Target models for range performance prediction of infrared imaging system

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This paper describes a commonly used target model and two improved models for range performance prediction of infrared imaging system in an original explicit way. We conclude the basic assumptions of each model, define the temperature difference, and give the mathematical equation to calculate the measurement of resolvable target details. The flow path for using the measurement to evaluate the range performance is briefly introduced. The features of these models are compared.

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To evaluate the range performance of infrared imaging system, we need a target model and a recognition criterion. The target model provides a group of assumptions and definitions, when a prospective target is abstracted according to it, the measurement of resolvable details of this target could be obtained. The recognition criterion is based on observing experiments, when comparing some criteria with the measurement, we could estimate whether the target could be detected, recognized or identified. After carefully considering the characteristics of infrared imaging system and target, a proper target model should be selected to make the prediction result more accurate. However, the homogenization model, which has appeared several decades ago and is still commonly used today, always contradicts the targets' actual infrared radiation distributions[1] and tends to bring an excessively simplified apparent temperature difference ΔT_{a}, and then leads to a deviation from the true range performance. Furthermore, in some particular situations, the calculated ΔT_{a} might be very small or even zero, which would cause serious error and make the prediction meaningless. Therefore, a more precise target model corresponding to the real infrared distribution will be necessary.

Using homogenization model to calculate ΔT is the common method. It averages the temperatures of all the subareas in a target, and the temperature difference is usually obtained from[2]

$$T_{\mathrm{ave}}=\frac{\sum_{i=1}^{N}A_iT_i}{\sum_{i=1}^{N}A_i}, \tag{1}$$

$$\Delta T=T_{\mathrm{ave}}-T_{\mathrm{B}}, \tag{2}$$

the target is divided into N subareas A_i with particular temperature T_i, T_{ave} represents the average temperature of the whole target, and T_{B} is the background temperature. Then, after subtracting T_{B} from T_{ave}, we get a temperature difference that could be called area-weighted ΔT.

However, this methodology apparently neglects the inner details of target, and loses the position information of target infrared distribution. In addition, this method needs to postulate the target in a single background, but this hypothesis is not always the truth. For example, among the long-distance applications, such as resource detection and wild rescue, whether the background is single or complex is determined by the angle of view and the special physiognomies appearing at the horizon; and among the short-distance applications, such as the infrared surveillance systems for law enforcement or automobile safety, the backgrounds are always very complicated. According to the analysis of area-weighted ΔT, we conclude the first target model as: 1) single background or averaging background; 2) single area-weighted radiation temperature of target; 3) according to the two assumptions, the formula to calculate the measurement of resolvable target details is

$$\text{cycles}=\Omega\times\mathrm{MRTD}^{-1}\left[\tau\cdot\left|T_{\mathrm{B}}-\frac{\iint_S T(x,y)\,\mathrm{d}\sigma}{S}\right|\right], \tag{3}$$

where $T(x,y)$ is the temperature distribution of target; MRTD is the minimal resolvable temperature differential function, MRTD^{-1} represents that the apparent ΔT intersects the MRTD curve and corresponds to the critical spatial frequency; τ is the infrared transmittance along the whole propagation path (including the atmosphere and the optical system); S is the target area (which contains the characters that could be used to distinguish the target out of whole infrared image); Ω is the solid angle corresponding to the target character dimension.

This model uses cycles as the measurement of resolvable target details, and the computed result could be compared with Johnson criterion to evaluate the range performance.

Taking an example of Fig. 1(a), this target model would

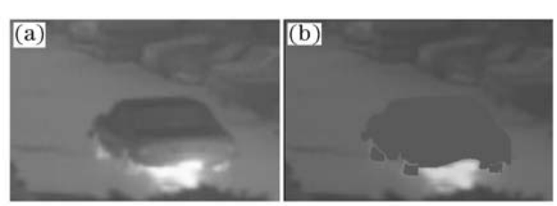

Fig. 1. Result of the first model.

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be like Fig. 1(b). From Fig. 1, we can see that based on this model, we could only get the measurement of rim details of the car from the averaging temperature.

