Research on Camouflage Effect of paint Detected by Hyperspectral Method

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Abstract: In order to make full use of the high-resolution spectral information provided by hyperspectral imaging technology, the camouflage effect of optical coatings was comprehensively evaluated. A comprehensive evaluation method combining the spectral Angle size, spectral curve shape and spectral vector size is proposed. The spectral Angle size, absolute correlation degree and Euclidean distance were used for quantitative evaluation, and the comprehensive evaluation was made from the Angle measure, shape measure and distance measure. And another background of the same kind of treatment to remove the contingency. This method is more rigorous in theory, avoid uncertainty, and has a guiding role in the design and use of coatings.

1. Introduction

Under the condition of modern war, the development of surveillance reconnaissance and capture attack in battlefield becomes more and more mature. It is an important problem to improve the survival ability of our army in this environment. As an important content of battlefield support, camouflage is an important factor that affects the victory or defeat of the war and the life or death of the equipment personnel. In order to achieve the unwillingness of the enemy, improve the survival ability of the battlefield and meet the requirement of sudden combat, Camouflage is also developing to a higher level. At present, the emergence of imaging spectrum technology has made remote sensing-like technology has made the traditional camouflage effect evaluation methods in the past less accurate, traditional camouflage effect detection equipment has panchromatic or Color camera or multi-spectral imager, these methods cannot get high resolution and continuous spectral information, so it is very important to add hyperspectral instrument to the testing equipment. It can not only give more accurate spectral detection of the existing coatings, but also provide a reference for our army to deal with the modern reconnaissance technology better in the future research of coatings.

Hyperspectral technology combines image and spectrum to obtain two-dimensional spatial information and one-dimensional spectral spatial information of the target. In this experiment, I put green paint in the same color background to obtain its hyperspectral image, the analysis method of hyperspectral image is mainly from spectral space, the spectral space can be from two angles, one is from the distance, the other is from the distance, the analysis method of the hyperspectral image is mainly from the spectral space. One is from the shape [1-2], from the distance is by the Euclidean distance analysis method [3-4], from the shape is by calculating the absolute correlation [5] and spectral angle [6] to carry on the quantitative judgment.

2. Basic principles

2.1. Spectral Angle size

Spectral Angle classification is a kind of spectral classification based on physics. A spectrum is regarded as a vector in a space with the same number of dimensions and bands. End-element spectra are obtained from ASCII files or spectral databases, or can be obtained directly from images (average ROI spectra). SAM compares the end element spectral vector with the Angle of each pixel vector in the n-dimensional space. The smaller the Angle is, the more matching it is with the reference spectrum. The calculation formula is as follows:

$$SAM = \cos\left[\frac{\sum_{i=1}^{n_b} t_i r_i}{\left(\sum_{i=1}^{n_b} t_i^2\right)^{\frac{1}{2}}\left(\sum_{i=1}^{n_b} r_i^2\right)^{\frac{1}{2}}}\right] \tag{1}$$

This method makes full use of the spectral dimension information, emphasizes the spectral shape characteristics, and greatly reduces the characteristic information.

SAM takes the average spectrum of the known points extracted from the image as the reference, and calculates the cosine value of the generalized included Angle between each pixel vector in the image and the reference spectral vector. The larger the cosine value is, the greater the similarity will be. The spectral Angle is defined as.

2.2. Spectral curve shape

Whether the shape of the spectral curve of the paint and the background is similar or not, I use the absolute correlation degree to judge. The method is as follows:

1) initializing the spectrum of the coating and the spectrum of the background, so as to make them comparable.

$$X_i = \left\{\frac{x(k)}{x(1)}, k = 1,2,\cdots n\right\} = \{x_i(k)\} \tag{2}$$

$$Y_i = \left\{\frac{y(k)}{y(1)}, k = 1,2,\cdots n\right\} = \{y_i(k)\} \tag{3}$$

