Distinguishing camouflaged man-made objects from a natural background

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The identification of made-made objects from their background is a fairly common issue. Objects which are hard to identify, like military camouflage, still pose a challenge for engineers working on methods of conducting image interpretation and processing. Because of the constant advances in camouflage techniques, the spectral contrast between such objects and their background is reduced. As a consequence, multispectral techniques, based on acquiring information in broad spectral bands, become useless. It has now become more adequate to use hyperspectral techniques. Such imagery is registered in very narrow spectral bands giving much more detailed information about the targeted objects.

The increasing role of image interpretation has forced the development of instruments and algorithms, which enable real time observations. A system, which would provide information which at the time of delivery would still be up-to-date should ensure fast image acquisition and visualization. Thanks to their rapid access to data, high resolutions and the possibility of processing data in real time, video techniques are used more and more often. This method is much more efficient in comparison to traditional photographic methods. In order to further enhance the efficiency of the system and shorten the time needed to retrieve information, the amount of bands processed within the system must be reduced by selecting only those, which carry the most important information. This article will describe the methods used to select the appropriate spectral bands to be registered, the method of processing and visualization of the resulting colour composition, used to identify man-made objects on a natural background.

1 Remote sensing techniques in object extraction

The detection of objects can be conducted using multispectral techniques in the appropriately selected spectral bands. The process of detection can be affected by the following factors:

- Contrast between the object and its background
- Atmospheric conditions
- Accuracy and resolution of the available sensors

Because it is almost impossible to have control over these last two factors, it is essential to focus on the spectral contrast between objects. A small spectral difference between objects and their background may cause multispectral techniques to be insufficient. In such a case hyperspectral techniques will be more adequate. Such sensors acquire imagery in very narrow, adjacent spectral bands, supplying very detailed spectral and spatial data about objects in the registered scene.

The increasing role of image reconnaissance has forced the development of instruments and algorithms, which enable real time observations. A system, which would provide information which at the time of delivery would still be up-to-date should ensure fast image acquisition and visualization. Thanks to their rapid access to data, high resolutions and the possibility of processing data in real time, video techniques are used more and more often. This method is much more efficient in comparison to traditional photographic methods.

In situations where we do not have any additional information about the object which we are trying to extract, it is essential to focus on the background. Green vegetation is the most common type of background. This is why the use of vegetation indices for object extraction may be adequate. Using vegetation indices has many advantages – using NDVI or RATIO [4] operation on hyperspectral imagery Is very simple and fast. Additionally most of these operations require a small number of images, which means that it could be possible to process them in real-time.

The selection of the appropriate bands to be registered and algorithms which will eliminate the natural background enables quick object extraction. It is essential to establish an automatic method of selecting spectral bands, which will ensure the biggest possible contrast between the object and its background. One of the most effective ways of evaluating the contrast is calculating the Mahalanobis distance [6].

2 Analyzing contrast

2.1 Single band analyses

Most spectral analyses are based on single hyperspectral images. In such cases we can use TCR (Target - to - Clutter Ratio) to evaluate the contrast between the object (Target) and its background (Clutter):

$$TCR^2 = \frac{(\Delta L^S)^2}{(\sigma_T^2 + \sigma_B^2)} \tag{2.1}$$

where ΔL_S is the difference between the mean radiances of the background and targets, and σ_T σ_B are the sample standard deviations of the target and background classes. Such an analysis allows for the selection of single bands in which the contrast between the two classes is greatest

2.2 Dual band analyses

The aforementioned TCR parameter Has also been used to evaluate operations involving indices based on a pair of spectral bands. This analysis has enabled the selection of the best vegetation index and spectral bands for the detection of given objects from their background. Four vegetation indices have been analyzed:

- Simple Ratio Index (*SRI*) [4]

$$SRI = \frac{\rho_{NIR}}{\rho_{RED}} \tag{2.2}$$

- Normalized Difference Vegetation Index (*NDVI*) [4]

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{2.3}$$

- Soil Adjusted Vegetation Index (*SAVI*) [4]

$$SAVI = (1+L)\left(\frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+\rho_{RED}+1}\right) \quad (2.4)$$

