USING INFORMATION ENTROPY TO ASSESS AIRCRAFT SIGNATURES INTEGRATED EFFECT

XiaoHui Guo, BiFeng Song
School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, P.R. China

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Abstract

The subject of this paper deals with Low Observable (LO) technology and the objective is to develop an aircraft signatures integrated measuring model in the detecting scenario. A methodology and an integrated model of aircraft signatures assessment are discussed in paper. From the point of view of information theory, defense system gain aircraft information through the aircraft's signatures in detecting scenario. The amount of information gained by defense system is closely correlative with the size of aircraft's signatures. So we can measure aircraft signatures integrated effect through the aircraft information gained by defense system. Along this idea, a modeling of defense system gain aircraft's information is developed. Appendixes show the up to date research results of aircraft detection scenario with information theory.

1 Introduction

There are four important aircraft signatures (radar, IR, visual and aural).The aircraft's signatures are important for the aircraft susceptibility assessment because the probability of detection, the tracking errors and the effectiveness of countermeasures are so strongly dependent upon the size of the aircraft's signatures. Some research about the aircraft's signatures has been done earlier [1] [2] [3] [4] [5] and [6]. But seldom has analyses for integrated assessment of aircraft signatures been done of these research. In this paper we will study the integrated effect of aircraft's signatures.

Every time detectors of defense system detect aircraft, they will get some information of aircraft. The more defense gain aircraft information the more aircraft is dangerous. Size of aircraft signatures (radar, IR, visual and aural) will decide the amount of information gained by defense system. So aircraft signatures integrated effect can be measured through the aircraft information gained by defense system.

2 Modeling of Defense System Gain Aircraft Information

Information theory has been used in military region. In reference [7] a measure is proposed for analytically determining the amount of information gained by a tactical battle commander as a result of intelligence, scouting or reconnaissance reports. The measure is based on concepts from information theory, and involves modeling a commander's uncertainty in terms of probability distributions over sets of possible states his adversary may occupy. As the commander gets information, these distributions are updated, by various means, to represent his current state of uncertainty.

From the point of view of information theory [8] [9] [10] and [11], the detecting of aircraft scenario can be described as an information transmitting model shown in fig. 1. Here aircraft become an information emission source, aircraft's signatures are the encoding mode, and defense system is the aircraft information receiver.

Assume λ_i^{a-b} denote any aircraft signature, i denote signature type (radar, IR, visual and aural), a-b denote wave band of

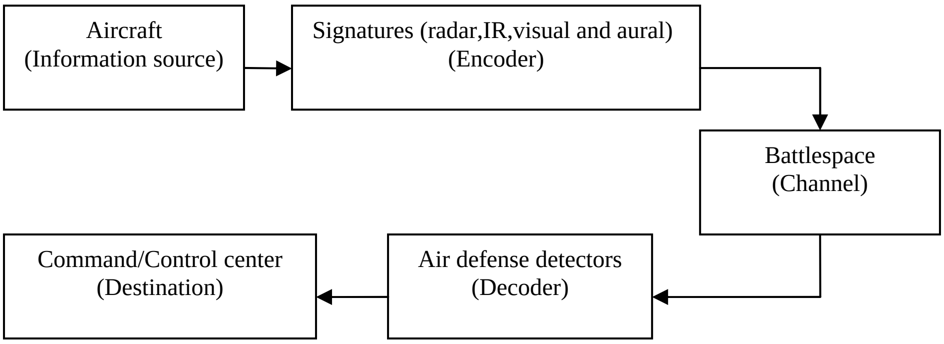

Fig.1 Description of detecting scenario with information theory

aircraft signature. D_{ij}^{a-b} is one detector of defense system that capture signature λ_i^{a-b}, P_{ij}^{a-b} denote the detected probability of D_{ij}^{a-b} every detecting time. Divide the surveillance area of defense system into N cells, variable X_{ij}^{a-b} denote the event that detect aircraft in any cell of surveillance area. To D_{ij}^{a-b}, before D_{ij}^{a-b} detects aircraft, D_{ij}^{a-b} has a prior probability distribution of X_{ij}^{a-b}. After D_{ij}^{a-b} give once detecting to aircraft, it get aircraft information and the probability distribution of X_{ij}^{a-b} is updated to posterior probability distribution, aircraft information gained by D_{ij}^{a-b} during this detecting process is Discrimination information entropy from prior probability distribution to posterior probability distribution [11] [12].