2) carry out first-order differentiation, through which the slope of each point on the paint spectrum and background spectrum curve can be found:

$$\begin{aligned} \partial_x(k+1) &= x_i(k+1) - x_i(k) \\ \partial_y(k+1) &= y_i(k+1) - y_i(k) \end{aligned} \tag{4}$$

$k = 1,2,\cdots n-1$

Introduce correlation coefficient:

$$\xi(k+1) = \frac{1}{1+\left|\partial_x(k+1) - \partial_y(k+1)\right|} \tag{5}$$

3) calculate the absolute correlation degree

$$r_{x,y} = \frac{1}{n-1}\sum_{k=2}^{n}\xi(k). \tag{6}$$

In addition, the influence of spectral vector size on curve shape judgment was removed. At the same time, the degree of correlation is only determined by two spectral curves, which are comparable and symmetrical. The higher the correlation degree is, the more similar the geometric shapes of the two curves are; on the contrary, the absolute correlation degree is to determine whether the geometric shapes of the two curves are more different by comparing the similarity of the slope of each point on the curve.

2.3. Spectral vector size

Spectral vector size refers to the vector size composed of spectral characteristic response values of ground objects. The spectral vector size of different ground objects can be determined by calculating the geometric distance between spectral vectors. Therefore, the spectral vector size difference between the paint and the background is expressed by applying Euclidean distance (SBD)[7]. Suppose $r_i = (r_{i1}, r_{i2}, \cdots, r_{iN})^T$, $r_j = (r_{j1}, r_{j2}, \cdots, r_{jN})^T$ are the spectral vectors of paint and background respectively.

$$\text{SBD}（r_i, r_j）= \sqrt{\frac{1}{N}\sum_{k=1}^{N}(r_{ik} - r_{jk})^2} \tag{7}$$

Where N represents the number of spectral bands. The coefficient $\frac{1}{N}$ in the square root removes the correlation between the size of two vectors and the number of spectral bands, and thus SBD represents the average distance between the size of two vectors. The smaller the spectrum SBD is, the closer the spectral vector size is, and the closer the spectral curve is, and vice versa.

2.4. Comprehensive spectral similarity

The spectral Angle size, spectral curve shape and spectral vector size are added with certain weights to obtain the comprehensive spectral similarity d_c :

$$d_c = w_1 \cdot (1 - d_e) + w_2 \cdot (1 - d_s \cdot 10) + w_3 \cdot d_b \cdot 10^{-4} \tag{8}$$

Where: (w_1, w_2, w_3) is the weight vector, and $w_1 + w_2 + w_3 = 1$ 。 Since the comprehensive evaluation is to be carried out, it is necessary to change d_e , d_s , d_b into the same order of magnitude.I will $d_s \cdot 10$, $d_b \cdot 10^{-4}$, So that all three variables can be used in the Within the range of $(0 \sim 1)$. the comprehensive spectral similarity, that is d_c , the evaluation index of the degree of similarity with the background. The smaller the value d_c is, the better the similarity between the target and the background will be; on the contrary, the larger the value d_c is, the worse the similarity will be. In order to highlight the influence of spectral shape features and Angle size on the similarity between paint and background, the weight vector is set as (0.4, 0.4, 0.2).

3. Asic principle

The design is to test four green paint pallets in figure 1, namely light green 1 (A), light green 2 (B), dark green 1 (C) and dark green 2 (D)；The background of the experiment was selected as two common shrubs, and the weather conditions were compared with those under direct sunlight and shadow.

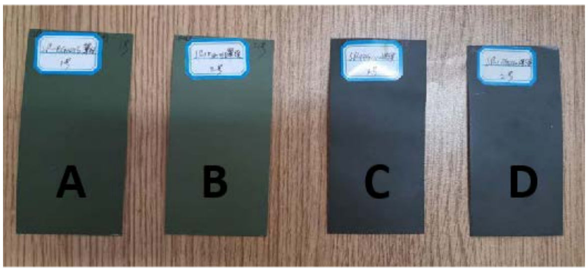

Fig.1 Experimental object diagram

The first experiment was arranged as shown in figure 2. These four paint touch plates were placed on a sunlight-irradiated shrub. The four colors were compared with the background, and the fitting degree between the coating and the background was quantitatively analyzed.

