OPTIMUM SYSTEMS FOR SATELLITE FIRE DETECTION

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1. PROBLEM FORMULATION AND PREVIOUS WORKS

The systems performance optimization for the detection of thermal anomalies in multispectral satellite data is a challenging as well as an intricate task. The goal of our work is to analyze, from a new perspective based on the detection rate, the algorithm proposed in [1], where the main purpose was to keep constant the false alarm rate (CFAR), without care of the detection probability. The system designed in [1] takes advantage of the multiple bands of the MODIS sensor and a multiple-channel processing is proposed: a CFAR detection is applied to each channel and the binary decisions are combined in a fusion center. For evaluating and controlling the overall false alarm probability after the fusion rule the single detections have to be independent, but the brightness temperatures from MODIS bands at $4\mu m$ and $11\mu m$ (channels 21 and 31) are statistically correlated. For this reason, the data are reprojected on a decorrelating basis through the Principal Component Analysis (PCA) and, given the assumption for the joint statistical model, they turn out to be also independent [2]. The per-channel detections can be finally combined in the fusion block through an AND or OR rule. On each channel, the local detection thresholds are chosen according to the design value of the false alarm probabilities, P_{FA_1} and P_{FA_2} where, for the AND rule, $P_{FA_1} = P_{FA_2} = \sqrt{P_{FA_{tot}}}$, whereas, for the OR rule, $P_{FA_1} = P_{FA_2} \approx P_{FA_{tot}}/2$, and $P_{FA_{tot}}$ is the global false alarm probability of the system, which is kept constant.

To optimize the above CFAR system it is necessary to analyze, control and maximize the probability of detection. Our purpose is to optimize the system performance or, in other words, to maximize the probability of detection, P_D, of the multiband system, keeping the overall false alarm at a constant rate. The optimization process consists in finding the pair (P_{FA_1}, P_{FA_2}) and the fusion rule so as to maximize the detection probability, provided that the overall probability of false alarm is constant and is equal to the design value $P^*_{FA_{tot}}$ [3]. Unfortunately, a statistical model for thermal anomalies is not available, so the expression of the detection probability cannot be evaluated in a closed form. Thus we are required to define an appropriate model for the data under H_1 hypothesis and to perform a Monte Carlo simulation for evaluating the P_D. The *mixed pixel model* [4] is, therefore, introduced, where a pixel is composed by two sub–areas, one entirely covered by the thermal anomaly and the other entirely covered by the background. The sub–areas have different temperatures and spectral emissivities. The simulated data have been compared with the fire pixel temperatures from NASA-DAAC MOD14.

2. MIXED PIXEL MODEL

We assume that in a *mixed pixel* a fraction p of the pixel is covered by the anomaly, at temperature T_f, and a portion $(1-p)$ is covered by the background, at temperature T_b. The radiance measured by the sensor at wavelength λ_i, with $i \in \{1, 2\}$, is

$$R_i = p\varepsilon_f B(\lambda_i, T_f) + (1-p)B(\lambda_i, T_{b_i}) \tag{1}$$

where ε_f is the emissivity of the thermal anomaly, λ_i is the central wavelength of the channel i and $B(\cdot)$ is the Planck function. Values of the brightness temperature of the thermal anomalies can be generated through the inverse of the Planck function

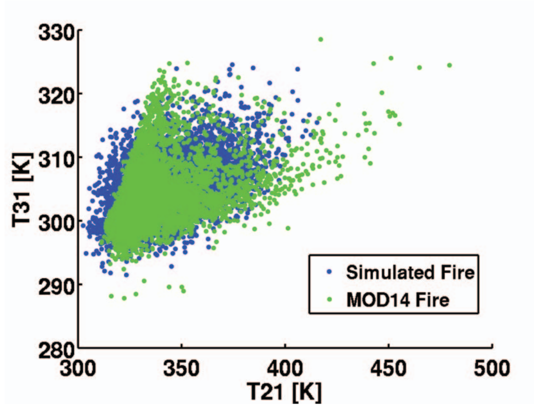

Fig. 1. Scatter plot of the simulated T_{21} and T_{31} anomalous values and brightness temperature for MOD14 fire pixel

applied to simulated values of the radiance in (1). We assume that the value of T_{b_i} is the brightness temperature of the background, compatible with a three-parameter (α, β, δ) Weibull distribution [2], already including the emissivity of the $(1-p)$ portion of the pixel, covered by the background. Accordingly, in eq. (1), the objects are not supposed to emit as blackbodies. To make the simulated model more realistic, the three parameters of the background distribution are estimated from a real area of analysis (that is we use a real dataset to make the simulation). As area of interest, we have chosen a region of Sierra Leone with a reasonably homogeneous background. The anomalous temperatures T_f are usually in the range $700K \pm 100K$; thus, we draw it from a uniform population in the interval $[600, 800]K$ [5]. Instead, the fractional area p is drawn from a truncated normal distribution with $\mu = 0.001$ and $\sigma = 0.0038$ in the interval $[0, 1]$ [6]. This choise gives a good tradeoff between the real fractional area covered by the fire and the total area of the pixel.

As an example of the simulation output, the scatter plot of the generated temperatures T_{21} and T_{31} is shown in figure 1, where a comparison with the brightness temperatures of the fire pixels from NASA-DAAC MOD14 is also reported.

