Research on filter’s parameter selection based on PROMETHEE method

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Abstract. The selection of filter’s parameters in target recognition was studied in this paper. The PROMETHEE method was applied to the optimization problem of Gabor filter parameters decision, the correspondence model of the elemental relation between two methods was established. The author took the identification of military target as an example, problem about the filter’s parameter decision was simulated and calculated by PROMETHEE. The result showed that using PROMETHEE method for the selection of filter’s parameters was more scientific. The human disturbance caused by the experts method and empirical method could be avoided by this way. The method can provide reference for the parameter configuration scheme decision of the filter.

1. Introduction

The Gabor function could simulate the working mechanism of biology visual neuron. The target with a certain shape in the image can be accurately recognized only with a series of proper filter’s parameters. The preference ranking organization methods for enrichment evaluations (PROMETHEE) is an important multi attributes decision making method, which can be used to solve the problem about image filtering parameter selection.

PROMETHEE is a series of methods based on Outranking Relation (OR) and Outranking Methods (OM). It is a classic multi attributes decision method, and people use this method to solve many problems. Jiang used the PROMETHEE method to research the multiple attribute decision making problems in [1]. SUN researched and compared the robustness of multiple attribute decision making methods, and pointed out in several articles in [2-4]. Dong and other people used PROMETHEE method to simulate some specific problems, proved that this method can provide a good reference for solving incomplete information decision-making and their research are described in the published papers [5-10]. Fang provided a weight calculation method for multiple attribute decision making problems in [11].

Gabor filter has been used in computer vision widely, which meets the demand of image processing during the battlefield reconnaissance. Gabor filter is used in various fields of image processing widely. Chen combines Gabor filter and ant colony algorithm for segmented images, he shows his research in [12]. Guo researched the adaptive image registration based on Gabor filter in [13]. Chen completed the combination of Gabor filter and ICA technology for texture classification in [14]. Ye and Song else
used the Log-Gabor filter and its improved method for researching the face recognition in [15] and [16]. Tao used Gabor filter to recognize the road from high resolution remote sensing images in [17].

It’s the key to select the correct filter’s parameters for sifting out the distracters in the image, which is important for accurately identifying the targets. The principle of Gabor filter is similar to the biological optic nerve system, and the accurate target recognition of the image is beneficial to the decision maker’s analysis. The key to solve the target recognition of battlefield image is the configuration of filter’s parameters. The selection of the parameters in the Gabor filter function is regarded as the criterion in the PROMETHEE method. The selection of parameters can be solved by this way, and the optimal scheme could be selected according to different requirements.

2. Model establishments

2.1. Objective function

The basic expression of two dimensional Gabor function is like:

$$
\Psi(u,v,\sigma_G,\beta_G,\omega_0) = \frac{1}{2\pi\sigma_G^2\beta_G^2} \cdot e^{\left[-\frac{1}{2} \left(\frac{u^2}{\sigma_G^2} + \frac{v^2}{\beta_G^2}\right)\right]} \cdot e^{\left[2\pi i \omega_0(uv)\right]}
$$

(1)

In this function, \((u,v)\) means a set of data signal, \(\omega_0\) means the spatial frequency domain of complex planar wave. \(\lambda_G\) means the wavelength of filter, that is the scale of Gabor filter, and \(\lambda_G \geq 2\). The \(\sigma_G\) and \(\beta_G\) represent the Gauss standard deviation in the direction of \(u\) and \(v\) respectively. And the \(i\) represents the imaginary part of the filter function. We assume that the scales are the same in \(u\) and \(v\) directions, \(\sigma_G = \beta_G\). In order to remain the shape and scale of the filter unchanged during the filtering, it’s necessary to specify a scale factor \(k\) on the wavelength of the filter, which is controlled in the \(x\) axial direction and the \(y\) axis direction, and \(\sigma_G = \frac{\lambda_G}{k}\).