At the initial time (T=0) aircraft enter the surveillance area, D_{ij}^{a-b} begin to detect aircraft. At time T_K the prior probability distribution of X_{ij}^{a-b} is

$$\begin{pmatrix} X_{ij}^{a-b} \\ P_K(X_{ij}^{a-b}) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 & \cdots & x_v & \cdots & x_N \\ p_K(x_1) & p_K(x_2) \cdots & p_K(x_v) \cdots & p_K(x_N) \end{pmatrix}$$

$$(p_K(x_v) = 0 \quad or \quad 1, \quad v = 1, \cdots, N) \qquad (1)$$

At next time T_{K+1}, D_{ij}^{a-b} gives once detecting to aircraft. The posterior probability distribution of X_{ij}^{a-b} is

$$\begin{pmatrix} X_{ij}^{a-b} \\ P_{K+1}(X_{ij}^{a-b}) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 & \cdots & x_v & \cdots & x_N \\ p_{K+1}(x_1) & p_{K+1}(x_2) \cdots & p_{K+1}(x_v) \cdots & p_{K+1}(x_N) \end{pmatrix}$$

$$(p_{K+1}(x_v) = 0 \quad or \quad 1, \quad v = 1, \cdots, N) \qquad (2)$$

During this process the amount of aircraft information gained by X_{ij}^{a-b} is

$$I_{ij}^{a-b}(P_{K+1}, P_K; X_{ij}^{a-b}) = \sum_{v=1}^{N} P_{K+1}(x_v) \log \frac{P_{K+1}(x_v)}{P_K(x_v)} \quad \text{(bit)} \quad (3)$$

Introduce P_{ij}^{a-b} as weight value, we will get the weight Discrimination information entropy as follows

$$I_{ij}^{a-b}(P_{K+1}, P_K; X_{ij}^{a-b}) = P_{ij}^{a-b} \sum_{v=1}^{N} P_{K+1}(x_v) \log \frac{P_{K+1}(x_v)}{P_K(x_v)} \quad \text{(bit)} \quad (4)$$

If defense system is consisted of U detectors, and each detector is separated. Then during time T_K to T_{K+1} the total aircraft information gained by defense system is

$$I_{Aircraft}(T_{K+1}, T_K; X) = \sum_{1}^{U} I_{ij}^{a-b}(P_{K+1}, P_K; X_{ij}^{a-b})$$

$$= \sum_{1}^{U} P_{ij}^{a-b} \sum_{v=1}^{N} P_{K+1}(x_v) \log \frac{P_{K+1}(x_v)}{P_K(x_v)} \quad (bit) \quad (5)$$

3 Simulation Results

A conventional aircraft and a LO aircraft fly though an area under surveillance of defense system which is consisted of a radar and an IR sensor in same route. Fig.2 through 3 shows the radar gain aircraft information changes. The radar gains more information of conventional aircraft than information of LO aircraft every detecting time. But the aircraft information of the LO aircraft change rapidly.

