UNIT-1

SYLLABUS : Milestones in agricultural automation and monitoring in agriculture (Introduction, Sensing systems for PA, Benefits through sensing for PA farming systems, Current trends in agricultural automation, Current challenges of PA sensing applications**), Sensors for soil analysis and characteristics (**Visible (VIS)/NIR Spectroscopy, Soil sensing using airborne and satellite imaging**) , Yield sensing , Sensors for weed management, Sensors for disease detection and classification.**

1.1 Milestones in agricultural automation and monitoring in agriculture :

1.1.1 Introduction :

By 2050, It is expected that the world population will reach 9.8 billion according to a new launched United Nations report (www.un.org). Consequently, as the global demand for food and agricultural crops elevates. novel and sustainable approaches are needed that employ agricultural technologies focusing not only on agricultural activities for crop production but also on the global impacts concerning the appropriate nitrogen fertilizer use, reduced GHG emissions and water footprints.

The intensification of agricultural activities, mechanization, and automation throughout the years are regarded the main reasons that contributed significantly to the rise of agricultural productivity. This led to the evolution of autonomous farming systems for field operations, livestock management systems and growth control systems oriented mostly on greenhouse monitoring, climate control and irrigation management systems.

The efficient agricultural production management enables the decrease of negative environmental impacts allowing both efficiency, as well as agricultural products safety.

Agriculture has to meet significant challenges in the face of providing technical solutions for increasing production, while the environmental impact decreases by reduced application of agro-chemicals and increased use of environmental friendly management practices. A benefit of this is the reduction of production costs. Technologies of sensors produce tools to achieve the above-mentioned goals. The explosive technological advances and development in recent years enormously facilitates the attainment of these objectives by removing many barriers for their implementation, including reservations expressed by farmers themselves.

Precision Agriculture is an emerging area, where sensor-based technologies play an important role. Farmers, researchers, and technical manufacturers, all together, are joining efforts to find efficient solutions and improvements in production and in to reductions in costs.

Precision agriculture (PA) is based on the idea of sensing for monitoring and deploying management actions according to spatial and temporal crop variability. Therefore, sensor technologies are regarded as fundamental components of PA systems.

PA technologies combine sensors, farm management information systems, compatible machinery that can apply inputs according to map requirements, for production optimization.

Through adaptation of PA production inputs, an efficient and precise resources management for protecting the environment while maintaining the sustainability of the food supply is achieved.

Precision agriculture comprises a powerful tool for monitoring food production chain and securing both agricultural production quantity and quality by employing novel technologies to optimize the agricultural operations for producing simultaneously hiring yield and quality with site-specific input. More specifically, sensor-based monitoring technologies give precise yield predictions and early alerts concerning the crop condition.

PA makes farming more credible by improving registration of operations, by monitoring and documenting. Crop monitoring provides more precise predictions on agricultural products quality, making consequently the food chain easier to be monitored for stakeholders (producers, retailers, customers).

It is also capable of giving vital information for plant health condition. Recent technologies are able to monitor plants and crops at different scales of resolution. The monitoring scales vary from field (ca. 30X30m) to plant monitoring (ca. 30 X 30 cm). It is expected that the upcoming technologies will be 2 Intelligent data mining and fusion systems in agriculture capable of making leaf level (ca. 3 X 3 cm) and symptoms on leaves (ca. 0.5 X 0.5 cm) detectable by sensor based optical diagnostics. On the other hand, diseases untraceable by conventional means will be detected by automated optical sensing and optimal planning options

1.1.2 Sensing systems for PA :

Crop monitoring is not a new tendency. The first approaches for crop monitoring are dated back in ancient Egypt, where attempts to examine the River Nile water level fluctuations effect on crop yield have been indicated (Luiz, Formaggio, & Epiphanio, 2011). The above measurements were employed to contribute not only to the tax management system but also to the prevention of famine.

Nowadays, it is more than necessary to use the intelligent tools of agriculture to meet the multiple social needs that have arisen concerning trustworthy crop product information which consequently are capable of guaranteeing and assessing crop and food safety.

It should be stressed that sensing monitoring systems estimations in agriculture are crucial to be provided at an early stage during the growing period and updated regularly until harvesting so as timely vital information for crop production, condition and yield productivity both at the (sub)regional to the national level are provided. Consequently, this information are combined by forming early warning systems, which are capable of providing homogeneous data sets.

