THE OPTICAL SPECTRAL BAND OF THE OPTOELECTRONIC IMAGING SYSTEM SELECTION

Ľubomír UHERÍK[1*]

[2] *doc. Ing. Ľubomír Uherík, CSc., Alexander Dubček University of Trenčín, Faculty of Special Technology*
*Corresponding author E-mail address: lubomir.uherik@tnuni.sk

Abstract

The paper discusses a specific statistical method, which can be selected optical spectral band activities optoelectronic imaging system. It is used to describe the stochastic sensing optical information and discriminant analysis. How to test the suitability of the optical spectral band is used to minimize the probability of misclassification object to its surrounding use of the determination of the Mahanalobis distance. The suggestions for future research are using adaptive algorithms for estimations of the optical spectral bands with using datasets of the objects and background. The practical implications are identified in machine vision.

Keywords: optical spectral band, Mahalanobis distance, classification of classes of objects, imaging systems

1 Introduction

Recently gains importance with the development of robotics using of optical imaging systems in robotic systems such as in special equipment such as production systems and the surveillance. The purpose of these systems is detection the presence of certain objects, or assesses changes in the physical properties of the objects. The problem of detecting the presence of an object or the evaluation of changes in physical properties represents solution radiometric tasks. For reliable operation of optoelectronic imaging system should be chosen in a systemic solution to the probability of correct detection when dealing with radiometric tasks was as high as possible. One of the ways this is achieved by appropriate choice of the optical spectral band activities so that the natural differences of different objects. This is the basis of hyperspectral imaging, which recently represents an increased interest in the development of optical imaging systems.

First steps to use statistical methods to select the appropriate optical spectral band go back to the 80s of the last century [1]. At this time, however, not the technical means hyperspectral approach in optical imaging at a level that permitted the wider its use. The current hardware give a good position to be hyperspectral imaging method used more widely. A reflection is of the significant increase of interest in this area in recent years [2], [3], [4].

2 A description of the parameter field

Objects such as radiation sources, we can characterize the physical parameter field. The properties of this field describes the unit of radiance as a function of four variables, parameter

$$\boldsymbol{L\ x,y,\lambda,t}\ , \qquad (\mathbf{1})$$

where L - spectral radiance of the object,
x,y - coordinates of the object plane,
λ - wavelength optical radiation,
t - time.

Layer of Earth's atmosphere between the object and the detection system can be described by a spectral transmittance $\tau_A\ \lambda,t$ and the spectral radiance $L_A(\lambda,t)$.

The detection system is composed of elements (lenses, filters, detectors ...) whose characteristics are dependent on the wavelength of the optical radiation. A good selection of these elements can provide the required optical spectral range of its activities.

In practice, the transfer of information about the physical parameter field does not take place continuously, but is associated with the timing, spatial and spectral optical sampling. Suppose, in view of the time sampling, stationary physical parameter field in a given period of the sample.

The detection system may be described impulse response of $H(x,y,\lambda)$ characterizing the properties with respect to the transfer of radiant energy. Then, the specific radiance $L_0(x,y,\lambda)$ observed in the image plane will represent convolution measuring radiance the object plane $L(x,y,\lambda,t)$ and the impulse response of the detection of the contributions transmittance of the atmosphere and measuring radiance layer of the atmosphere between the object and the detection system.

$$L_O(x,y,\lambda) = [\tau_A(\lambda)\, L(x,y,\lambda) + L_A(\lambda)] \otimes H(x,y,\lambda) . \qquad (2)$$

This hyperspectral description is shown in Figure 1.

Assuming a constant sampling period $\Delta x, \Delta y, \Delta\lambda$ parameter space (x,y,λ) we obtain a description of the parameter field as a set of elements radiant intensity $I(m,n,p)$ of the individual samples

$$I(m,n,p) = \sum_{i,j,k=0} \delta(m-i, n-j, p-k)\, L_O(m,n,p) . \qquad (3)$$

Each object can thus be understood as a set of elements of $I(m,n,p)$ in the state space (x,y,λ). This account can be extended to a certain class of objects or the period in which the changes underway radiant intensity $I(m,n,p)$. In terms of cognition characteristics of a set of elements and in view of the difficulties associated with the deterministic description, it is appropriate to understand the value of elements such as random the variable measured. In the image plane of the object, we can describe the random flow of photons attributable to the individual elements (m,n,p) state space (x,y,λ).

