SELFSUSTAINED CROSS-BORDER CUSTOMIZED CYBERPHYSICAL SYSTEM EXPERIMENTS FOR CAPACITY BUILDING AMONG EUROPEAN STAKEHOLDERS

Monitoring
Remote Sensing

University "UKSHIN HOTI" Prizren

Co-funded by the Horizon 2020 programme of the European Union

DT-ICT-01-2019
Smart Anything Everywhere Area 2

www.smart4all-project.eu
Grant Agreement: 872614

Content

- Introduction
- Remote sensing
  - for crop biotic stresses
  - for crop abiotic stresses
  - for estimation of yield potential

Introduction

- Precision agriculture (PA), in the plant sector, concerns the application of the right amount of farming input (e.g., fertilizers, water for irrigation, manure, seeds) in the right time and right place using advanced sensing, modeling, and data mining, and control technologies.
- Today two categories of sensors are used, proximal sensors and remote sensors, associated with a Global Differential Positioning System (DGPS) to accurately determine the sampling position.

Remote sensing

- Remote sensing is defined as the technology enabling the measurement of soil or crop characteristics, by UAVs, airplane flights, or satellites from distances.
- Remote sensing applications in agriculture are based on the interaction of electromagnetic radiation with soil or plant material.
- The crop characterization includes crop growth, crop density, yield potential estimation, detection, and mapping of biotic and abiotic stresses.

Remote sensing

- Remote sensing offers the possibility to acquire information about an area by observing it from a distance.
- Several imaging sensors are used to acquire data while on board various platforms, such as satellites, airplanes, or UAVs.
  - UAVs capture data from 2 to 100 m distance.
  - Satellite sensing acquires data from several hundreds of kilometers above the crop.

Remote sensing for crop biotic stresses

- Crop biotic stresses can arise from weeds, insects, or diseases. Biotic stresses cause severe economic damage to crops when thresholds for incidence of the stress are exceeded.
  - At first, weeds can be small and difficult to distinguish from crops. Insects and diseases may cause no detectable signatures of crop damage.
  - Later, crop damage can appear as spots or stripes of differing colors (yellow, black, or white); leaves can curl or wilt and crop biomass can be reduced.
- Remote sensing offers the possibility of rapidly surveying large areas of a field for biotic stress based on images collected using satellites, airplanes, or UAVs.
- Detection of biotic stresses at early stages of incidence creates a particularly important need for high-resolution imagery.

Weed detection

- Early detection of weeds using remote sensing often relies on the segmentation of imagery to separate weeds from bare soil or growing crops.
- Segmentation seeks to first identify the location of crop rows based on the assumption that crop rows are linear. As a second step, green vegetation differing in the location from crop rows is classified as a weed.
- Lines perpendicular to crop rows were established on imagery at fixed distance intervals to define cells where the decision to spray or not spray was assessed using ground truth data.

Weed detection

- Detection of crop rows using segmentation often relies on analytical techniques such as the simple Hough transform.
- Segmentation techniques based on NDVI >0.2 and object-oriented classification were used to distinguish crop and weeds from bare soil and then to distinguish weeds from the crop.
- Tellaeche et al. (2011) used segmentation and Support Vector Machine (SVM) algorithms to successfully identify areas with excessive wild oat weed pressure in a small grain cereal crop field.

Detection of insects

- Insect and disease damages can be detected using various spectral indices based on VIS-NIR or hyperspectral reflectance, coupled with partial least squares regression (PLSR) analysis or machine learning techniques.
- Green and red edge wavelengths also may respond to a variety of biotic crop stresses.
- Satellite remote sensing of insect damage is primarily used to identify the location and magnitude of forest defoliation.
- Changes in NDVI values from sequential satellite images are used to identify the defoliation of trees as a result of insect damage.
- Hunt and Rondon (2017) showed that damage to potato crops from Colorado potato beetles could be detected with UAV imagery within 1 day of an increase in the infestation.
- Puig et al. (2015) used K-means clustering of high-resolution RGB imagery obtained using a UAV to classify white grub damage in a 6 ha Australian sorghum field.

