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Research Paper

Image analysis operations applied to hyperspectral images for non-invasive sensing of food quality — A comprehensive review



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Image analysis involving mathematical, statistical and software programming approaches are the essential elements of any computer-integrated hyperspectral imaging systems. The theoretical and practical issues associated with the development, analysis, and application of essential image processing algorithms are explored in order to exploit hyperspectral imaging for application to food quality evaluations. The breadth of different image processing approaches adopted over the years in attempting to implement hyperspectral imaging for food quality monitoring was surveyed. Firstly, the fundamental configurations and working principles of hyperspectral systems, as well as the basic concept and structure of hyperspectral data, were described and explained. The understanding of different approaches used during image acquisition, data collection and visualisation were examined. Strategies and essential image processing routines necessary for making the appropriate decision during detection, classification, identification, quantification and/or prediction processes are presented. Examples and figures were selected to reinforce the main approach of each analysis algorithm applied in different agro-food products to answer the question "What does the user want to see in the target food samples?" The theoretical background for each algorithm was beyond the scope of this article thus only essential equations were addressed. The literature presented clearly revealed that hyperspectral imaging systems have gained a rapid interest from researchers to display the chemical structure and related physical properties of numerous types of food stuffs and hyperspectral imaging systems are expected to gain more considerably more potential and application in food processing and engineering plants.

