Estimation of biophysical and biochemical parameters using optical satellite images and sensor onboard UAV

A thesis submitted in fulfilment for the Award of Degree of

Doctor of Philosophy

By

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Dedicated with love to my parents, dadi,
friends, and critics

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ABSTRACT

Hyperspectral (HS) sensors are essential for measuring minute changes in vegetation spectra, making it a useful tool to study vegetation parameters, for monitoring crop. Leaf Chlorophyll Content (LCC) indicate plant growth, stress, and nutrient availability, its detailed information is required in precision agriculture. Leaf Area Index (LAI), a biophysical vegetation parameter which indicates shadow imprint and density of vegetation. Hence, scientists must determine its precise quantity for monitoring of vegetation healthy growth.

Every object emits light in range of electromagnetic spectrum, in order to study such emissions and absorption HS sensors are required. These sensors acquire images in hundreds of bands with very high spectral resolution (as high as 5nm) making it a very useful tool to study any subjects that require information of very low spectral width. The parameters of interest in the present study are LCC and LAI.

HS images are not freely available, but multispectral images with low spectral resolution are widely available. The part of work in the thesis attempts to create AVIRIS-NG, a hyperspectral image, using Sentinel-2 image and a linear unmixing method called Universal Pattern Decomposition Method (UPDM), it decomposes each image pixel as a linear combination of many classes. Since, the image is reconstructed with three major classes present in the study site, so there is some information loss while simulation because there could be more than three classes present in the area. Ground-based LCC observations from a chlorophyll meter (Soil Plant Analysis Development (SPAD)) confirmed that the simulated AVIRIS-NG could calculate LCC efficiently. Further, generated image’s wavelength range depends on the number of

multispectral bands, but its spatial resolution is the same as the base image (multispectral image). Thus, an image from RedEdge MX installed on an Unmanned Aerial Vehicle (UAV), was used to simulate a half-range AVIRIS- NG image. The generated image was utilised to create a LAI and LCC map, which compared well to in-situ LAI and LCC.

Furthermore, denoising the vegetation spectra of diverse agricultural species using AVIRIS-NG imagery using different types of wavelets was used to improve LCC estimation accuracy. After noise removal, several Feature Selection Methods (FSMs) were employed to choose absorption bands relevant to chlorophyll content such as Recursive Feature Elimination (RFE), Regularised Random Forest (RRF), Least Absolute Shrinkage and Selection Operator (LASSO), and Partial Least Square (PLS). These FSMs selected the top three absorption bands to create new LCC retrieval Vegetation Indices (VIs). These VI indicators are used to form linear regression models for LCC mapping. PLS-based LCC retrieval model performed the best, whereas LASSO-generated chlorophyll model performed the least.

Another study used PLS's (Variable Importance in Projection) VIP score to select important VIs for LCC and LAI retrieval of various agricultural crops under different treatments such as fertilizers and irrigation. Twenty-Five hyperspectral VIs for LCC and seven canopy VIs for LAI assessment were tested using Support Vector Regression (SVR with linear, radial, and polynomial kernels), Partial Least Square Regression (PLSR), Hybrid neural fuzzy inference system (HyFIS), and Random Forest Regression (RFR). VIP from PLS and R^2 were determined for each VI to find the most sensitive information for vegetation parameters.

LAI was found to be most sensitive in red-edge reflectance region. The green, red, and red-edge VIs indices were responsive to lentil and maize crop bed temporal LCC values. However, for Mustard the temporal LCC values were sensitive to VIs generated from green, red, and NIR bands. Top three indices with the highest VIP and R^2 values were used as ideal inputs to create different machine learning models. SVR-Rad generated model gave the best estimation among others.

Conclusively, the work shows a successful attempt in generating models for LAI and LCC estimation, using different remote sensing technique such as from a simulated hyperspectral image, denoised hyperspectral image, and from a spectroradiometer data.