Therefore, the filter is expressed as:

$$
\Psi(u,v,\lambda_G / k,\omega_0) = \frac{k^2}{2\pi\lambda_G^2} \cdot e^{\left[-\frac{1}{2} \left(\frac{u^2}{\lambda_G^2} + \frac{v^2}{\lambda_G^2}\right)\right]} \cdot e^{\left[2\pi i \omega_0(uv)\right]}
$$

(2)

When the direction of the Gabor filter is \(\varphi_0\), the can be rewritten as:

$$
\Psi(u,v,\lambda_G / k,\varphi_0) = \frac{k^2}{2\pi\lambda_G^2} \cdot e^{\left[-\frac{1}{2} \left(\frac{(u \cos \varphi_0 + v \sin \varphi_0)^2}{\lambda_G^2} + \frac{(-u \sin \varphi_0 + v \cos \varphi_0)^2}{\lambda_G^2}\right)\right]} \cdot e^{\left[2\pi i \omega_0(u \cos \varphi_0 + v \sin \varphi_0)\right]}
$$

(3)

Therefore, the Gabor function may be decomposed into two functions like so that the scale and displacement of the target could be judged.

$$
\begin{align*}
\Psi_k(u,v,\lambda_G / k,\varphi_0) &= \frac{k^2}{2\pi\lambda_G^2} \cdot e^{\left[-\frac{1}{2} \left(\frac{(u \cos \varphi_0 + v \sin \varphi_0)^2}{\lambda_G^2}\right)\right]} \cdot \cos \left(\frac{2\pi (u \cos \varphi_0 + v \sin \varphi_0)}{\lambda_G}\right) \quad \text{Real part} \\
\Psi_i(u,v,\lambda_G / k,\lambda_G / k,\varphi_0) &= \frac{k^2}{2\pi\lambda_G^2} \cdot e^{\left[-\frac{1}{2} \left(\frac{(u \cos \varphi_0 + v \sin \varphi_0)^2}{\lambda_G^2}\right)\right]} \cdot \sin \left(\frac{2\pi (u \cos \varphi_0 + v \sin \varphi_0)}{\lambda_G}\right) \quad \text{Imaginary part}
\end{align*}
$$

(4)

2.2. Model of Multi attribute decision making

PROMETHEE provides priority for decision makers in the case of multi attribute and incomplete information. The database about the attributes of different targets is established, and marks this as the criterion set \(J (j_1, j_2, \ldots, j_i, \ldots, j_m)\). According to, the parameters need to be set for Gabor filtering
include \((\lambda_c, k, \varphi_c)\). The number of effective parameter combination schemes is \(n\), so set the scheme \(S(s_1, s_2, \cdots, s_j, \cdots, s_n)\). According to the preference of decision maker, set the weight coefficient about every target \(\omega = (\omega_1, \omega_2, \cdots, \omega_s, \cdots, \omega_m)\). Where \(\sum_{i=1}^{m} \omega_i = 1\), and \(\omega\) were greater than 0.

Establishing the priority function as \(p_{j_i}(s_i, s_k)\), this function represents the priority of the scheme \(s_i\) relative to the scheme \(s_k\) on the criterion \(j_k\), and the form of the priority function can be referenced in the Ref.[5]. The priority of each scheme is calculated by inflow and outflow, and the priority index between the two schemes is obtained, such as:

\[
d_{j_i}(s_i, s_k) = \frac{\sum_{s=1}^{n} \omega_s \cdot p_{j_i}(s_i, s_k)}{\sum_{s=1}^{n} \omega_s}, \quad d_{j_i}(s_i, s_j) = 0
\]  

(5)

The \(\phi^+(s_j)\) is expressing the corresponding preference weight \(\omega_j\) to the attribute \(j_j\) has been given by the decision makers in the case of incomplete information. The priority between the scheme \(s_j\) and the scheme \(s_k\) is being calculated for comparing the priority intensity of these two schemes under this attribute.

The definition of \(s_j\) net flow is:

\[
\phi^+(s_j) = \frac{1}{n-1} \sum_{k=1, k \neq j}^{n} d_{j_i}(s_j, s_k) \\
\phi^-(s_j) = \frac{1}{n-1} \sum_{k=1, k \neq j}^{n} d_{j_i}(s_k, s_j)
\]  

(6)

The priority relation of PROMETHEE is determined by:

\[
\phi(s_j) = \phi^+(s_j) - \phi^-(s_j)
\]  

(7)

where, the \(\phi_{j_i}(s_j) (j_j \in J, s_j \in S)\) satisfied the following.

