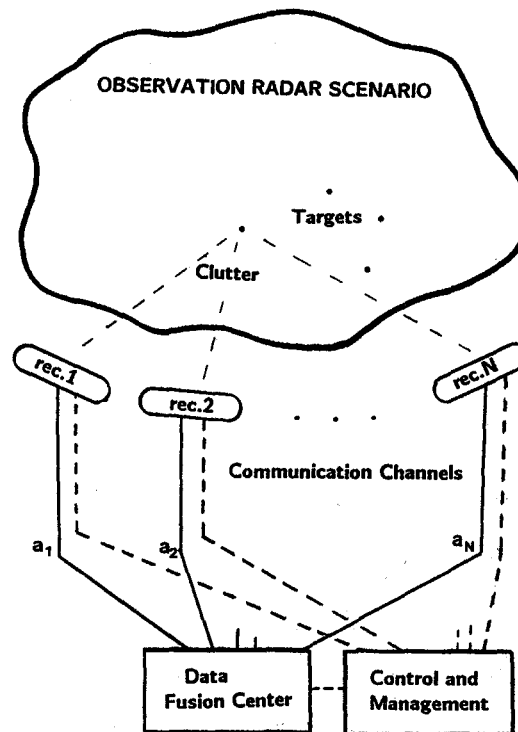

Fig.1 Fusion of a distributed sensor network data

probability of detection has been evaluated for both serial and parallel configurations. From these results the detection thresholds of the different receivers have been optimized. Finally some relevant results of this optimization are presented outlining the main conclusions of this work.

2. Parallel and Serial Configurations

The objective of a given network will be to maximize the probability of detection while keeping the false alarm ratio constant. The targets are assumed to be Swerling-1 type, with noise or interference due to clutter having similar Rayleigh statistics. In this case, the probabilities of detection and false alarm can be obtained with the following expressions [1]:

$$P_D = \left[\frac{1 + SNR}{1 + SNR + T} \right]^M \; ; \quad P_{FA} = \left[\frac{1}{1 + T} \right]^M$$

where:
SNR is the signal to noise or interference ratio
M is the number of cells of the CA-CFAR receiver
T is the detection threshold

The serial network with N receivers consists of N-1 binary fusion centers, this configuration is depicted in fig.2 a). A parallel structure which has been evaluated as a reference is shown in fig.2 b).
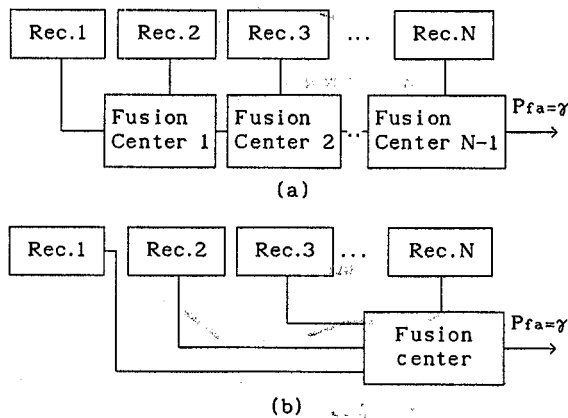

(a)

(b)

Fig. 2
a) Distributed Fusion in a serial configuration
b) Fusion in a parallel configuration

In both configurations a non-parametric 'k of N' decision rule is used, in this way the fusion center decides the presence of a target if at least k of the N receivers have detected the target. For the serial structure the fusion is binary and the possible rules are the 'AND' (2 of 2) or the 'OR' (1 of 2). In a parallel structure it is possible to weigh the individual decisions with a coefficient a_i with values between 0 and 1. The unweighted case using equal coefficients has been studied in [2].