The defect of the first model is obvious. For the infrared radiation of target area is always not homogeneous distribution, the various temperature differences among each subareas will correspond to different critical frequencies. As a result, the detailed cycles obtained from the first model would only be an approximate value from average method, and probably contains a great error.

So we propose an ideal model as: 1) true background outside the target; 2) real radiation temperature distribution in the target area; 3) according to the two assumptions, the formula to calculate the measurement of resolvable target details is

$$\text{pixels} = \iint_S \mathrm{MRTD}_{\mathrm{2D}}^{-1}\left[\tau \cdot |\Delta T\,(x,y)|\right]\frac{\mathrm{d}\sigma}{R}, \tag{4}$$

where $\Delta T(x,y)$ is the gradient magnitude of the target radiation temperature distribution $T(x,y)$, and gotten through Sobel operators $\begin{pmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{pmatrix}$ and $\begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix}$.

Supposing that the gray level of the image in Fig. 2(a) is in proportion to the radiation temperature, $\Delta T(x,y)$ is shown in Fig. 2(b). The number of gray scales in the two images is 256.

$\mathrm{MRTD}_{\mathrm{2D}}$[3] is the two-dimensional (2D) minimal resolvable temperature differential function. It generates from the horizontal and vertical MRTDs. On the $\mathrm{MRTD}_{\mathrm{2D}}$ curve, the value of temperature difference corresponds to f_{2D}. Supposing $f_{\mathrm{2D}} = f_{\mathrm{H}} \cdot f_{\mathrm{V}}$, the unit of the independent variable (spatial frequency) would be cycles^2/rad^2, and when the radians are less than $\pi/6$, it could be approximately considered as pixels/sr. τ, R, and S have been defined in the first model.

This target model uses pixel number rather than cycles as the measurement for the resolvable details through certain imaging system. For this methodology, Moser's experiment result[4] could play the role of Johnson criterion: 36 pixels for detection, 100 pixels for recognition, and 500 pixels for identification.

From the equation above, we know the pixels are integrated together. The pixel used as the dimension of resolvable target details is defined as the smallest element that can be resolved by an imaging system. Therefore, we believed that, for the various temperature difference, the pixels integrated together always have different sizes, although each of them is equally counted as unit.

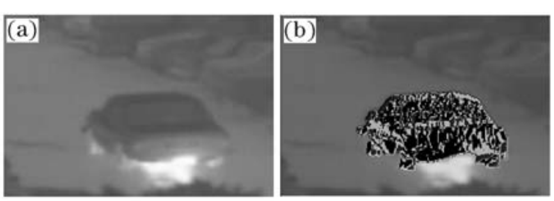

Fig. 2. Result of the second model.

Based on the typical target images, through the MRTD method, the second target model mentioned above could theoretically yield a better resolvable details value. However, image characters of many targets to be recognized often assemble in one direction, so for less mathematical operation load and more precise target details, we bring forward the third model for compromise: 1) true background outside the target; 2) one-dimensional (1D) distribution of real radiation temperature in the target area; 3) according to the two assumptions above, the formula to calculate the measurement of resolvable target details is

$$\text{cycles} = \int_{Y_b}^{Y_t} \mathrm{MRTD}_y^{-1}\left[\tau \cdot |\Delta T(y)|\right]\frac{\mathrm{d}y}{R}, \tag{5}$$

where $\Delta T(y)$ is the vertical temperature difference distribution in the typical target area, and gotten through the Kirsch operators. MRTD_y is the MRTD function in vertical direction. Figure 3(b) shows the averaging temperature difference distribution in vertical direction. Figure 3(c) is the result processed through the original operator $\begin{pmatrix} 3 & 3 & 3 \\ 3 & 0 & 3 \\ -5 & -5 & -5 \end{pmatrix}$, whereas Fig. 3(d) is the one processed through the intensified operator $\begin{pmatrix} 30 & 30 & 30 \\ 30 & 0 & 30 \\ -50 & -50 & -50 \end{pmatrix}$. The number of gray scales in the images of Fig. 3 is also 256.

From Fig. 3, we find that modifying operator could intensify this model. For the extreme situation, binarization processing of images will maximize this intensifying effect[5]. This extreme situation will be realized when the infrared imaging system is equipped with a pre-processing program of directional operator, and it could also be realized on the second model.