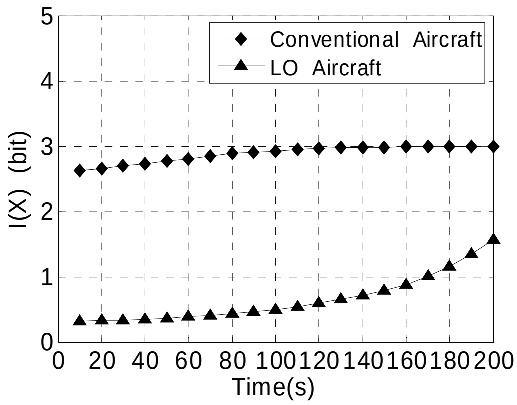

Fig.2 changes of aircraft information gained by radar along with detecting time

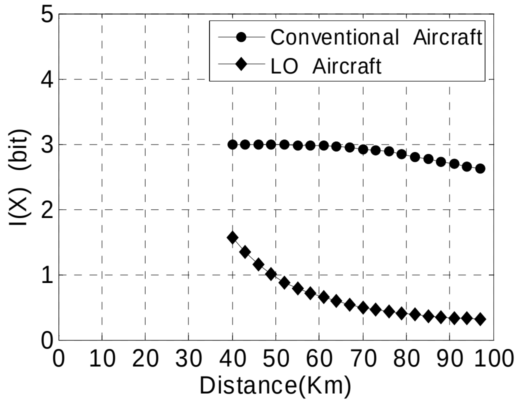

Fig.3 changes of aircraft information gained by radar along with detecting distance

Changes of the IR sensor gain aircraft information are shown in Fig.4 and fig.5. Also the conventional aircraft provide more information to IR sensor every detecting time.

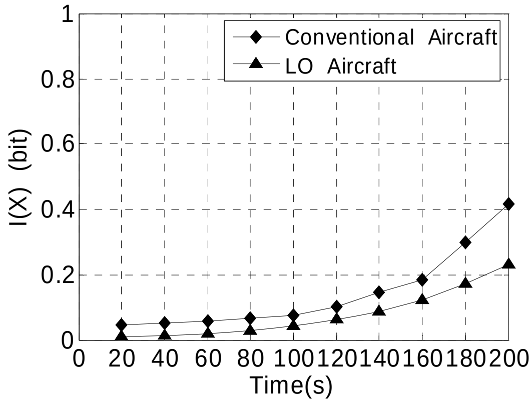

Fig.4 changes of aircraft information gained by IR sensor along with detecting time

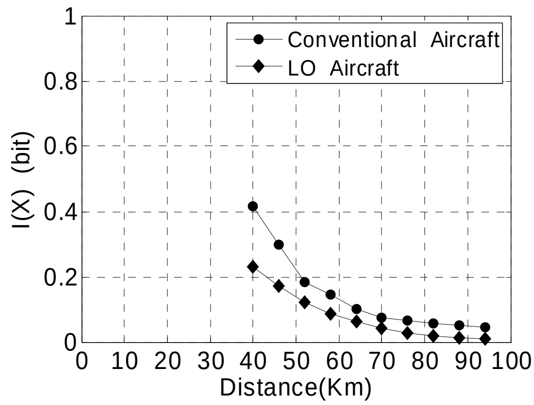

Fig.5 changes of aircraft information gained by IR sensor along with detecting distance

Add radar gain information and IR sensor gain information, we will get the integrated aircraft information gained by defense system as shown in Fig.6 and Fig.7.

