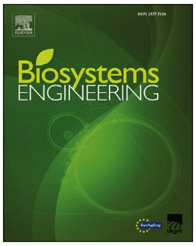
BIOSYSTEMS ENGINEERING 164 (2017) 49–67

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110



Review

Close range hyperspectral imaging of plants: A review

Puneet Mishra [a,d,*], *Mohd Shahrimie Mohd Asaari* [a], *Ana Herrero-Langreo* [b], *Santosh Lohumi* [c], *Belén Diezma* [d], *Paul Scheunders* [a]

[a] *Vision Lab, Department of Physics, Campus Drie Eiken, University of Antwerp, Edegemsesteenweg 200-240, 2610 Antwerp, Belgium*

[b] *Irstea, UMR ITAP, 361 Rue J.F. Breton, 34196 Montpellier Cedex 5, France*

[c] *Department of Biosystems Machinery Engineering, College of Agricultural and Life Science, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 305-764, South Korea*

[d] *LPF-TAGRALIA, School of Engineering for Agriculture, Food and Biosystems, Technical University of Madrid, 28040 Madrid, Spain*

ARTICLE INFO

Article history:
Received 20 March 2017
Received in revised form
6 September 2017
Accepted 24 September 2017
Published online 23 October 2017

Keywords:
Plant traits
Phenotyping
Pigments
Non-destructive
Imaging spectroscopy

The increasing need to develop a rapid understanding of plant functional dynamics has led to the employment of sensor technology for non-destructive assessment of plants. Hyperspectral Imaging (HSI) being an integration of two modalities, imaging and point spectroscopy, is nowadays emerging as a potential tool for rapid, non-destructive and automated close range assessment of plants functional dynamics both in terms of structure and physiology.

Firstly, this paper presents an overview of some basic concepts of close range HSI on plants, concerning the plant–light interaction, instrumental setup, and spectral data analysis. Furthermore, the work reviews recent advances of HSI for plant related studies under controlled experimental conditions as well as in natural agricultural settings. Applications are discussed on foliar content estimation, variety identification, growth monitoring, stress and disease-related studies, phenotyping and adoption of HSI in high-throughput phenotyping platforms (HTPPs).

Close range HSI is a challenging task and suffers from technical complexities related to external factors (e.g. illumination effects) as well as plant-related factors (e.g. complex plant geometry). The paper finally discusses some of the technical challenges related to the implementation of HSI in the close range assessment of plant traits.

1. Introduction

To increase the agriculture productivity, it is important to develop high-yielding crops which can adapt to future climatic conditions (Furbank & Tester, 2011). Moreover, the assessment of existing and to be developed high-yielding crop plants is crucial to understand how the detrimental effects of surrounding environment limit their growth and yield, further

---

* *Corresponding author*. Pure and Applied Chemistry, Thomas Graham Building, University of Strathclyde, 295 Cathedral St, Glasgow G1 1XL, United Kingdom.

E-mail address: puneet.mishra@alumnos.upm.es (P. Mishra).