This model also use cycles as the measurement of resolvable target details, and the computed result could be compared with Johnson criterion to evaluate the range performance.

In fact, the third mode could choose any direction to calculate the temperature difference, which is determined by image characteristics, although the temperature difference distribution is easy to get in vertical or horizontal direction. When other direction is selected, corresponding directional operators should be used.

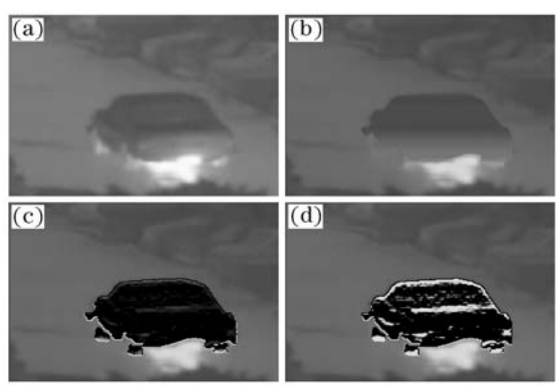

Fig. 3. Results of the third model. (a) Original image; (b) temperature difference averaged in the vertical direction; (c), (d) processing results through different operators.

When we get reasonable measurement of target details, no matter cycles or pixels, corresponding to some criteria, we will know whether the target in prospective distance could be recognized. If the value of cycles or pixels is much smaller than the criterion, the prospective range performance should be chosen again, until the measurement meets the criterion. This process is shown in Fig. 4, where f_c is the critical frequency.

In practice, a target transfer probability function (TTPF) always takes the place of the Johnson criterion in Fig. 4. This function describes the relationship between the measurements and their corresponding recognizable probability. With this function, when we propose a distance, a recognizable probability will be gotten, rather than a constant 50% probability as the presuppositions of Johnson criterion.

The first model in this paper is easy to understand and requires small mathematical operation load. It works well under the conditions of single background and simple target which always takes a small area in the whole field of view. However, while the performance of infrared imaging system improves and their application areas increase, people's concern about range performance expands from detection and recognition to more precise identification. For this, people systematically research the infrared radiations of various kinds of backgrounds and targets, and construct practical database[6]. Evidently, ignoring this fruitful work and averaging the radiation intensity of targets cannot meet the requirement.

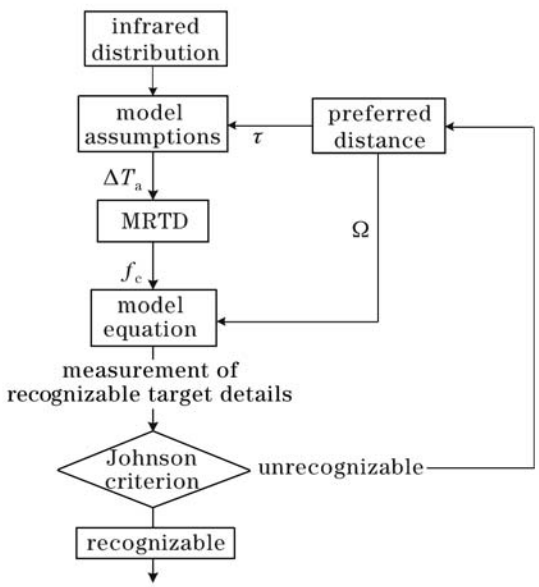

Fig. 4. Flow chart to predict the range performance.

On the other hand, for the systems used for auto-target-recognition (ATR), an auto image analyzer endowed with some programs always plays an important role. Many of those programs used for target recognition are based on the algorithms like rim detection, texture classification, or other detail analyzing. The second and third models in this paper can provide the measurement of resolvable target details, predict the range performance of this kind of system and serve the program design. While the analyzer uses intensity threshold algorithm, reasonable measurement can generate from the first model.

Therefore, according to the specific application, carefully considering whether general recognizing or precise identifying, manual observing or auto recognizing, boundary algorithm or region algorithm could lead to a correct selection of target model and better prediction result of range performance.

The original image in this paper is derived from http://www.x20.org. Y. Zhang's e-mail address is zyhbh2004@yahoo.com.cn.

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