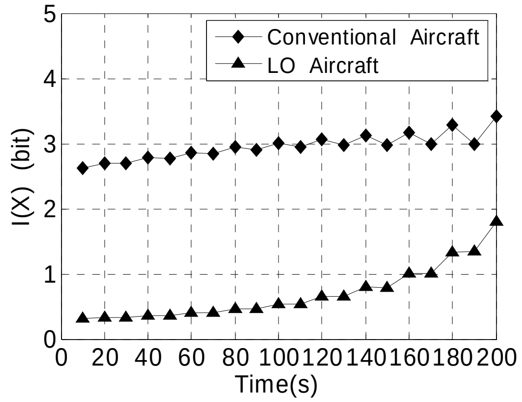

Fig.6 changes of integrated aircraft information along with detecting time

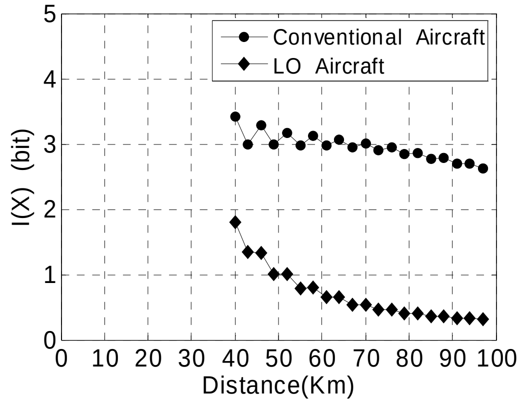

Fig.7 changes of integrated aircraft information along with detecting distance

Obviously LO aircraft emit less aircraft information to defense system, because the size of the signatures of LO aircraft is small. So LO technology do enhance aircraft survivability. LO aircraft is more safety than the conventional aircraft in the same detecting condition.

4 Conclusions

When defense system detects aircraft, they will get aircraft information. The amount of gained aircraft information is strongly dependent upon the size of signatures of the aircraft. On the contrary if we know the total gained aircraft information, we can estimate the integrated level of aircraft signatures. That is the idea of the paper. The simulation results show that the method expatiated in this paper is reasonable and effective.

Existing question is that the method requires each detector is separated. If the detectors are correlative, the method is not suitable. We will study this question in the future.

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6 Appendixes

On 27 March, 1999 a low observable (LO) aircraft F-117 is shot down by air defense system of Yugoslavs. Some factors causing the shooting down event are that the Serbian defense system has known some prior flight information of F-117 through recon tactics. So the question is: how to assess the prior aircraft information gained by defense system? This prior aircraft information gained by defense system is always ignored at past time. At the following paragraph this question will be discussed.

Assume such a scenario: an aircraft fly through the region under air defense system surveillance. For easy to our depiction, assume the detector of air defense system is PPI radar (shown in Fig.8). Variable R_0 denote PPI radar Maximum detecting range, S denote alert area value, then

$$S = \pi R_0^2$$

Divide the surveillance region into N cells, random variable X denote the event that the aircraft is in the surveillance region.

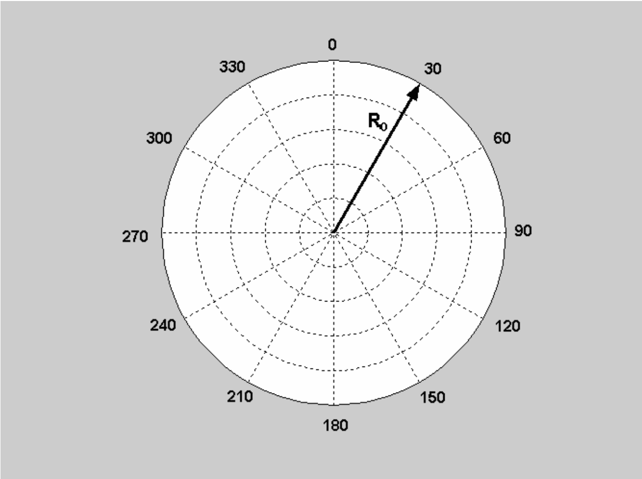

Fig.8 PPI Radar

None-prior aircraft information

If air defense system has none prior flight information of the plane, the prior probability distribution of X is

$$\begin{pmatrix} X \\ P_0(x) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 \cdots x_K \cdots x_N \\ 0 & 0 \cdots 0 \cdots 0 \end{pmatrix}$$

When the aircraft is detected in cell K (K=1,…,N)by the PPI radar, the posterior probability distribution of X is

$$\begin{pmatrix} X \\ P_1(x) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 \cdots x_K \cdots x_N \\ 0 & 0 \cdots 1 \cdots 0 \end{pmatrix}$$