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LIST OF ABBREVIATIONS

A	Absorption
AGL	Above Ground Level
ALI	Advance Land Imager
AVIRIS	Airborne Visible InfraRed Imaging Spectrometer
AVIRIS-NG	Airborne Visible InfraRed Imaging Spectrometer - Next Generation
AUC	Area Under Curve
BHU	Banaras Hindu University
CARI	Chlorophyll Absorption Ratio Index
CASI	Compact Airborne Spectrographic Imager
CB	Crop Bed
CCI10	Chlorophyll Content Index 10
CS	Class Separability
CWC	Canopy Water Content
DN	Digital Number
DoY	Day of Years
DWT	Discrete Wavelet Transform
EMR	Electromagnetic Radiation
EnMAP	Environmental Mapping and Analysis Program
ESA	European Space Agency
EO-1	Earth Observation-1
ETM+	Enhanced Thematic Mapper Plus
FA	Fourier Analysis
FS	Feature Selection

FSM	Feature Selection Method
FOV	Field of View
FWHM	Full Width at Half Maximum
GI	Greenness Index
GLM	Generalized Linear Model
GPS	Global Positioning System
GSD	Ground Sampling Distance
HS	Hyperspectral
HSI	Hyperspectral Imaging
HSS	Hyperspectral sensor
HyFIS	Hybrid Neural Fuzzy Inference System
HySIS	Hyperspectral Imaging Satellite
ISRO	Indian Space Research Organisation
IFOV	Instantaneous Field of View
IR	Infrared
LAI	Leaf Area Index
LCC	Leaf Chlorophyll Content
LiDAR	Light Detection and Ranging
MAE	Mean Absolute Error
MCARI	Modified Chlorophyll Absorption Ratio Index
MODIS	Moderate Resolution Imaging Spectroradiometer
MS	Multispectral
MSI	Multispectral Imaging
MSR2	Modified Simple Ratio 2
MSS	Multispectral Sensor

NASA	National Aeronautics and Space Administration
NIR	Near Infrared
NDR	Normalized Difference Ratio
NDVI	Normalized Difference Vegetation Index
OA	Overall Accuracy
OSAVI	Optimised Soil Adjusted Vegetation Index
OOB	Out of Bag
PLS	Partial Least Square
PLSR	Partial Least Square Regression
Rf	Reflection
RADAR	Radio Detection and Ranging
RDVI	Renormalized Difference Vegetation Index
RFE	Recursive Feature Elimination
RFR	Random Forest Regression
RGB	Red Green Blue
RMSE	Root Mean Square Error
ROC	Receiver Operating Characteristic
RRF	Regularised Random Forest
RTM	Radiative Transfer Model
SAM	Spectral Angle Mapper
SFM	Structure From Motion
SIPI	Structure Insensitive Pigment Index
SNAP	Sentinel Application Platform
SNR	Signal-to-noise Ratio
SONAR	Sound Navigation and Ranging

SPAD	Soil Plant Analysis Development
SR	Simple Ratio
SRF	Spectral Response Function
SVM	Support Vector Machine
SVR	Support Vector Regression
SWIR	Short Wavelength Infrared
T	Transmission
TAS	Throttle Aerospace Systems
TCARI	Transformed Chlorophyll Absorption Reflectance Index
TVI	Transformed Vegetation Index
UAV	Unmanned Aerial Vehicle
UPDM	Universal Pattern Decomposition Method
UV	Ultraviolet
VNIR	Very Near Infrared
VI	Vegetation Index
VIP	Variable Importance in Projection
VIS	Variable Importance Score
VS	Vegetation-Soil
VSA	Vegetation-Soil-Asphalt
VSC	Vegetation-Soil-Concrete
VSCA	Vegetation-Soil-Concrete-Asphalt
WA	Wavelet Analysis

LIST OF SYMBOLS

A	Angle between vectors (reference and original spectra)
E	Insensitive loss
B	Bias
α_i	Lagrange multiplier
$\varphi(s_i)$	Different kernel function (linear, polynomial, radial)
C	Regularisation constant
σ	Bandwidth
λ	Wavelength
$\bar{\lambda}$	Centre wavelength
R_i	Reflectance in i^{th} band
C_{mx}	Decomposition Matrix for multispectral image for class x
C_h	Decomposition Matrix for hyperspectral image
P_{mx}	Standard Matrix for multispectral image for class x
P_h	Standard Matrix for hyperspectral image
P_m^T	Transposed Standard Matrix for multispectral image
f_{obs} f_{est}	Standard deviation of observed and estimated data
m	Meter
cm	Centimetre
mm	Millimetre
μm	Micrometre
nm	Nanometre
^{o}	Degree

‘	Minute
“	Second
km	Kilometre
ft	Feet
Kts	Knots
sq	Square
R	Correlation coefficient
R^2	Coefficient of Determination

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