- Two bands Enhanced Vegetation Index (*EVI2*) [4]
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$$EVI = 2.5\left(\frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+6\rho_{RED}-7.5\rho_{BLUE}+1}\right) \Rightarrow EVI2 = 2.5\left(\frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+2.4\rho_{RED}+1}\right) \quad (2.5)$$

2.3 Multi band analyses

Multiple band analysis can be applied to any number of spectral bands. An algorithm based on Mahalanobis distance has been used for selection the best combination of three hyperspectral channels. Contrast between targets and their background may be understood as an abstract distance between the background and objects in the spectral plane. The Mahalanobis distance is described as:

$$d_i = (x-\mu_i)^T \Sigma_i^{-1} (x-\mu_i) \quad (2.6)$$

This function takes into account the covariance among the variables during calculating the distance. The algorithm can be used in the detection of spectral outliers. If we treat the target class as outliers from the background class, it is possible to calculate the distance between the background and target classes. The above equation can be simply modified to the form:

$$d_{BT} = (\mu_B-\mu_T)^T \Sigma_T^{-1} (\mu_B-\mu_T) = \frac{(\mu_B-\mu_T)^2}{\sigma_T^2}$$
$$d_{TB} = (\mu_T-\mu_B)^T \Sigma_B^{-1} (\mu_T-\mu_B) = \frac{(\mu_T-\mu_B)^2}{\sigma_B^2} \quad (2.7)$$

After further modifications, his equation can take a form enabling the calculating of the Mahalanobis distance:

$$d_i = (\mu_B-\mu_T)^T (\Sigma_B+\Sigma_T)^{-1} (\mu_B-\mu_T) \quad (2.8)$$

Where μ_T and μ_B are the vectors of three mean signatures of the background and target groups. Σ_B and Σ_T are the covariance matrices of background and target respectively:

$$X = [X^1 X^2 X^3] \qquad \mu_T = \begin{bmatrix}\mu_{X^1}\\ \mu_{X^2}\\ \mu_{X^3}\end{bmatrix} \qquad \sum_T = \mathrm{cov}(X) \quad (2.9, 2.10, 2.11)$$

An especially compiled program in the MathWorks MATLAB programming environment enables the automatic creation of all possible 3-channel combinations, the calculation of the Mahalanobis distance between chosen objects and their background (in all 3 channels) and the automatic selection of a combination with the greatest spectral contrast. The three chosen spectral bands are used in generating a colour composite image.

The described methods have been applied to two sets of data.

3 The experiment

3.1 Datasets

Research was conducted to check the dependence between proper band selection and possibility of human-made object detection from natural vegetation. Data was acquired by means of a terrestrial hyperspectral system designed at the Military University of Technology in Warsaw. which consists of a digital video camera and optoelectronic tunable filter [1] [2].

For the purposes of this research, two datasets were acquired. The scene consisted of a series of military uniforms on a natural background. Both sets included 10nm spectral resolution images captured in two spectral ranges: 440-620nm and 660-1100nm with a 10nm bandwidth and 20nm step. For the analysis purposes, all possible band combination for indicators NDVI and SAVI were created. Algorithms were developed using Interface Description Language and RSI ENVI software. Multiband analyses were carried out in MATLAB-based software.

3.2 Results of analyses

Preliminary analyses have shown that the spectral contrast between the targets and their background is minimal in the visible range of the spectrum. Therefore this spectral range has been omitted in further analyses.

3.2.1 Single band analyses

The search for the band with the highest spectral contrast between objects on the single hyperspectral image usually gives better results than multispectral band analysis. The proper channels of acquisition can ensure the detection of objects undistinguishable to human eye. The TCR parameter used for contrast measurement achieved very low values in all hyperspectral bands For quite visible military uniforms TCR did not exceed the value of 2 (very low). It means that the tested objects can be treated as a difficult targets, and detection using single band analysis is not efficient in this case.