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Active contour model Active contour model ACM ACTIVE contour manalysis DT Distance transform UK, y, X) A hyperspectral image "hypercube" A hyperspectral image between sample and reference spectrum ACM ACM ACTIVE contour model model ACM ACTIVE contour	Nomenclature β Threshold chosen for tuning the detection rate				
ACM Active contour model ACM Active contour model ACM Active contour model ANN Artificial neural network DA Discriminant analysis DT Distance transform EDM Euclidean distance measure EDMCD Electron-multiplying charged coupled device FCM Fuzzy C-means FDR Fisher discriminant ratio FTP Fourier transform GLCM Grey level co-occurrence matrix GML Gaussian maximum likelihood IR Infrared LDA Linear discriminant analysis LDA Linear discriminant analysis LDA Linear discriminant analysis LDA Linear discriminant analysis RMS Maximum likelihood classification MLC Maximum likelihood classification MLC Multiplicative scatter correction RMS Multiplicative scatter correction RMS Neural Gas NRI Near-infrared SCO Orthogonal signal correction RMS Partial least square PCA Principle component analysis PLS Partial least square discriminant analysis QDA Quadratic discriminant analysis QDA Quadratic discriminant analysis QDA Quadratic discriminant analysis QDA Quadratic discriminant analysis QDA Spectral correlation measure SCM Spectral correlation measure SCM Spectral correlation measure SCM Spectral angle mapper VT Wavelet transform WTA Wavelet transform VTA Wavelet tr			•		
ACM Artifical neural network λ _c Sample spectrum DA Discriminant analysis Symbol DT Distance transform I(x, y) Two-dimensional sub-image EMCCD Electron-multiplying charged coupled device I(x, y) A hyperspectral image 'hypercube' FCM Fuzzy C-means I(x) Spectrum at one point in the image FDR Fisher discriminant ratio P ₀ Piskel value at position (i, j) FT Fourier transform Up Pixel value in the dark reference image GLCM Gey level co-occurrence matrix W ₁ Pixel value in the dark reference image GLM Gey level co-occurrence matrix P ₀ Pixel value in the dark reference image GLM Grunt and six simulation analysis P ₁ Spectral value at wavelength (a) GLM Multi-linear regression P ₀ Reflectance of the sample at wavelength \(a) MLR Multi-linear regression Cos(w) Factor that relates the percentage of direct and diffice light reflected at each point MC Ninciple component E(V, w) Exclude an distance PC				~ -	
ANN Artificial neural network λ _r Reference spectrum DA Discriminant analysis 1/(x, y) Two-dimensional sub-image EDM Euclidean distance measure 1/(x, y) A hyperspectral image 'hypercube' FCM Fuzzy C-means 1/(x) Spectrual aron eopoint in the image FDR Fisher discriminant ratio Pg Pixel value at position (i,i) FT Fourier transform Pg Pixel value in the dark reference image GLM Grey level co-occurrence matrix Wij Pixel value in the bark reference image GLM In navial discriminant analysis n Number of wavelengths, number of objects IR Infrared p. Spectrual value at wavelength (i) ILS-SVM Least-squares support vector machine pg ph ph pr Pixel value at wavelength, number of objects MLC Maximum likelihood classification n n number of wavelengths, number of objects pg pg pg pefector the sample at wavelength (i) pg pg pg pg pg pg pg	ACM	Active contour model	λ_t	-	
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DT Distance transform EMCCD Electron-multiplying charged coupled device EMCCD Electron-multiplying charged coupled device FCM Fuzzy C-means FTM Fisher discriminant ratio FTM Fisher discriminant analysis FTM Fish	DA	Discriminant analysis		•	
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Figure 1. Figur			I(x, y, λ)		
FDR Fisher discriminant ratio P_{ij} Spectrum at one point in the image P_{ij} Fisher value at position (i.) FT Fourier transform P_{ij} Fisher value at position (i.) Fisher value at wavelength (i.				-	
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GLCM Grey level co-occurrence matrix W_{ij} Fixel value in the white reference image W_{ij} Causaian maximum likelihood (ausaian maximum likelihood) W_{ij} Spectral value at wavelength λ Number of wavelengths, number of objects λ Reflectance of the sample at wavelength λ Number of wavelengths, number of objects λ Reflectance of the sample at wavelength λ and λ and λ Reflectance of the sample at wavelength λ Reflectance of the sample diffuse light arriving at the sample cos($\delta(\phi)$) Factor modulates the amount of direct light reflected at each point $E(C, c_1, c_2)$ Energy function $E(V, W)$					
GML Gaussian maximum likelihood $ P_i $ Spectral value at wavelength (λ) in Number of wavelengths, number of objects $ P_i $ Spectral value at wavelength (λ) in Number of wavelengths, number of objects $ P_i $ Reflectance of the sample at wavelength (λ) Reflectance in the sample of difference and diffuse light arriving at the sample of (λ) Reflectance in the sample of surviving at the sample of (λ) Reflectance in the sample of (λ) Reflectance in the sample of interation diffuse light arriving at the sample of (λ) Reflectance in the sample o				<u> </u>	
IR Infrared			W_{ij}	——————————————————————————————————————	
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MIC Maximum likelihood classification MIR Multi-linear regression MSC Multiplicative scatter correction NG Neural Gas NR Near-infrared OSC Orthogonal signal correction PC Principle component PCA Principle component analysis PLS Partial least square discriminant analysis QDA Quadratic discriminant analysis RGB Red, green and blue ROI Region of interest S/N-ratio Signal-to-noise ratio SAM Spectral angle mapper SCM Spectral angle mapper SCM Support vector machine UV Ultraviolet VIS Visible range WT Wavelet transform WTA Wavelet texture analysis X-matrix Spectral data Y-matrix Spectral data Y-matrix Spectral data for all pixels i Class number $\rho(\omega_i)$ Probability of class having ω_i $p(\omega_i)$ Probability of class number are for the spectral data for all pixels belonging to class i. $v(\omega_i)$ Factor trait relates the percentage of direct and difficus light arriving at the sampunt of direct light reflected at each point E(C, c_1 , c_2) Energy function E(V, W) Energy function E(V, W) Degree of neighbourhood cooperation $k_1(V,W_i)$ Degree of neighbourhood cooperation $k_2(V,W_i)$ Number of prototypes Neighbourhood range γ			$\rho(\lambda)$		
MLR Multi-linear regression MSC Multiplicative scatter correction MSC Multiplicative scatter correction MSC Multiplicative scatter correction MSC Neural Gas MR Near-infrared OSC Orthogonal signal correction PC Principle component PCA Principle component analysis PLS-DA Partial least square PLS-DA Partial least square discriminant analysis QDA Quadratic discriminant analysis RGB Red, green and blue ROI Region of interest S/N-ratio Signal-to-noise ratio SAM Spectral angle mapper SCM Spectral angle mapper SCM Spectral correlation measure SNV Standard normal variate SVW Standard normal variate SVW Ultraviolet UV Ultraviolet VIS Visible range WT Wavelet transform WTA Wavelet transform MEAN OR			α_{D}		
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NIR Near-infrared $E(C, c_1, c_2)$ Energy function SCC Orthogonal signal correction SCC Orthogonal signal correction SCC Orthogonal signal correction SCC Principle component SCC Principle component analysis SCC Partial least square SCC Partial least square discriminant analysis SCC Post S					
OSC Orthogonal signal correction $d = E(V, W)$ Energy function $d = E(V, W)$ English entry $d = E(V, W)$ Engrey function $d =$					
PC Principle component $h_{\gamma}(r, V, W_c)$ Degree of neighbourhood cooperation $h_{\gamma}(r, V, W_c)$ Number of prototypes $h_{\gamma}($			E(V, W)	Energy function	
PCA Principle component analysis $h_r(V, W_c)$ Degree of helmotourhood cooperation $h_r(V, W_c)$ Number of prototypes $h_r(V, W_c)$ Number of prototype objective function $h_r(V, W_c)$ Number of prototype objective function $h_r(V, W_c)$ Number of prototype objective function $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$ Number of prototype of the centre object $h_r(V, W_c)$			d	Euclidean distance	
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SCM Spectral angle mapper M Spectral angle mapper M Spectral angle mapper M Support vector measure M Support vector machine M Mean of clusters M Standard deviation of rows in GLCM Standard deviation of columns in GLCM Standard deviation of columns in GLCM Number of rows in the image M Number of columns in the image M Number of columns in the image M Support			u _{ik}	Degree of membership of x_k in cluster i	
Scale Spectral correlation measure $d(x_k, v_i)$ Distance measure between object x_k and cluster solved x_k and clus			m		
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belonging to class i. with a gan (a)	m_i			<u> </u>	
R(x) Calibrated image			(11, 3)		
	R(x)	Calibrated image		5 1 0,	

1. Introduction

Interests in food quality are driven from the essential need to supply consumers with consistent products at an affordable

price. The ideal way to enhance food supplies and consider food safety issues is to regularly monitor food products during all stages of handling chain to detect the onset of potential issues and to take timely action once a problem has been identified. Effective monitoring systems and an intelligent

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