Analysis of Passive Millimeter Wave Detection Signal Based on Entropy Feature

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Abstract. It is easy to be planar metal and ground water mistakenly identified as an armored target, when the signal amplitude value was deemed as a decisive characteristic in passive millimeter wave detection system. Aiming at this problem, this paper proposes a new characteristic which named entropy. The extraction method of entropy is proposed from the point of view of the antenna temperature of typical objects in the millimeter wave passive detection. Studied a certain amount of samples detection signal’s entropy. The results showed that the entropy of the armored targets and metal plane and ground water have obvious difference, the armored target recognition research provides a new analysis method and theoretical guidance.

1. Introduction
In the millimeter wave band, there is a big difference in brightness temperature between background and target [1-2]. So the ground armored target can be effectively detected by using passive millimeter wave technology [3-4]. However, due to the passive millimeter wave detection signal of other targets (such as planar metal, ground water, etc.), which have low brightness temperature, is similar to armored target in amplitude, and so easy to mistakenly identified [5-8]. In order to find a effective method for armored target anti passive jamming, when detected with passive millimeter wave technology, starting from the basic principle of passive millimeter wave detection, analysis of the radiation of typical objects detection mechanism, put forward a method to extract the entropy feature, calculate the signal entropy feature of armored target and other passive targets, provide the necessary support for armored target recognition with passive millimeter wave technique.

2. Principle of passive millimeter wave detection
The antenna temperature is a form of passive millimeter wave detection results of target and background, and its expression is

\[ T_d = \frac{1}{4\pi} \int_{\Omega_M} T_{\text{app}}(\theta, \phi) F(\theta, \phi) d\Omega \]  

(1)

Eq.1, \( T_d \) is the antenna temperature; \( F(\theta, \phi) \) is the antenna pattern; \( \Omega_M \) is the solid angle of the main antenna beam; \( T_{\text{app}}(\theta, \phi) \) is the apparent temperature. By the knowledge of radiation measurement
theory we know, when ignoring the brightness temperature of atmospheric upward radiation and atmospheric attenuation, apparent temperature is expressed as,

\[
T_{ap}(\theta, \phi) = T_{ap}(\theta, \phi) + T_{ap}^{'}(\theta, \phi) = \epsilon(\theta, \phi)T_I + \Gamma(\theta, \phi)T_{other}(\theta, \phi)
\]  

Eq.2, \(T_{ap}(\theta, \phi)\) is the brightness temperature; \(T_{ap}^{'}(\theta, \phi)\) is the brightness temperature reflected by the measured target, which comes from the other radiations; \(T_I\) is the physical temperature; \(\epsilon(\theta, \phi)\) is the radiation rate; \(\Gamma(\theta, \phi)\) is the reflection rate, meets \(\Gamma(\theta, \phi) + \epsilon(\theta, \phi) = 1\); \(T_{other}(\theta, \phi)\) is the brightness temperature of other targets, which radiate to the measured target.

Usually, for a passive millimeter wave detection system, the antenna pattern is constant, so the antenna temperature is determined by apparent temperature [9-10].

3. Apparent temperature of typical targets

3.1. Apparent Temperature of A Planar Metal Target

Assuming that the antenna main beam was entirely filled by the planar metal, as showed in Fig.1 (a).

![Figure 1. Schematic diagram of apparent temperature.](image-url)
Fig. 1, $T_{DN}^{\theta,\phi} \text{ is the brightness temperature of atmospheric downward radiation. Here, we take the planar target in Fig.1(a) is planar metal target. In 8mm, the radiation rate of metal is } \varepsilon(\theta, \phi) \approx 0,$ reflection rate is $\Gamma(\theta, \phi) \approx 1,$ so according to the Eq.2 the apparent temperature of planar metal is

$$T_{\text{APplaneMetal}}(\theta, \phi) = T_{DN}^{\theta,\phi} \quad (3)$$

### 3.2. Apparent Temperature of Ground Water

Fig.1(b) shows the apparent temperature of ground water. In 8mm, the radiation rate of water is 0.37, the reflection rate is 0.63. Therefore, the difference between ground water and planar metal target is ground water is not only reflecting the brightness of the atmospheric upward radiation, but also radiate energy itself. So according to the Eq.2 the apparent temperature of ground water is,

$$T_{\text{APWater}}(\theta, \phi) = 0.37T_{\alpha} + 0.63T_{DN} \quad (4)$$

### 3.3. Apparent Temperature of Amored Target

Compared to the planar target, armored target is a complex geometry metal target. Its apparent temperature composition is shown in Fig.1(c). From Fig.1(c), we know that armored target is different from planar metal target and ground water lies in its scatter temperature has two parts: (1) some armored target panel reflect the brightness temperature of atmospheric upward radiation, $T_{\text{Air}}(\theta, \phi);$ (2) some other armored target panel reflect the brightness temperature of background, $T_{\text{Back}}(\theta, \phi).$ So according to the equation (2) the apparent temperature of armored target is,

$$T_{\text{APArmored}}(\theta, \phi) = \sum_i T_{DN}^{\theta,\phi} + \sum_j T_{BBj} \quad (5)$$

Eq.5, $T_{DNi}$ means panel i reflect the brightness temperature of atmospheric upward radiation; $T_{BBj}$ means panel j reflect the brightness temperature of background.