3. Evaluation of the Global Probability of Detection

The expressions obtained in [3] for a system consisting of two sensors can be generalized to the case of N sensors and 'k of N' rules, obtaining the probability of detection and false alarm of the parallel configuration. In this case the expressions of the total probabilities of detection or false

alarm are the following:

$$\begin{aligned}
P_T = & R(0,\ldots,0) \cdot (1-P_0) \cdot (1-P_1) \cdots (1-P_{N-1}) + \\
& R(0,\ldots,0,1) \cdot (1-P_0) \cdots (1-P_{N-2}) \cdot P_{N-1} + \\
& R(0,\ldots,0,1,0) \cdot (1-P_0) \cdots P_{N-2} \cdot (1-P_{N-1}) + \\
& \ldots \ldots \\
& R(1,\ldots,1) \cdot P_0 \cdot P_1 \cdots P_{N-1}
\end{aligned}$$

R() gives the fusion decision according to the decision rule, the individual decision vector $\vec{u}$ and the weighting vector $\vec{a}$ as follows:

$$R(\vec{u}) = \begin{cases} 1 \text{ (target detected) if } \vec{a} \cdot \vec{u} = \sum a_i \cdot u_i \geq k \\ 0 \text{ (not detected)} \quad \text{if } \vec{a} \cdot \vec{u} < k \end{cases}$$

The serial structure suggest a recursive evaluation based on the basic fusion cell as shown bellow
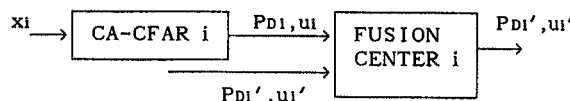
From the basic cell j the following recursive expression can be deduced

$$P'_{Dj+1} = (-1)^{R_j+1} \cdot P_{Dj} \cdot P'_{Dj} + \left[P_{Dj} + P'_{Dj} \right] \delta(R_j)$$

where:

P'_{Dj+1} is the probability of detection obtained in the decision center j
P_{Dj} is the probability of detection in the CA-CFAR j

$$R_j = \begin{cases} 1 \text{ for the AND rule} \\ 0 \text{ for the OR rule} \end{cases} \text{ is the decision rule in}$$

the cell j

$$\delta(R_j) = \begin{cases} 1 \text{ if } R_j = 0 \\ 0 \text{ if } R_j = 1 \end{cases}$$

The probability of false alarm can be obtained in the same way substituting P_D by P_{FA}.

4. Network Optimization Method

The network optimization consists on finding the detection thresholds of the sensors that maximize the total probability of detection while keeping the total probability of false alarm P_{FAT} constant. The optimization of a function with the restriction of keeping a parameter (P_{FAT}) constant is solved by the Lagrange multipliers method. In this way we obtain a system of N+1 non-linear equations and N+1 unknowns which has been solved with the Newton-Raphson second order fixed-point method. An initial solution is calculated from the restriction imposed to P_{FAT} and the bisection method [4].

5. Results

Several probabilities of detection have been evaluated for different network configurations and SNR values, after threshold optimization. Figure 3 shows the probability of detection against the SNR in three receivers for a fixed total false alarm probability of 10^{-5} and for different decision rules O: OR, A: AND. The receivers use a similar Mi=8 cell CFAR. The results obtained with a unweighted parallel decision center using a 2 of 3 rule are also shown as a reference, which in this case gives the optimum probability of detection. For high SNR the OR-OR rule give similar results to the optimum, for intermediate SNR the best serial rule is the AND-OR and finally for low SNR the AND-AND rule gives better probability of detection. Figs. 4 and 5 show the dependence of the probability of detection with the number of sensors when a 12 cell CFAR is used in the receivers. Fig.4 corresponds to the case of an OR decission rule and fig.5 shows the results of using AND rules in the network, it can be seen that the probabilities of detection are generally higher when the OR rule is used in the fusion centers. Fig.6 show the results obtained for an inhomogeneous four sensor network with different CFAR lengths and SNR ratios, the results corresponding to a unweighted parallel architecture using 2 of 4 and 3 of 4 rules are also shown. The optimum configuration in this case is a serial network using OR rules in the fusion centers.
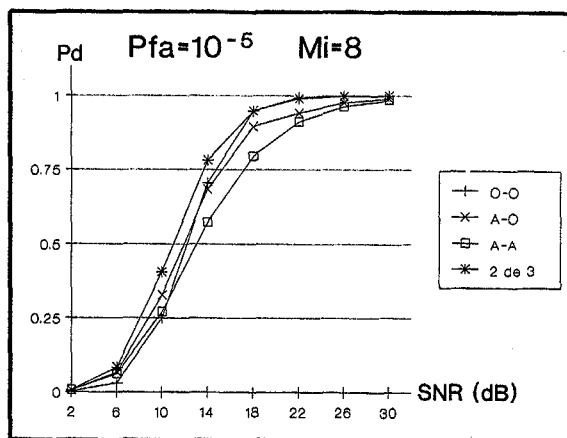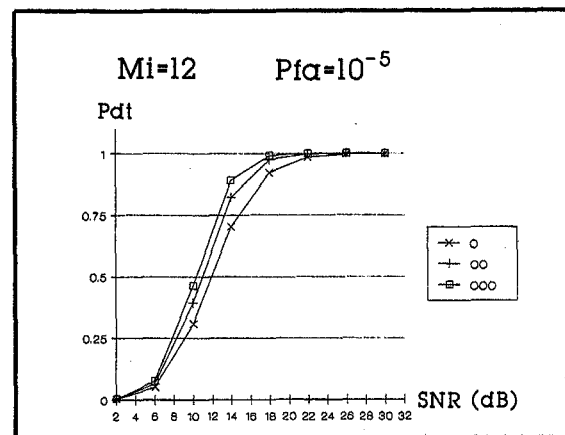