The target was imaged by hyperspectral imager with a spectral range of 300~1100nm. The hyperspectral imager can obtain images of 1200 wavebands. Figure 1 is a false-color image synthesized by 172 (449.32nm), 351 (549.27nm) and 526 (649.43nm) wavebands.

Fig.2 Experiment 1 arrangement diagram

The spectral images of the paint and the background of the leaflet shrub are shown in figure 3. It can be seen from figure 2 that the radiant energy of the leaflet shrub is generally lower than that of the paint. Paint D is close to the spectral curve of the leaves in the spectral map. The leaves in the red band have an obvious steep decline trend, and then there is a sharp increase. And coating board is in gules wave band is a more stable

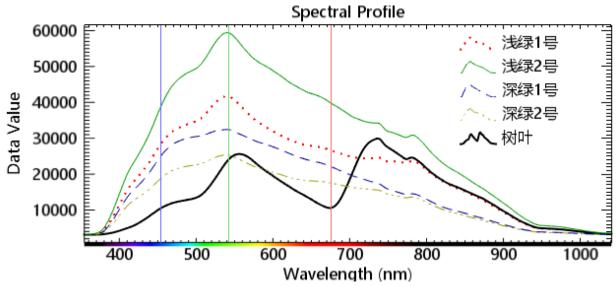

Fig.3 Experiment 1 Spectral image

Then the spectral image is de-enveloped, and the image is shown in figure 4.

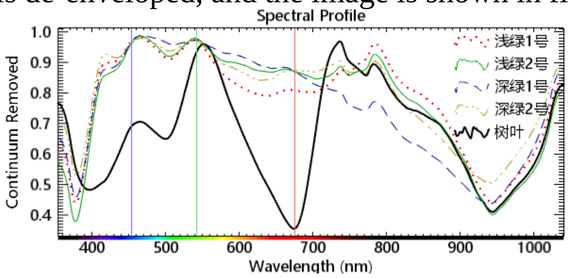

Fig.4 Experiment 1 to envelop the image

The next step is to output the spectral information of the experimental coating board and the leaflet shrub, and calculate the spectral Angle, Euclidean distance and absolute correlation degree. The results are shown in table 1

Table 1 Experiment 1 calculation data table

	A	**B**	**C**	**D**
d_e	0.52	0.49	0.41	0.49
$d_s \cdot 10$	0.31	0.33	0.45	0.29
$d_b \cdot 10^{-4}$	1.08	2.02	0.91	0.67
d_c	0.684	0.876	0.638	0.622

As can be seen from the table, the size of the spectral Angle is A coating plate is closer to the background of the leaflet shrub. From the shape of the spectral curve, the C coating plate is close to the background. From the spectrum vector size, is D paint plate is close to the background. From the comprehensive spectral similarity obtained by taking the three parameters into consideration, it can be seen that in the background of small-leaved shrub, D coating plate is the most suitable for the background. For the background of leaflet shrubs, the fitting degree is D, C, A and B from good to bad.

In experiment 2, four coating plates are placed in the background of broad-leaved shrubs in the shadow as shown in the diagram. Figure 5 is a false color picture composed of three bands: 172 (449.32nm), 351 (549.27nm) and 526 (649.43nm). The similarity between coating plate and background was analyzed by the same spectral analysis method as experiment one.

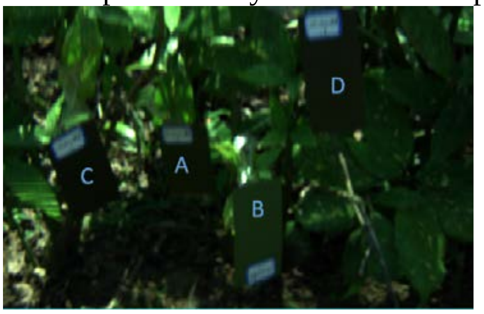

Fig.5 Experiment 2 arrangement diagram

The spectral information of the paint and the background leaves was extracted as shown in figure 6. It can be seen from the figure that the spectral curve shape of the broad leaf and paint plate A is roughly the same, and there is still A certain gap with other paint plates in terms of radiation energy. In the red band green broad leaves will still have a sharp sharp rise, and paint plate decline and rise are relatively flat.