### 4. Signal entropy feature

The above analysis about the composition of apparent temperature knows that, the antenna temperature curve of planar target (planar metal and ground water) is a smooth change process, but the apparent temperature of armored target is determined by the irradiation conditions. In the process of probing beam scanning armored target, the spatial relations between the antenna and armored target are constantly changing, so the same panel may reflect the brightness temperature of the atmosphere, and may reflect the brightness temperature of background. Generally, the brightness temperature of background is higher than the atmosphere. Therefore, the antenna temperature of armored target may exhibit a range of non-uniform.

For the non-uniform of armored target, reference the chaos degree in physics characterization – entropy [11], proposes the concept of signal entropy feature of passive millimeter wave detection. Assumes that the detection signal is a set of N sample points $T_\alpha = \{T_{\text{Air}}, \ldots , T_{\text{DN}}\},$ define the detection signal entropy feature is,

$$S = \frac{1}{N-1} \sum_{i=1}^{N-1} \left| T_i - T_{\alpha} \right| \quad (6)$$

Eq.6, $S$ is the signal entropy feature; $T_\alpha$ means the i antenna temperature of detection signal. The value of S reflects the degree of disorder of the signal, the higher the value the greater the degree of
signal confusion. The above theoretical analysis shows, armored target's S value is higher than the planar metal target and ground water.

5. The entropy feature of typical targets

![Figure 2. Different targets’s antenna temperature curve and its difference sequence.](image)
In order to analyze the entropy feature of typical target, using panel method establishes the planar metal target mode, groundwater model, and armored target mode. Simulations obtain the detection signal of the typical target, and calculate the entropy feature. At the same time, in order to more clearly show the signal fluctuation, calculate the result of difference sequence $\left( a_{i+1} - a_i \right)$. Fig.2 shows different target’s antenna temperature curve and its difference sequence. Among them, (a) & (b) shows the meadow’s, (c) & (d) shows the planar metal’s, (e) & (f) shows the ground water’s, and (g) & (h) shows the tank’s.

As is shown in Fig.2(a) and Fig.2(b), no matter simulation signal or measured signal of meadow, difference sequence is smooth change. According to Eq.6, the entropy feature of the simulation signal and the measured signal is 0.7819 and 0.0266, respectively; By Fig.2(c) and (d), we can see that compared to the meadow, the difference sequence of planar metal presents a certain fluctuation, and the entropy feature of the simulation signal and the measured signal is 1.1920 and 1.0378, respectively; Fig.2(e) and Fig.2(f) shows that the difference sequence of ground water is similar to planar metal, and the entropy feature of the simulation signal and the measured signal is 0.9840 and 0.4121, respectively; Fig.2(g) and Fig.2(h) shows the difference sequence fluctuation of the armored target is the most obvious, and the entropy feature of the simulation signal and the measured signal is 2.9242 and 3.7561, respectively.

6. Simulation and analysis
Based on MATLAB, under different detection conditions, we carried out 200 times simulation on meadow, planar metal, ground water, and the armored target, respectively. Calculated the entropy feature and its mean, the results are as showed in Table 1.

| Entropy feature | Meadow | Planar metal | Ground water | Tank |
|-----------------|--------|--------------|--------------|------|
| 0.7926          | 1.0078 | 1.2370       | 3.1030       |

As is shown in Table 1, the entropy feature of different target is different. And planar metal is similar to ground water, but the tank is much bigger than other targets. So, we can identify tank from other targets based on the value of entropy feature. Fig.3 shows the histogram of entropy feature distribution of the different targets.

Figure 3. Comparison charts of entropy feature distribution of different targets.
Fig. 3(a) shows that the entropy feature of ground water and planar metal is obviously intersect, so based on the theory of probability, there is a high error probability that one be recognized as the other one. But analyze the diagram of (b), (c) and (d) can be seen, the entropy feature of tank and meadow, planar metal and ground water almost nonexistent intersection. So according to the entropy feature, we can accurately separate the tank from them, and realize the recognition of the tank from the typical background.

7. Conclusion
Starting from the basic principle of passive millimeter wave detection, analyzing the composition of apparent temperature of armored target and the other jamming targets, which easily be error recognized as armored target, such as planar metal and ground water, pointing out their differences. According to differences, we proposed the concept of entropy feature and its calculation method. Statistic the entropy feature distribution of a large amount of the detection signal, include simulation signals and measured signals. Results showed that by using signal entropy feature, armored target can be effectively identified from the typical background, and further improve the passive millimeter wave detection system’s ability of anti-passive interferences (such as planar metal, ground water, etc.).

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