Fig.4 Probability of detection vs. signal to noise ratio for a serial configuration using 2, 3 and 4 sensors for an OR decision rule. The receivers use a 12 cell CFAR.
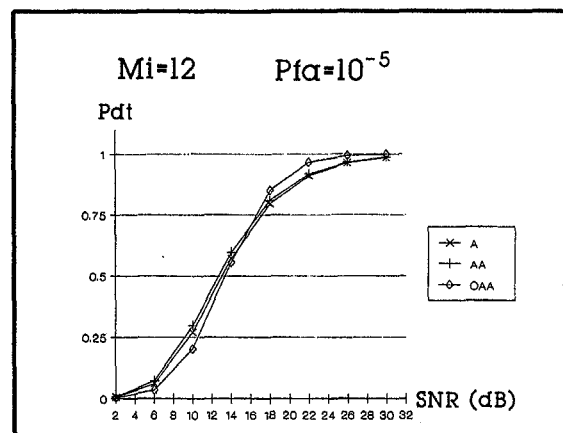

Fig.5 Same as fig.3 but using AND, AND-AND, OR-AND-AND rules

Fig.3 Probability of detection vs. signal to noise ratio for a serial configuration using diferent decision AND (A) or OR (O) rules, and for a parallel configuration using a 2 of 3 decision rule. The receivers use a 8 cell CFAR.
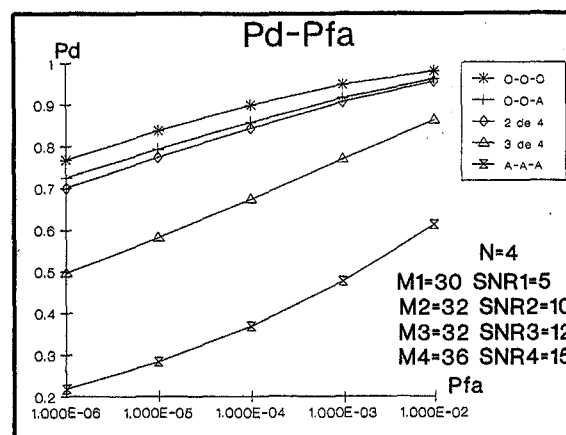

Fig.6 Probability of detection vs. probability of false alarm for an inhomogeneous network of 4 receivers with different CFAR lengths and SNR. Several serial and parallel fusion modes have been evaluated.

6. Conclusions

From the results obtained the following conclusions can be outlined:

A serial structure can always be simulated by a conveniently weighted parallel configuration, therefore this configuration is always the optimum although similar results can be obtained in some cases with an optimized serial structure.

In general for a serial network better results are obtained using OR rules for high SNR whereas for low SNR the probability of detection is higher for AND rules.

In a serial network the last receivers have more influence in the total detection characteristics, for this reason it is convenient to place the best sensors at the end of the network. In this case the serial configuration can have comparable or even better performance than a unweighted parallel network.

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