1. \(-1 \leq \Phi_{j_i}(s_j) \leq 1\)
2. \(\sum_{j=1}^{n} \omega_j \Phi_{j_i}(s_j) = \Phi(s_j)\)
3. \(\sum_{j=1}^{n} \phi_{j_i}(s_j) = 0\)

And.

\[
\Phi_{j_i}(s_j) = \begin{bmatrix}
\phi_1(s_j) & \cdots & \phi_2(s_j) & \cdots & \phi_n(s_j) \\
\phi_1(s_j) & \phi_2(s_j) & \phi_3(s_j) & \cdots & \phi_n(s_j) \\
\vdots & & & & \\
\phi_1(s_j) & \cdots & \phi_2(s_j) & \cdots & \phi_n(s_j) \\
\phi_1(s_j) & \cdots & \phi_2(s_j) & \cdots & \phi_n(s_j)
\end{bmatrix}
\]  

(8)

It represents the entire priority index net of all schemes based on different attribute. So we can get the collection of all schemes. When the value of \(\phi(s_j)\) is bigger, the priority of the scheme \(s_j\) is higher.
Figure 1. The element correspondence of two methods.

The sets involved in PROMETHEE method include the attribute set and the scheme set, such as figure 1. Assign weight values to each attribute and select an appropriate priority function model. The complete order of scheme priority can be calculated through the comparison between the priority schemes and the calculation of each scheme net. It is necessary to analyze the target attributes to deal with the filtering of image. The target model database about to different military targets need to be established. The "attribute" set is formed by summing up the appearance, size, color and other characteristics. The different filtering parameters are selected from the scheme \( G(\lambda, k, \varphi) \). In order to construct target firing sequence chain, the threat degree of target need to be analyzed, the normalized matrix of index feature need to be established, the weight set of target attribute could be formed. And the firing sequence corresponds to the weight value.

The response value of the pixel is obtained through the convolution calculation in the image. The different parameter schemes could obtain the different pixel response value. Which the response value is higher, the priority of the target recognition is higher. The priority of target recognition is more consistent to the sequence of target threat degree, the scheme is more suitable.

3. Image processing based on Gabor filtering

3.1. Parameters of Gabor filter

The parameters of the Gabor filter include \( (\lambda, k, \varphi) \). When the decision is not made by using the PROMETHEE method, the parameters of the filter can only be set for many times to distinguish the battlefield target in image. The better recognition result and the filter’s parameter combination scheme are selected from the multi group of filter results.

The wavelength is selected as an example in this paper, so, the scale factor \( k \) is set to 0.5, and the filtering direction \( \varphi \) is set to \( \frac{\pi}{4} \) and \( \frac{3\pi}{4} \). We get the best filtering result when \( \lambda = 2 \) or 3 without any decision algorithm intervention. The original image is shown in figure 2(a), set \( \varphi = \frac{3\pi}{4} \) first, and the filtering result when \( \lambda = 2 \) and \( \lambda = 3 \) is shown in figure 2(b) and (c).
In the figure 2 (a), the target number 1 and 2 are tank models, the target number 3-6 are aircraft models parked on the airport pavement and the military airports as a building target, numbered 7.

The texture features of tank model and aircraft model are different from the surrounding environment in military image. The airport pavement shows line characteristics obvious. Every pixel point will respond in different direction after Gabor filtering. It can be considered that the pixels are likely to be the target location or the contour of the target area when these pixel points have large texture response value. The pixel response value can be getting by:

\[ T(u, z) = P(u, z) \ast \Psi_{\lambda_i}(u, v, \lambda_i / k, \varphi_0) \tag{9} \]

where, \( T(u, z) \) represents the pixel response value, \( P(u, z) \) represents the gray value of original image, and \( \ast \) represents convolution.

3.2. Analysis of image filtering results
In order to recognize the targets, it is necessary to analyze the gray histogram of each filtering result. The peak value in the gray histogram is \( g_{\text{max}} \). \( T_g \) represents the number of the pixel which the gray value is in the range of \( g_{\text{max}} \pm r \), \( r \) is 15. The image processing can be judged successful when \( T_g \) is greater than \( D_{\text{max}} \), and the desired target may be identified. Otherwise, the desired target cannot be accurately identified from the image.