The information gained by the air defense system during this process is

$$I(P_1, P_0; X) = \sum_{i=1}^{N} P_1(x_i) \log \frac{P_1(x_i)}{P_0(x_i)}$$

$$= \sum_{i=1, i \neq K}^{N} P_1(x_i) \log \frac{P_1(x_i)}{P_0(x_i)} + P_1(x_K) \log \frac{P_1(x_K)}{P_0(x_K)} \quad (bit)$$

Gain Aircraft's Azimuth and Distance Prior Information

If air defense system has known azimuth and distance prior information of aircraft (for example, spy near the airfield will know the direction and time of the aircrafts taking off, or aircraft use same flighting routes), air defense system would estimate the aircraft is in an arc area of the surveillance airspace (Fig.9). If the arc area contains $N_{R\varphi}$ cells, $S_{R\varphi}$ denote arc area value, then

$$N_{R\varphi} = \left[\frac{S_{R\varphi}}{S} \right] \cdot N = \left[\frac{\varphi(R_2^2 - R_1^2)}{2\pi R_0^2} \right] \cdot N$$

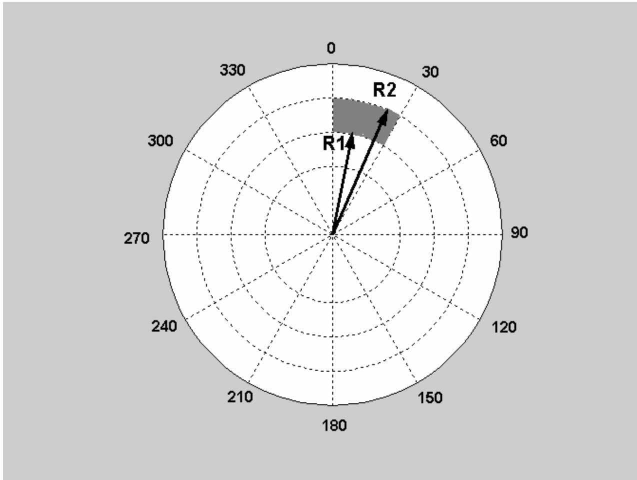

Fig.9 arc surveillance area in PPI radar

If air defense system is sure about the prior aircraft information, the prior probability of X event is 1. If air defense system is not sure about the prior aircraft information, the prior probability of X event is p (p<1). Define Q is the assurance function of prior aircraft information, $I_{pre}^{aircraft}$ denote prior aircraft information, then

$$p = Q(I_{pre}^{aircraft})$$

The probability that aircraft appear in the arc area is p, and if the probability that aircraft appear in every cell of the arc area is equal, then the prior probability distribution of X is

$$\begin{pmatrix} X \\ P_0(x) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 \cdots & x_{N_{R\varphi}} & x_{N_{R\varphi}+1} \cdots x_N \\ \frac{p}{N_{R\varphi}} & \frac{p}{N_{R\varphi}} \cdots & \frac{p}{N_{R\varphi}} & 0 \quad \cdots \quad 0 \end{pmatrix}$$

The posterior probability distribution of X is

$$\begin{pmatrix} X \\ P_1(x) \end{pmatrix} = \begin{pmatrix} x_1 & x_2 \cdots x_K & x_{K+1} \cdots x_{N_{R\varphi}} \cdots x_N \\ 0 & 0 \cdots 1 & 0 \quad \cdots \quad 0 \quad \cdots \quad 0 \end{pmatrix}$$

The aircraft information gained by the air defense system during this process is

$$I(P_1, P_0; X) = \lim_{\delta \to 0} \Big(\sum_{i=1, i \neq K}^{N_{R\varphi}} \delta \log \frac{\delta}{p / N_{R\varphi}} + 1 \cdot \log \frac{1}{p / N_{R\varphi}}$$

$$+ \sum_{j=N_{R\varphi}+1}^{N} \delta \log \frac{\delta}{\delta} \Big) = \log \frac{N_{R\varphi}}{p} = \log \frac{N_{R\varphi}}{Q(I_{pre}^{aircraft})} \quad (bit)$$