3. PERFORMANCE OPTIMIZATION

We propose here an approach to select the free design–parameters for optimizing the global performance. The free parameters of the system are the local false alarm rates, P_{FA_1}, P_{FA_2}, on each channel, and the fusion rule. So, the optimization process executes an exhaustive search for the optimal pair (P_{FA_1}, P_{FA_2}), for each detection on the image data, to allow the highest probability of detection, according to the design fusion rule. This problem can be formalized as follows:

$$\max_{K, P_{FA_1}, P_{FA_2}} P_{D_{tot}}(K, P_{D_1}(P_{FA_1}), P_{D_2}(P_{FA_2})) \tag{2}$$

with the condition

$$P_{FA_{tot}}(K, P_{FA_1}, P_{FA_2}) = P^*_{FA_{tot}} \tag{3}$$

where P_{D_i} and P_{FA_i} are the local probabilities of detection and false alarm, the value of K is 1 for the OR rule and 2 for the AND rule, and $P^*_{FA_{tot}}$ is the overall probability of false alarm, fixed at the desired level. The optimization procedure consists in solving the problem (2), subject to the condition (3), for each K; the pair (P_{FA_1}, P_{FA_2}) that maximizes the probability of detection is the optimal solution for each fusion rule. Results have been evaluated for the AND and OR fusion rule and the optimal K rule is the one which gives the best probability of detection. Since the local receiver operating characteristics and the adaptive threshold, on each channel, depend on the local probability of false alarm and on the surrounding environment, these optimization steps must be repeated for each pixel of the image, to get the optimal single binary decision.

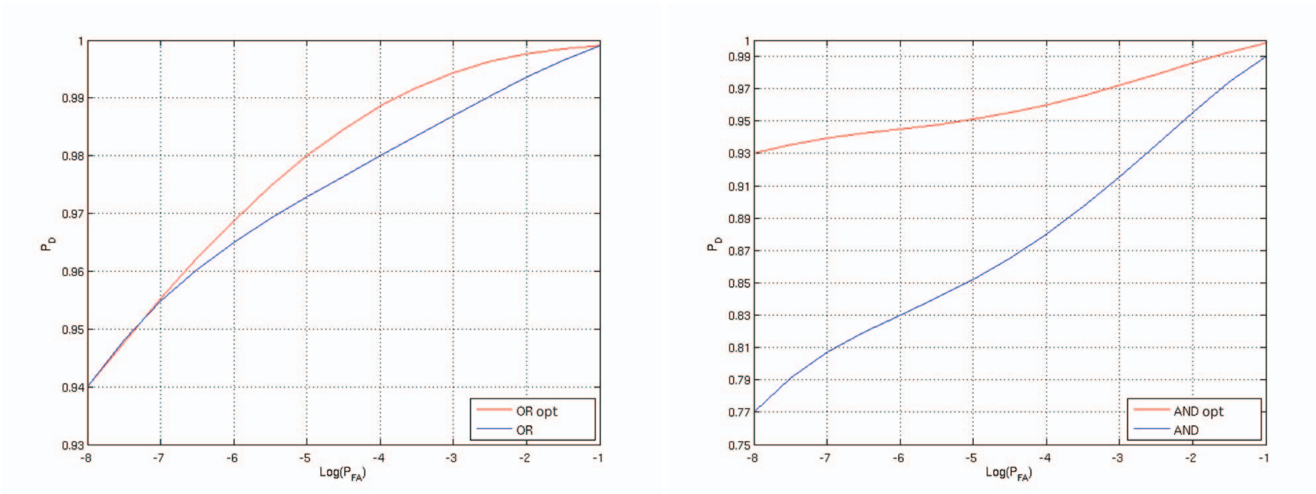

Fig. 2. Optimal ROC curve vs classic ROC curve for the OR and AND fusion rule ($\alpha_{21} = 5.95$, $\beta_{21} = 2.74$, $\delta_{21} = 307.01$, $\alpha_{31} = 2.73$, $\beta_{31} = 2.84$, $\delta_{31} = 300.33$)

4. FIRST RESULTS

The performance of the optimized system has been evaluated on simulated data, drawing the Receiver Operating Characteristic curve (ROC). The ROC curve of the optimized algorithm, with the optimal pair (P_{FA_1}, P_{FA_2}), and the ROC curve for the classic algorithm [1], with $P_{FA_1} = P_{FA_2} = \sqrt{P^*_{FA_{tot}}}$ for the AND rule, $P_{FA_1} = P_{FA_2} = P^*_{FA_{tot}}/2$ for the OR rule, have been computed and compared. Indeed, figure 2 shows a comparison between the performance of the algorithm with and without optimization process, both for the OR rule and for the AND rule, when the brightness temperatures of the background are drawn from a Weibull distribution with parameters $\alpha_{21} = 5.95$, $\beta_{21} = 2.74$, $\delta_{21} = 307.01$, for the $4\mu m$ band, and $\alpha_{31} = 2.73$, $\beta_{31} = 2.84$, $\delta_{31} = 300.33$, for the $11\mu m$ band. These parameters are estimated on a set of real data acquired by AQUA-MODIS pass over Sierra Leone on March 17th 2009. Experimental results show that the performance of the OR rule system are, usually, better than the AND rule system; furthermore in the OR case the ROC curves with and without optimization are quite close. Following these results we have chosen the OR fusion rule as the best one.

Since the optimization algorithm should be applied on each pixel, with a very high computational load especially when the data dimension is large, we have decided to apply the classic algorithm, without optimization of (P_{FA_1}, P_{FA_2}) and with the OR rule, to process images in near real-time. This algorithm is able to assure high performance, even if not the highest, but it has a computational complexity much lower than the optimized system.

5. REFERENCES

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