3.2.2 Dual band analyses

The main goal of this part of research was finding the best band combination for vegetation indices. The appropriate band combination is understood as the combination which gives the highest TCR values on the resulting image. Preliminary analysis included contrast measures on all resulting images generated using NDVI and SAVI indices. Fig. 1 presents TCR values for all possible combinations for these two indices. The brightest areas on the image correspond to the highest values of the TCR parameter and point out the best band combination.

In this case the combination of the 680nm and 740nm bands gives the result at the level of 6,02 TCR for NDVI and 7,32 TCR for SAVI. A very high score for the SAVI index, is caused by eliminating the soil influence from the vegetation index calculation. Soil together with natural vegetation were the clutter background for the military uniforms. This analysis has confirmed that the processing of the two proper bands can give better results and higher possibility of object detection than single signature analysis. TCR rates are higher for two bands analysis than for single band analysis and they point out similar regions. These areas are strongly related with region of maximal vegetation adsorption and maximal vegetation reflectance. Use of the hyperspectral technique allows for very precise determination of these region and increases detection ability of difficult objects.

Image 1

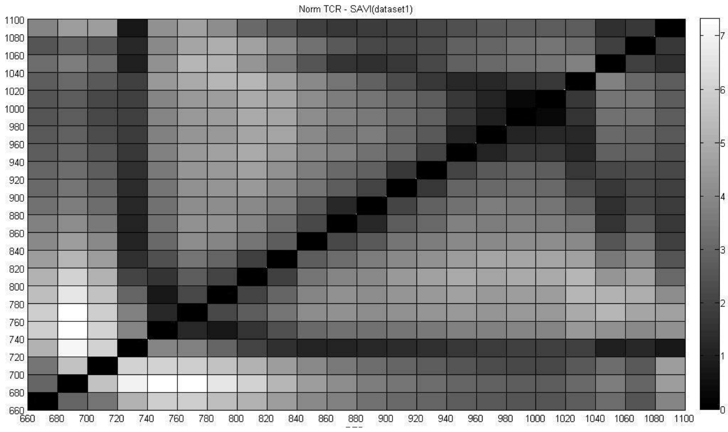

Image 2

Fig. 1. TCR values calculated for imagery taken in the infrared range – SAVI vegetation index

3.2.3 Multi band analyses

The described method based on the Mahalanobis distance was used also as a contrast measure between three spectral channels. All possible composition of three bands was created and contrast were checked. The highest value of TCR, as in the previous cases, is characterized by the composition with the highest spectral contrast between the targets and background. This analysis was carried out automatically, together with the selection and displaying of the appropriate combination. The one limitation of this method is the time needed for image acquisition and processing in comparison to the single band approach. The time needed to acquire such a large amount of hyperspectral images is dependant mainly of the lighting conditions of the studied scene and the amount of data that needs to be obtained. The acquisition times for an image set consisting of 46 images in the 650-1100nm range, taken with a 10nm step, can vary from as little as 10minutes to over 90minutes, depending on the exposure time for each image [1].

TCR factor achieved value 10.60 for the band combination: 720nm, 680nm and 660nm (fig. 2.). This is a significant increase compared to single band analysis. This is a confirmation that multichannel analysis provides greater opportunities for man-made object detection.

Fig.2. Automatically generated colour composite image composed of the 720nm, 680nm and 660nm bands

4 Conclusion

The comparison of obtained results allows us to make a classification of these methods. Where individual hyperspectral images not always produce the expected results, processing two or more spectral bands gives significant opportunities to
improve the detection of objects.

Based on the outcome from two band analysis, vegetation indices can be clearly classified as a method of unknown object detection. In the case when we do not have any information about targets it is necessary to focus attention on the background. Appropriate determination the regions of maximum vegetation absorption and maximum reflectance can develop higher contrast between target and clutter on the resulting image. This objective can be achieved only by using hyperspectral
imagery.

The algorithm used to choose three spectral channels cannot be used for unknown object detection. This procedure requires additional information about spectral signatures of the targets. This information can be delivered for example from spectral libraries.

This paper shows the possibility of distinguishing unknown man-made objects from a natural plant background. It is necessary to work on methods for other kinds of backgrounds like soil, water or snow. Developing the system further to give the ability to detect objects from various backgrounds is the main goal of future work.

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