The pixels which their response value are in the range of \( g_{\text{max}} \pm 15 \) when \( \lambda_i = 2 \) and 3 are displayed, the results and the corresponding gray histogram are show in figure 3.

\[ \lambda_i = 2 \quad \lambda_i = 3 \]
Display the pixels’ response in the range.

Figure 3. The result of filtering.

The same method is used to calculate when $\phi_u = \frac{\pi}{4}$, and the results of the two image processing are combined finally in figure 4.

Figure 4. The pixel response of multi angle and different wavelength.

The two results can be evaluated only by visual, and there is no scientific evaluation basis to determine whether the choice of parameters is appropriately. The filtering effect is better from the clarity of the graph when $\lambda_u = 3$.

4. Gabor filter’s parameter scheme decision making based on PROMETHEE

4.1. Priority function

There are 7 targets in the attribute set from figure 2(a). The wavelength varies from 1-8, so, there are 8 options in the scheme set, that means $S(s_1) = S(s_1(\lambda_1 = 1), s_2(\lambda_2 = 2), \cdots s_8(\lambda_8 = 8))$. The priority function can be chosen as in this case.

$$p(T_g) = \begin{cases} 
0 & T_g \leq D_{\text{min}} \\
\frac{(T_g - D_{\text{min}})}{(D_{\text{max}} - D_{\text{min}})} & D_{\text{min}} < T_g \leq D_{\text{max}} \\
1 & T_g > D_{\text{max}} 
\end{cases} \quad (10)$$

4.2. Weight

The threat degree of target is taken as the weight of the PROMETHEE method according to figure 1. In order to obtain the weight of every attribute in the decision problem accurately, the target assessment will be carried out in the following section.

According to the target type, size, state and direction (fairway crosscut) of movement, tactical threat, attack ability and so on, using the method of catastrophe decision model, the target threat assessment model is set up as shown in figure 5.
Figure 5. Target threat assessment index classification.

Assigning values to the target attributes as shown in Table 1.

| Attributes | Target number | No.1 | No.2 | No.3 | No.4 | No.5 | No.6 | No.7 |
|------------|---------------|------|------|------|------|------|------|------|
| Target type| 3             | 3    | 6    | 6    | 6    | 6    | 6    | 8    |
| Tactical threat degree | 3 | 3 | 7 | 4 | 7 | 4 | 8 |
| Attack capability | 5 | 5 | 6 | 1 | 6 | 1 | 1 |
| Defensive capability | 4 | 4 | 5 | 1 | 5 | 1 | 3 |
| State of battle | 5 | 5 | 6 | 3 | 6 | 3 | 3 |
| Location | 4 | 4 | 5 | 2 | 5 | 2 | 8 |
| Fairway crosscut | 1 | 1 | 7 | 2 | 7 | 2 | 3 |
| Speed | 3 | 3 | 2 | 2 | 2 | 2 | 1 |

The threat attributes of each target are represented by $TV_{ij}(i = 1, 2, \cdots, n; j = 1, 2, \cdots, 7)$, where $P_i$ is the target number, and $j$ is the number of second level of attributes. The standardization index value of each target can be expressed as:

$$N_{-value}_{ij} = \frac{TV_{ij} - TV_{j}(\text{min})}{TV_{j}(\text{max}) - TV_{j}(\text{min})}, \quad TV_{ij} \neq TV_{j}(\text{min})$$

According to the importance of attributes, the standardization index values are normalized as:

$$\begin{align*}
N_{\text{标准化}}_{1} &= \sqrt{N_{-value}_{p,1}}; N_{\text{标准化}}_{2} = \sqrt{N_{-value}_{p,2}}; N_{\text{标准化}}_{3} = \sqrt{N_{-value}_{p,3}}; N_{\text{标准化}}_{4} = \sqrt{N_{-value}_{p,4}}; \\
N_{\text{标准化}}_{5} &= \sqrt{N_{-value}_{p,5}}; N_{\text{标准化}}_{6} = \sqrt{N_{-value}_{p,6}}; N_{\text{标准化}}_{7} = \sqrt{N_{-value}_{p,7}}; N_{\text{标准化}}_{8} = \sqrt{N_{-value}_{p,8}}
\end{align*}$$