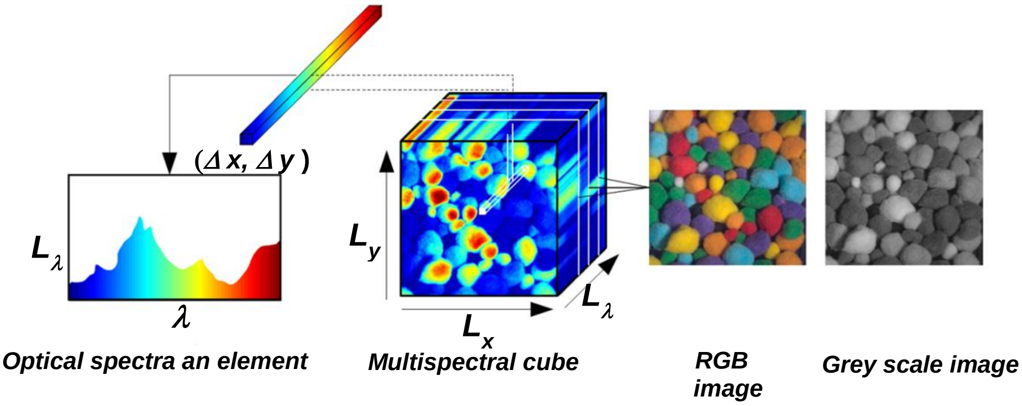

__Fig. 1__ Hyperspectral description of the parameter field $L_0(x,y,\lambda)$). [5]

The mean number of photons *N(m,n,p)* representing an element of the image plane of the index (m,n,p) is

$$N_{m,n,p} = [(I_{m,n,p})_\varepsilon + (I_{m,n,p})_\rho] \cdot (\tau_A)_{m,n,p} + (I_{m,n,p})_A] . T \qquad (4)$$

where $(I_{m,n,p})_\varepsilon$ - component of the photon radiant intensity for the emissivity of the object,
$(I_{m,n,p})_\rho$ - component photon radiant intensity for the reflectance of the object,
T - time integration of photons,
$(\tau_A)_{m,n,p}$ - transmittance layer of the earth's atmosphere in an element *(m, n, p)* of the parametric field,
$(I_{m,n,p})_A$ - photon component of radiant intensity layer of the earth's atmosphere in an element *(m, n, p)* of the parametric field.

Individual acts of the impact of photons on the image plane are independent of each other and with sufficient accuracy to be Poisson probability distribution. For practical interests in cases where the mean values of the components of the total number of photons are $(N_{m,n,p})_\varepsilon$, $(N_{m,n,p})_\rho$, $(N_{m,n,p})_A > 10$, we can Poisson probability distribution to approximate a normal distribution with a dispersion $D_{m,n,p}\ N$ equal to the mean. Probability distribution random variable (the number of photons in an element *(m, n, p)* during time *T*) is

$$f_{m,n,p}\ N\ = \frac{1}{\overline{2\pi.D_{m,n,p}(N)}}.exp\ \ -\frac{(N-N_{m,n,p})^2}{2.D_{m,n,p}(N)}\ \ . \qquad (5)$$

Probability distribution $f_{m,n,p}\ N$ is characterized as a random variable N corresponding to one element space *(m, n, p)*, to us not characterize the whole object. For the characterization of the entire object, it is necessary to know the distribution of the mean values $N_{m,n,p}$ number of photons around the object in the element of the optical spectrum of $f_p\ N_{m,n}$. This distribution is different from the normal probability distribution and are generally determined experimentally [1]. For the class of objects, we can even this probability distribution $f_p\ N_{m,n}$ be considered normal with mean value $M_p(N_{m,n})$, and the dispersion of $D_p(N_{m,n})$

$$f_p\ N_{m,n}\ = \frac{1}{\overline{2\pi.D_p(N_{m,n})}}.exp\ \ -\frac{(N_{m,n}-M_p(N_{m,n}))^2}{2.D_p(N_{m,n})}\ \ . \qquad (6)$$

With regard to the free statistical dependency variables N and $N_{m,n}$, these variables can be considered independent. The resulting density of the probability distribution of the random variables N and $N_{m,n}$ in the optical spectrum of the element p,

$$f_p\ N,N_{m,n}\ = f_{m,n,p}\ N\ .f_p\ N_{m,n}\ . \qquad (7)$$

For a variety of objects, we can establish a different probability distribution $f_p\ N,N_{m,n}$, we can characterize them.

3 Selecting the optical spectral band

When choosing a suitable optical spectral band optoelectronic imaging device this is a discriminant analysis of the two groups to class background and class objects that are of interest. Scale efficiency discrimination in a particular spectral band $\Delta\lambda_p$ is the overall probability of misclassification ω for which it applies [1, 2]

$$\omega = \pi_T \underset{\varphi_B}{\quad} f_{p,T}(N,N_{m,n}).dN.dN_{m,n} + \pi_B \underset{\varphi_T}{\quad} f_{p,B}(N,N_{m,n}).dN.dN_{m,n} \qquad (8)$$

where $f_{p,T}\ N,N_{m,n}$ - conditional probability distribution for the object of interest in the p-element optical spectra $\Delta\lambda_p$,
$f_{p,B}(N,N_{m,n})$ - conditional probability distribution for the background in the p-element optical spectra $\Delta\lambda_p$,
$\boldsymbol{\pi_T},\boldsymbol{\pi_B}$ - an apriority probability of classification of the object of interest and background,
$\boldsymbol{\varphi_T},\ \boldsymbol{\varphi_B}$ - fields of the sample space of possible values $N,N_{m,n}$ the relevant to object of interest and background.