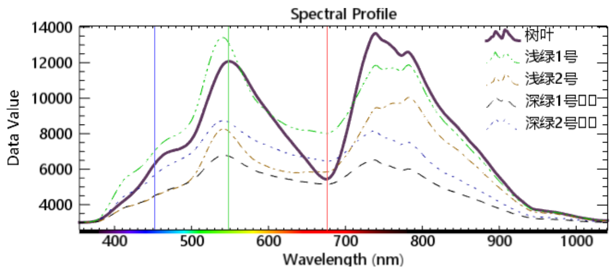

Fig.6 Experiment 2 Spectral image

The obtained spectral image is de-enveloped, and the resulting image is shown in figure 7.

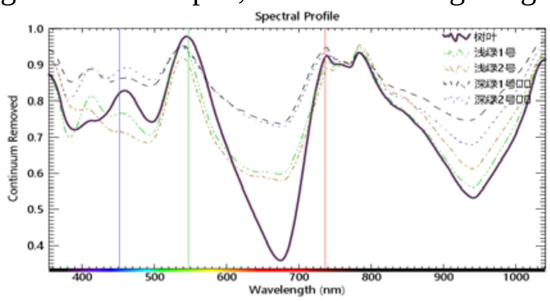

Fig.7 Experiment 2 to envelop the image

After that, the spectral information of the coating board and the background was output in a table to calculate the spectral Angle, absolute correlation degree and Euclidean distance. The results are shown in table 2

Table 2 Experiment 2 calculation data table

	A	B	C	D
d_e	0.70	0.84	0.73	0.79
$d_s \cdot 10$	0.51	0.59	0.51	0.26
$d_b \cdot 10^{-4}$	0.24	0.11	0.37	0.26
d_c	0.364	0.25	0.378	0.432

As can be seen from table 2, from the size of spectral Angle, B coating plate is closer to the background of broad-leaved shrub. From the shape of the spectral curve, B paint plate is close to the background. From the spectrum vector size, is B paint plate is close to the background. From the comprehensive spectral similarity obtained by taking the three parameters into consideration, it can be seen that in the background of broad-leaved shrub, the B coating board is the most suitable for the background. For the background of broad-leaved shrubs, the fitting degree is B, A, C and D from good to bad.

4. Experimental analysis

Through the analysis of the target using the method, it can be seen from the spectrogram that the spectral trend of the paint plate and the leaf background at the band of 600nm to 700nm is very different. The fitting degree of the three evaluation parameters is not as good as that under the shadow, indicating that it is easier to be found under the sun. And from the perspective of the final calculated comprehensive spectral similarity, it is the spectral characteristics of paint D (dark green no. 2) that are compared with the fitting background under sunlight. In the shadow is paint B (light green 2) more fitting.

5. Conclusion

Detection devices have their own advantages in terms of different measurements. Hyperspectral imagers combine images and spectra into one, making detection more convenient. Moreover, hyperspectra can well distinguish paint plates and backgrounds whose spectral trends are very similar with its very high resolution. The stability of a single measure is poor. Therefore, coating evaluation should be carried out from multiple perspectives. Three evaluation methods, namely, image color difference, spectral curve shape and spectral vector size, can make full use of the rich information of hyperspectral images, so that the theory is more rigorous and the evaluation result is more perfect. In addition, another plant background was selected for detection to reduce the chance, and multiple points of the same background were used to confirm the absolute correlation degree of leaf spectrum and the fluctuation range of Euclidean distance, so as to ensure the reliability of data. It has important guiding significance and reference value for the design and use of camouflage coatings.

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