Research on Camouflage Target Detection via Computational Analysis with Spectral Imaging

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ABSTRACT

Camouflage target detection is one of most important techniques in a great number of applications such as remote sensing, security monitoring and industrial production. In this paper, high-resolution spectral imaging together with computational analysis on spectral data cube is adopted to solve camouflage target recognition problem. Spectral data cubes of certain experimental scene are collected by a self-developed visual-band imaging spectrometer, and spectral information divergence (SID) is adopted as difference descriptor to discriminate abnormal target. SIDs of the whole spectral region and several specific ranges are all measured to quantitatively evaluate the effort of band selection on camouflage detection. This is proven to be a low-cost and effective tool for camouflage target detection and can be further developed beyond visual band spectral imaging technique.

INTRODUCTION

Target detection is widely used in many fields such as security inspection, industrial production monitoring, food testing and so on [1]. In assistant with remote sensing and spectral imaging technology, camouflage target detection becomes an effective tool for many applications so as to discover aircraft wreckage, oil leakage, drug vegetation, camouflage military targets in a secure and rapid way [2]. Precise target recognition inevitably relies on the support from geometric, spectral or even polarization characteristics of the target. Since Grey-scale and RGB images can provide only geometric information rather than abundant spectral information, target detection task can be carried out with the help of spectral imaging technique plus further data analysis method [3].

Data analysis methods for target detection that associates with spectral imaging are basically divided into two categories. The first type is spectral signature technique, which requires the spectral feature of the target to be input in advance. Revised pattern matching methods are studied mainly in the spectral domain while novel algorithms that integrate both spectral and texture or polarization information are also presented on early days [4][5][6]. The second kind is anomaly detection technique, which detects outlier from background signal. Many algorithms based on different approaches work well for addressing disguise variations [7]. Related researches keeps studying on background modeling, band selection and matching filter optimization in anomaly detection [8][9][10]. Camouflage targets usually has similar or even the same geometric characteristics as normal objects but differs in spectral features so that target matching and detection can be implemented with certain spectral feature descriptor [11].
Classical classification technique such as spectral angle mapping is taken advantage of for target detection [12]. To further cut down the calculation cost, user-defined camouflage evaluation index is attempted to realize camouflage target detection [13]. In this paper, a kind of target analysis and camouflage discrimination method using spectral imaging plus spectral information divergence (SID) measurement is presented. Experiment of camouflage detection in a real scene is carried out. This low-cost method is particularly suitable for target detection task on routine remote sensing or regular monitoring occasions and is of reference significance to other target detection applications with other imaging techniques.

This paper is arranged as follows: After a general introduction of the research background and ideas, principle of spectral imaging and SID calculation procedure are introduced in the second part. Imaging spectrometer performance, Experiment scene and data collection process are presented in the third chapter. Experimental results with the effort of spectral range selection is discussed in the fourth chapter. Finally the conclusion is drawn.

HYPER-SPECTRAL IMAGING AND SPECTRAL INFORMATION DIVERGENCE MEASUREMENT

The camouflage target detection procedure mainly consists two parts. Firstly routine spectral imaging is carried out with a hyper-spectral imaging system to obtain spectral data of certain scene. Then SIDs of every pixel in the whole spatial range and three regions of interest are calculated to judge probable target variation at certain location. The principle and method for spectral imaging and SID measurement are respectively introduced in the following chapter.

Push-broom Hyper-Spectral Imaging

Spectral imaging is widely used in many applications and its operating band is primarily decided by the spectral feature of the shooting targets. The spectral signatures of many potential targets are not usually known in advance so that anomaly detection is preferred for general application. Visual-band focal plane detector has relatively small size, high quantum efficiency and low cost, and is particularly suitable to be used in routine aerial survey or production testing for anomaly detection. There are many scanning modes that are used by spectral imaging to obtain spectral data cube (Figure 1) [14]. Push-broom pattern is adopted in this paper to realize repeated high resolution spectral imaging for a stationary scene.

![Figure 1. Description of spectral imaging data cube, which can be viewed as spectrum at every pixel (x,y).](image-url)
Spectral Information Divergence Measurement

Spectrum $I(x, y, k)$ at every pixel location $(x, y)$ contains the basic spectral information that is needed to distinguish the target property. For every pair of two pixels of the same spatial coordinates $(x_i, y_j)$ in two data cubes, SID can be worked out in three steps [15]. Intensity proportions are computed by using formula (1) and (2) in the first step, and relative entropies are successively worked out with formula (3) and (4) in the second step. Finally SID values are calculated by using formula (5).

$$p_{1z} = \frac{I_1(x_i, y_j, z)}{\sum_k I_1(x_i, y_j, k)}$$ \hfill (1)

$$p_{2z} = \frac{I_2(x_i, y_j, z)}{\sum_k I_2(x_i, y_j, k)}$$ \hfill (2)

$$D(I_1 \parallel I_2) = \sum_k p_{1k} \cdot \log_2 \left(\frac{p_{1k}}{p_{2k}}\right)$$ \hfill (3)

$$D(I_2 \parallel I_1) = \sum_k p_{2k} \cdot \log_2 \left(\frac{p_{2k}}{p_{1k}}\right)$$ \hfill (4)

$$SID(I_1, I_2) = D(I_1 \parallel I_2) + D(I_2 \parallel I_1)$$ \hfill (5)

Final SID result can be of either whole spectral range or partial spectral range, depending on whether all spectral bands or only special bands of interest are adopted for calculation. Different band selections can be executed in the experiment by changing the interval of parameter $k$ in formula (1) to (4) and will certainly lead to the change of detection effort, which is also to be investigated in the experiment.