Crop disease detection

- Yuan et al. (2016) used multispectral imagery with the SPOT-6 satellite at 6 m spatial resolution for regional mapping of powdery mildew infestation of wheat in China.
- Red and green satellite bands as well as the NDVI, triangular vegetation index (TVI) and atmospherically resistant vegetation index (ARVI) spectral indices were combined using spectral angle mapper (SAM) to estimate whether or not specific farmer fields were infested or not.
  - NDVI indicates the impact of disease on crop biomass.
  - TVI is an indirect measure of the impact of disease on chlorophyll.
  - ARVI suppresses atmospheric interferences in satellite imagery.

Crop disease detection

- UAVs have been increasingly used to identify locations within agricultural fields affected by crop disease.
- Traditional approaches for the identification of crop biotic stresses are often based on multispectral and hyperspectral remote sensing and the use of spectral indices such as NDVI.
- They are most useful when a field is known to be infested with a particular type of biotic stress, and the objective is to quantify the spatial extent and severity of infestation.

Remote sensing for crop abiotic stresses

- The use of remote sensing images to detect and map abiotic stresses and to monitor the status of two important and highly variable resources, namely, water and plant-available N.
- Remote sensing images with adequate analysis tools may be used for variable rate fertilization (VRF) and irrigation (VRI) management.
- The practicability of remote sensing images for that aim depends on the spectral, temporal, and spatial resolutions of the images.

Spectral and thermal properties of plants

- Green vegetation has very prominent spectral features in the VIS spectral portion: two chlorophyll pigment absorptions in the blue (450 nm) and red (680 nm) regions that bound a reflection in the green region (550 nm).
  - These bands were used to monitor N content.
- Water absorption bands are mostly noted at around 760, 970, 1200, 1470, 1900 and 2500 nm.
  - These bands used to monitor water content.
- Leaf temperature can be sensed by measuring the far-infrared or TIR (8e14 mm) radiation they emit.
- As plant stomata close, the evapotranspiration rate decreases; the energy heat balance between the vegetation and its environment is changing, and leaf temperature rises.

Spectral analysis methods to estimate N and water status in crop

- Spectral data in the VIS-NIR short-wavelength infrared (SWIR) range are divided into multispectral and hyperspectral data.
  - Multispectral imagery generally refers to 3-5 bands, which are relatively wide (20-100 nm).
  - Hyperspectral imagery consists of much narrower bands (1-5 nm), with hundreds of bands.
- There are three main methods for spectral analysis:
  - spectral indices,
  - band selection, and
  - linear and nonlinear multivariate statistics and machine learning.

Nitrogen crop status

- Nitrogen deficiency is one of the most important types of crop abiotic stress to be detected because it directly affects the productivity of the crop.
- Many VIs have been developed to estimate crop N status at leaf and canopy levels. A list of indices can be found in various studies.
- Best-performing VIs include simple ratios in the red edge region, in the blue region, and in the SWIR region.
- The capabilities of the VIs to predict N content are affected by various factors: crop type, site, year, growth stage, and spectral, spatial, and temporal resolutions of the sensor.

Nitrogen crop status

- The medium-resolution imaging spectrometer terrestrial chlorophyll index (MTCI) was found the best spectral index to be used for variable rate N recommendations in two varieties of potato (USA).
- PLSR analysis has resulted in a stronger correlation between predicted and measured leaf N content (R^2 = 0.95).
- Techniques related to machine or deep learning concepts, were introduced to the analysis of remotely sensed data to estimate N levels, due to the capability of these techniques to process a large number of inputs and handle nonlinear tasks.

Canopy/leaf relative water content

- Spectral characteristics of water can be used to quantify the leaf and canopy relative water content (LRWC/CRWC).
- Methods that use the whole spectrum performed better than commonly used water content index formulations.
- A recent study proposed an index that is based on a spectral area difference that was suitable for a wide variety of crop types, with an $R^2 = 0.8$ obtained using an exponential regression algorithm.

Thermal image analysis to estimate water crop status

- Thermal cameras provide either panchromatic images or multispectral images in the range of 3-14 μm.
- The core of the thermal image analysis is to convert the surface temperature to agriculturally meaningful crop water status indices.
- Leaf water potential (LWP) in crops and stem water potential (SWP) in orchards are important biophysical parameters that indicate the ability of the crop to transfer water from soil to the atmosphere by the leaf.