https://doi.org/10.1016/j.biosystemseng.2017.09.009

Nomenclature

(x,y)	Spatial coordinate of HSI
3D	Three dimensional
AMB	Apple marssonina blotch
ANN	Artificial neural network
BLR	Binary logistic regression
deg C	Celsius
C–O	Carbon and oxygen bond
CCD	Charge coupled device
CLS	Cercospora leaf spot
CMOS	Complementary metal-oxide-semiconductor
CSIRO	Commonwealth scientific and industrial research organisation
e.g.	Example
ELM	Extended learning machine
EM	Electromagnetic
EMR	Electromagnetic radiation
g cm^{-2}	gram per square centimetre
GA-PLS	Genetic algorithm partial least square
g kg^{-1}	gram per kilogram
g m^{-2}	gram per square metre
HPLC	High performance liquid chromatography
HSI	Hyperspectral imaging
HTPPs	High-throughput phenotyping platforms
I_{dark}	Dark reference
I_R	Reflectance
I_{raw}	Raw image
I_{white}	White reference
ICA	Independent component analysis
InGaAs	Indium gallium arsenide
λ	wavelength
LDA	Linear discriminant analysis
LED	Light emitting diode
mg g^{-1}	milligram per gram
MLR	Multiple linear regression
MSC	Multiplicative scatter correction
N–H	Nitrogen hydrogen bond
NIR	Near-infrared
nm	nanometre
O–H	Oxygen hydrogen bond
O_3	Ozone
PCA	Principal component analysis
PLS-LDA	Partial least square linear discriminant analysis
PLSR	Partial least square regression
POD	Per-oxidase
PSI	Photon system instruments
R^2	Correlation coefficient
R692/R530	Ratio of 692 and 530 wavebands
R692/R732	Ratio of 692 and 732 wavebands
R702/R718	Ratio of 702 and 718 wavebands
RGB	Red green blue
RMSE	Root mean squared error
ROI	Region of interest
SAM	Spectral angle mapper
SiVM	Simplex volume maximisation
SNV	Standard normal variate
SVM	Support vector machine
SVR	Support vector regression
SWIR	Short-wave infrared
TMV	Tobacco mosaic virus
UV	Ultraviolet
VIB	Vlaams Instituut voor Biotechnologie
VIS	Visible

supporting the development of optimal plant varieties. Traditional methods used for plant assessment are still time-consuming, labour intensive and destructive in nature (Busemeyer et al., 2013).

The need for fast, non-destructive and high throughput alternative technologies for plant assessment has lead to the development of new and the re-use of different existing sensor technologies from various scientific domains (Li, Zhang, & Huang, 2014). One such emerging sensor technology for non-destructive, rapid and automated assessment of plants is the hyperspectral imaging (HSI) (Matsuda, Tanaka, Fujita, & Iba, 2012). The application of HSI can be found in diverse domains of research such as remote sensing (Blackburn, 2007), foods (Mishra et al., 2015, 2016; Wu & Sun, 2013), microbiology (Gowen, Feng, Gaston, & Valdramidis, 2015) and pharmaceutical sciences (Gendrin, Roggo, & Collet, 2008). In particular, in remote sensing, vegetation monitoring has been studied using HSI for many years (Blackburn, 2007), and has motivated the use of HSI for exploring plants at close range.

A HSI system integrates a spectrograph that records reflectance in a wide range of the spectrum, including the ultraviolet (UV), visible (VIS) and near-infrared (NIR) into a digital sensor (Bock, Poole, Parker, & Gottwald, 2010). Data is generated in the form of a 3D spatial map of spectral variation: the first two dimensions provide the spatial information and a third dimension accounts for the spectral information. Being an integration of imaging and conventional spectroscopy, HSI can obtain complementary information from both domains. While point spectroscopy gathers information to understand the physiology of the plants (Montes, Melchinger, & Reif, 2007), the information from imaging technology is used to understand the structural dynamics (Apelt, Breuer, Nikoloski, Stitt, & Kragler, 2015; Bucksch et al., 2014; Dhondt et al., 2014). In combination, HSI has the potential to extract integrated spatial and spectral information related to the plant's functional dynamics regarding both structure and physiology (Bergsträsser et al., 2015; Kuska et al., 2015; Mahlein, Oerke, Steiner, & Dehne, 2012; Rascher et al., 2011; Ustin & Gamon, 2010).

Various emerging applications of HSI related to plants biochemistry estimation (Vigneau, Ecarnot, Rabatel, & Roumet, 2011), stress detection (Rumpf et al., 2010; Mahlein, Steiner, Dehne, & Oerke, 2010, 2013), species identification (Kumar, Skidmore, & Mutanga, 2010) and Phenotyping (Leucker et al., 2017; Wahabzada et al., 2016) have gained the interest of plant biologists and agronomist all over the globe, covering the need for a fast, non-destructive and visually