Significant simplification optimal classification is achieved when the covariance matrices are random variables N and $N_{m,n}$ of the relevant object of interest and background are identical, i.e. $\boldsymbol{C}_T\ N,N_{m,n}\ = \boldsymbol{C}_B\ N,N_{m,n}\ = \boldsymbol{C}\ \ N,N_{m,n}$. The classification can be then performed using linear discriminant function $W\ \boldsymbol{N}$ [3]

$$W\ \boldsymbol{N}\ =\ \boldsymbol{\mu}_T-\boldsymbol{\mu}_B\ ^T\boldsymbol{C}^{-1}\ \boldsymbol{N}\ .\boldsymbol{N}\,, \qquad (9)$$

where $\boldsymbol{N}$ - a column vector of random variables N and $N_{m,n}$,
$\boldsymbol{\mu}_T,\boldsymbol{\mu}_B$ - vectors means values distribution $\boldsymbol{f_{p,T}}\ \boldsymbol{N}$ and $\boldsymbol{f_{p,B}}(\boldsymbol{N})$.

The probability distribution of the discriminant function $W\ \boldsymbol{N}$ is again a normal distribution and its parameters can be expressed as a function of Mahalanobis distance [6]

$$\Delta^2 = \ \boldsymbol{\mu}_T - \boldsymbol{\mu}_B\ ^T C^{-1}\ \boldsymbol{N}\ .\ \boldsymbol{\mu}_T - \boldsymbol{\mu}_B\ , \qquad 10$$

between the vectors of the median values both groups. Valid values for median is

$$M_T\ W\ \boldsymbol{N}\ \ = \frac{1}{2}\Delta^2,\ M_B\ W\ \boldsymbol{N}\ \ = -\frac{1}{2}\Delta^2, \qquad (11)$$

and dispersion

$$D_T\ W\ \boldsymbol{N}\ \ = D_B\ W\ \boldsymbol{N}\ \ = \Delta^2\,. \qquad (12)$$

In this case, the total probability of misclassification is

$$\omega = \boldsymbol{\pi_T}\,.\,\boldsymbol{\phi}\ \ \frac{\ln\frac{\boldsymbol{\pi_B}}{\boldsymbol{\pi_T}} - \frac{\Delta^2}{2}}{\Delta}\ \ + \boldsymbol{\pi_B}\,.\,\boldsymbol{\phi}\ \ \frac{-\ln\frac{\boldsymbol{\pi_B}}{\boldsymbol{\pi_T}} - \frac{\Delta^2}{2}}{\Delta}\ \ , \qquad (13)$$

where $\boldsymbol{\phi}$ is the distribution function of the normal distribution. In case $\boldsymbol{\pi_T} = \boldsymbol{\pi_B}$ achieve even simplify

$$\omega = \boldsymbol{\phi}\ \ -\frac{\Delta}{2}\ \ . \qquad (14)$$

Selection of the appropriate optical spectral band activities optoelectronic imaging system then performs the appropriate optimization method minimizes the likelihood of misclassification ω in changing the impulse response *H (x, y, λ)* in the space *(m, n, p)*.

4 Conclusion

Known methods of selection of optical spectral band activities optoelectronic imaging systems do not capture fully the real conditions for the detection of optical radiation. In practice, this leads to more or less intuitive solutions with subsequent costly and time consuming experimentation. Using the above methodology allows the selection and evaluation of optical spectral band activities with a view to minimizing the misclassification of the objects on the often complex backgrounds. This will also create the conditions for the automation of the classification of objects of interest, which is important for using optical imaging systems in the robotics.

Acknowledgement

The paper was treated within the project no. ITMS 26110230099 " Alexander Dubček University of Trenčín wants to offer high-quality and modern education" EU operational program "Education".

References

[1] Ľ. Uherík: *Optické spektrálne pásmo činnosti optoelektronického prieskumného zameriavača*, [Kandidátska dizertácia] Brno, VA AZ 1982.

[2] J.P. Kerekes and J.E. Baum: *Hyperspectral Imaging System Modeling,* Lincoln Laboratory Journal, Special Issue on Spectral Imaging, vol. 14, no. 1, pp. 117-130, 2003.

[3] Eduardo C. Meidunas: *Robust Estimation of Mahalanobis Distances in Hyperspectral Images,* Air Force Institute of Technology, DISSERTATION, Wright-Patterson Air Force Base, Ohio 2006 280p.

[4] J. Ahlberg, I. Renhorn: *Multi and hyperspectral Target and anomaly detection*, Swedish defence research Agency, 2004, ISSN 1650-1942, 41 p.

[5] Z. Khan, F. Shafait, A. Mian: *Towards Automated Hyperspectral Document Image Analysis*, In: Proceedings of ICDAR 2013, Washington DC, USA, 22 - 23 August 2013, ISSN 1613-0073.

[6] P. Hebák a kol.: *Vícerozměrné statistické metody*, Informatorium, 2007, ISBN: 8073330393.