Thermal image analysis to estimate water crop status

- LWP/SWP does affect the status of the leaves' stomata, which control the evapotranspiration process and affect leaf temperature.
- The crop water stress index (CWSI) based on canopy temperature has become an acceptable index to map the in-field variability of crop water status using thermal images.
- Thermal crop sensing technologies have been widely used as tools for monitoring and mapping crop water status in various orchards, grapevines, olives, almonds and other various crops.

Integration of remotely sensed data in fertilization and irrigation decision-making

- A normalized sufficiency index (NSI) approach was suggested to address the observed interchangeability of wavelengths and indices along with crops, cultivars, growth stages, years, and sites.
- NSI in the context of spectral-based N estimation is calculated according to the following equation:

$$NSI = N_i / N_{ref}$$

- where N_i is the measured value of the spectral index and N_{ref} is the spectral index value of the nonlimiting N reference area.
- The N-rich plants are likely to develop differently from the remaining field and not represent the normal canopy.

Integration of remotely sensed data in fertilization and irrigation decision-making

- Irrigation decision-making also benefits from using tools that monitor water crop requirements throughout the season. For irrigation, the crop coefficient (Kc) method is a practical and reliable technique for estimating evapotranspiration coefficients (ETc).
- Computer-aided tools are available for farmers that retrieve accumulative water amounts required for irrigation according to the crop type, growth stage, and meteorological conditions.
- Kc has been shown to vary between sites and between seasons and provide imprecise ETc estimations caused by weather anomalies.
  - One approach to address this need is by using satellite remote sensing imagery.

Remote sensing for estimation of yield potential

- *Measurable crop growth and yield parameters, accuracy and practicality*
- There are several parameters used in the literature to estimate crop growth and yield.
- These include among others crop height, crop biomass, LAI, NDVI, crop volume, and density.

Vegetation height

- Vegetation height is an important structure-related parameter that defines the growth status of crops, fodder, and forests.
  - It is a straightforward parameter for monitoring vegetation development, health and predicting its aboveground biomass.
- RGB images of a low-cost UAV digital camera were used to estimate various VIs.
- The combination of structural and spectral data was considered essential to achieve high accuracy of height estimation.
- Terrestrial laser scanning (TLS) is an effective tool for monitoring the height of short crops or during the early growing period.
- In another experimental plot in Texas (USA), maize height was estimated using SfM analysis of RGB images acquired from various UAV platforms.
- A VISNIR camera onboard a UAV was used to estimate tree heights over olive orchards in southern Spain.

Leaf area index

- An important parameter to characterize vegetation biomass is LAI, which is defined as the one-sided green leaf area per unit ground area (m^2/m^2).
- Knowledge of LAI is crucial to describe the vegetation development of a crop, estimate water loss by transpiration, and assess various stress factors.
- Data for LAI estimation can be acquired from multispectral cameras onboard UAVs, from commercial VHR satellite images (WorldView-2, Quickbird, etc.), and commercial high-resolution satellites (Sentinel-2, SPOT, Landsat, etc.) for very large fields.

Yield and biomass prediction

- Crop development is a function of meteorological conditions such as temperature, sunlight, and precipitation.
- Advance prediction of crop yield or yield potential will be valuable to farmers to take site-specific decisions to increase the final yield.
- Crop models are classified into two main categories, dynamic models and empirical models.
  - Dynamic models are also called process-based models, which simulate the development of the crop using differential equations.
  - Empirical models, also known as statistical models, are expressed as regression equations with one or few parameters.

Yield and biomass prediction

- The main advantages of combining remote sensing data with crop models are the accurate description of crop conditions during the growing season and the incorporation.
- Lambert et al. (2017) studied the use of remote sensing to estimate and map yield in sub- Sahara Africa.
- Pantazi et al. (2016a) examined three self-organizing maps to predict wheat yield using as inputs NDVI data as well as VIS-NIR spectra acquired from an online soil scanner.
- Machine learning is also used for yield prediction while assimilating remote sensing data.

Session Q&A