The normalization values of second level attributes are calculated to complement their first level attributes. The first level attributes value of each target are summarized as:

$$\begin{align*}
AV_{p,1} &= \min(N_{\text{标准化}}_{p,1}, N_{\text{标准化}}_{p,2}) \\
AV_{p,1} &= \max(N_{\text{标准化}}_{p,3}, N_{\text{标准化}}_{p,4}) \\
AV_{p,1} &= \frac{N_{\text{标准化}}_{p,5} + N_{\text{标准化}}_{p,6} + N_{\text{标准化}}_{p,7} + N_{\text{标准化}}_{p,8}}{4}
\end{align*}$$

Thus, the threat degree of the target is:
The weight of PROMETHEE can be expressed as by normalization,

\[
\omega_1 = 0.1448; \omega_2 = 0.1448; \omega_3 = 0.2172; \omega_4 = 0.0788; \omega_5 = 0.2172; \omega_6 = 0.0788; \omega_7 = 0.1182
\]  

Therefore, the most threatening targets are the number 3 and number 5 target.

### 4.3. Scheme decision

According to the Section B in Chapter II, we can calculate the net flow of each scheme \( \phi(s_j) \).

\[
\phi(s_1) = 0.4836; \phi(s_2) = 0.6626; \phi(s_3) = 0.5440; \phi(s_4) = 0.2726;
\]
\[
\phi(s_5) = -0.0718; \phi(s_6) = -0.4145; \phi(s_7) = -0.6518; \phi(s_8) = -0.8247
\]

The priority of the scheme is:

\[ a_2 > a_3 > a_4 > a_5 > a_6 > a_7 > a_8 \]

Therefore, the optimal scheme is \( s_2 (\lambda = 2) \).

### 4.4. Verification

The verification method is to analyze the results of two image processing results when \( \lambda = 2 \) and \( \lambda = 3 \). The higher the proportion of pixels satisfying the response value range, the topper of the target recognition order is. The order of target recognition should be corresponding to their threat degree sequence. The calculation results of the pixel response values of different targets in the two filtering cases are such as:

\[
\lambda = 2 (\text{Ratio}_1 = 96.86\%; \text{Ratio}_2 = 94.53\%; \text{Ratio}_3 = 97.35\%; \text{Ratio}_4 = 92.75\%; \text{Ratio}_5 = 99.67\%; \text{Ratio}_6 = 92.50\%; \text{Ratio}_7 = 54.49\%)
\]
\[
\lambda = 3 (\text{Ratio}_1 = 95.17\%; \text{Ratio}_2 = 86.72\%; \text{Ratio}_3 = 92.86\%; \text{Ratio}_4 = 71.37\%; \text{Ratio}_5 = 93.75\%; \text{Ratio}_6 = 87.73\%; \text{Ratio}_7 = 51.69\%)
\]

The proportion of pixels satisfying the response range is sorted as follows:

\[
\lambda = 2: 5 > 3 > 1 > 2 > 6 > 4 > 7; \lambda = 3: 1 > 5 > 3 > 6 > 2 > 4 > 7
\]

Compared with the two schemes, the target number 5 and 3 can be identified first when \( \lambda = 2 \). It is more consistent with the target threat sequence.

### 5. Conclusions

Target recognition determines the success or failure of military operations. Multi-targets appearing in the battlefield image is very common. The Gabor filter is used for solving the problem of target recognition, and the selection of filter’s parameters is the multi-attribute decision-making problem faced by the decision makers. And then, the PROMETHEE method is used for parameters selection in this paper, which provides a scientific basis for the selection of filter’s parameters. The following conclusions are obtained through the research of this paper.

The combination scheme of filter’s parameter is numerous; the proper scheme could help recognize the important or the main target. The filter’s parameters can also be selected by expert method. However, the PROMETHEE can provide a reasonable and scientific decision on the parameter scheme choice. The human disturbance caused by subjective factors is avoided.

The PROMETHEE method is applied to the image filtering problem, and the element correspondence model is established, which provides a better filter’s parameter selection method.

The feasibility and effectiveness of the PROMETHEE method in solving the decision problem of Gabor filter’s parameters are verified by simulations.
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