EXPERIMENTAL IMPLEMENT

To carry out camouflage detection experiment, a self-developed visual-band hyperspectral imaging instrument (Figure 2) is used to acquire the data cube of certain scene. The instrument is composed of Offner optical system and convex grating, which leads to high optical efficiency and low aberrations. Its designed band number is 1024 and operates from 400nm to 780nm. The instrument uses push-broom mode to acquire data cube. The data acquisition time for each frame is 0.18s and it takes 90 minutes for it to acquire a 500-frame data cube.

![Figure 2. Self-developed hyper-spectral imaging instrument.](image-url)
Three special scenes are constructed as shown in Figure 3. All three images are of the 100th spectral band extracted from the acquired data cube and the spatial size is 1024×500. Original objects of a car, a tree and a reflecting plate can be seen in the 1st scene (as shown in graph A), and three 40×40 regions, marked from a to c, separately represent them. In the 2nd and the 3rd scene (as shown in graph B and C), the car is respectively covered with thin and thick protecting mesh to generate common and enhanced camouflage. A 1024×500×1024 data cube is collected for every scene. After three data cubes are acquired, four kinds of SID parameters are calculated with five formulas in the last section to implement further target analysis and discrimination. The condition of four kinds of SIDs are illustrated in TABLE I. As pointed out in the previous section, different SID values call for different set of spectral intervals during calculation. More concretely, F-SID covers the whole 1024 bands in the visual region, while B-SID, G-SID and R-SID each includes 100 bands in blue, green and red regions.

![Figure 3. Spectral images of three different scenes.](A: original objects, B: with common camouflage, C: with enhanced camouflage)

| SID type | band range | spectral interval (nm) |
|----------|------------|------------------------|
| F-SID    | 1–1024     | 400.1–780.0            |
| B-SID    | 101–200    | 437.2–474.0            |
| G-SID    | 301–400    | 511.5–548.2            |
| R-SID    | 801–900    | 697.1–733.9            |

**EXPERIMENTAL RESULTS AND DISCUSSION**

All SID results are separately illustrated in the eight secondary graphs in Figure 4. The top four graphs show SID between scene 1 & 2 and the bottom four shows that between scene 1 & 3. From left to right, results of F-SID, B-SID, G-SID and R-SID are successively listed. All the final SID values are not normalized and it can be observed from the color-bar that F-SID value is higher than the other three SID values since the former takes five times the spectral bands into calculation. Complete contour of the car can be clearly observed in graph A and E, which proves the solid effort on camouflage detection. SID of blue and green band has a better target fringe detection effort than that of red band, in which the plate number area of the car presents high SID. It is to be emphasized that the inside area of the car obtains no high F-SID value. This is different from other differential methods and is especially beneficial to the applications in which the fringe of camouflage objects is particularly concerned. In all graphs, warm hue also
turns out in some other regions besides the car region. This is mainly created by unavoidable environmental influence such as the shaking of branches and leaves caused by wind.

![Figure 4. SID results of original scene with common camouflage (A–D) and with enhanced camouflage (E–H) (A & E: F-SID, B & F: B-SID, C & G: G-SID, D & H: R-SID).](image)

To further indicate the target divergence quantitatively, mean FSID values in the three region marked from a to c in Figure 3 are calculated and listed in TABLE II. F-SID of region a where camouflage target appears turns out to be one or two order of magnitude larger than that of region b and c where no camouflage but only small variation occurs. Except for G-SID in region b, all SIDs of scene 1 & 3 is larger than the matched ones of scene 1 & 2, which proves stronger camouflage in scene 3 than in scene 2. SIDs of the whole spectral region are higher than that of specific band range, which appears to be more solid for camouflage discrimination. B-SID and R-SID are more credible for camouflage target detection in this situation, because the color of the camouflage material is green. Single-band SID values in region b and c stay low since none camouflage appears there. All these prove the distinguishing ability of SID for camouflage and environmental change.

| TABLE II. MEAN SID VALUES IN DIFFERENT SITUATIONS. | mean SID ($\times 10^3$) of scene 1 & 2 | mean SID ($\times 10^3$) of scene 1 & 3 |
|---|---|---|
| | F-SID | B-SID | G-SID | R-SID | F-SID | B-SID | G-SID | R-SID |
| region a | 40.7 | 2.14 | 0.41 | 3.62 | 44.4 | 5.58 | 0.50 | 4.17 |
| region b | 5.80 | 0.07 | 1.20 | 0.68 | 7.7 | 0.21 | 0.67 | 1.56 |
| region c | 0.11 | 0.06 | 0.05 | 0.15 | 0.11 | 0.06 | 0.15 | 0.16 |
CONCLUSIONS

Hyper-spectral imaging technique and spectral information divergence measurement are jointly used to implement camouflage target detection. Experiment proves that SID is not only able to judge the target camouflage accurately but also extract the fringe of anomaly region. The effort of SIDs of full spectral region and certain spectral bands on target anomaly detection is studied as well. Further study may focus on the influence of environmental factors on detection effort.

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