The statistically valid precision and accuracy data gives the opportunity to stakeholders, to recognise and discriminate areas, which vary a lot in terms of production and productivity, and to take early decisions.

However, sensing monitoring of agricultural production often conveys some additional limiting-factors closely related to the ability of unfavorable growing conditions altering within short time periods including the seasonal patterns associated with crops biological lifecycle, the physical landscape, the management practices and the climate variability.

Food and Agriculture Organization stresses the contribution of early and accurate information that concerns crop status and yield productivity to underlying agricultural statistics and to the decision making process of the associated monitoring systems.

On the contrary, information is not considered of high value if it is available too late. Considering variables space and time sensitivity and crops perishable nature, it is concluded that agricultural monitoring systems are vital to be timely assessed.

1.1.3 Benefits through sensing for PA farming systems :

The positive effects of PA farming systems adaptation in agricultural activities are reflected mainly in two areas including the farmers profitability and the protection of the environment.

For achieving profitability, it is important that the cost of investing in such promising sensing technologies is fully focused on some envisioned reasonable return.

PA farming systems allows detailed agricultural production tracking and tuning by enabling farmers to modify and timely program the fertilization and agrochemicals application according to the field's spatial and temporal variability.

By adapting PA technologies, the farmers are given the opportunity to manage, their own agricultural machinery in a more precise and efficient way to meet the cultivated crop needs.

PA systems are capable of forming a database of many years, which enables the combination of both yield and weather data for adjusting crop management and predicting crop productivity.

Agricultural machinery movements and their work recordings, also contribute to the creation of a useful database tool able to assess the duration of several farming activities.

Based on the crop yield variability in a field and the inputs cost, farmers can assess the economic risk and consequently estimate the cash return over the costs per hectare in a more precise and trustworthy way. Moreover, parts within a field demonstrated low yield productivity, are isolated and subjected to site-specific management treatment (Goddard, 1997).

Nowadays, there are environmental legislations already established in some European countries including Denmark, Germany, and UK and in USA and Australia, More countries across Europe are expected to follow and introduce novel legislations focusing on the rational use of water resources and on the significant reduction of fertilizers and agro-chemicals usage. As PA farming systems are fully complied to the principles of those legislations, novel and effective solutions for accurate application, recording of farming activities in the field, operation to operation tracking, and transfer of recorded crop information after harvesting will be offered (Stafford, 2000).

Automation systems has contributed significantly to lowered production cost by reducing the manual labor work, offering higher quality productivity, leading to a more effective environmental control.

Automation in agriculture employs advanced technologies to face its complexity and its highly variable environment. The GNSS-based vehicle guidance is used extensively for several PA activities because it allows the operation of agricultural vehicles working on parallel tracks or on predefined paths, contributing to more comfortable driving, avoiding gaps and overlaps. Initially, navigation systems were used to help agricultural vehicles operators by utilizing visual feedback (e.g. light bars, graphical displays). Current autoguidance systems do not need any direct input from operators. Taking into account the high complexity and variability of agricultural environment and the extensive use of resourcees.

Intelligent PA's sensing technologies are capable of offering beneficial solutions to difficult problems including crop variability and environment (size, shape, location, soil properties, and weather),

delicate products, and hostile environmental conditions (dust, dirt, and extreme temperature and humidity).

1.1.4 Current trends in agricultural automation:

PA systems utilizes a several heterogeneous technologies including:

- **Automated steering systems :**

They control specific driving tasks following field edges and overlapping of rows. Through this type of agricultural automation, human errors are avoided while soil and site management is achieved.

• **Sensors and remote sensing :**

Parameters such as moisture content, soil nutrients, soil compaction, and possible crop infections are collected from distanced sensors usually installed on mobile machines to assess soil and crop status. Many farmers across Europe already utilizes several sensors (thermal, optical, mechanical and chemical) for capturing variations in climatic conditions, soil and crop properties and status so as to quantify accurately crop biomass, fertilization or pest application.

• **Future autonomous agricultural robots**:

These robots will utilize electricity power produced at the field and will be able to reconfigure their own architecture to perform various tasks offering an enormous potential for sustainability: Their weight will minimise soil compaction due to their lighter weight.

Future autonomous agricultural robots will be also permanently situated on the field area in order to function only where they are needed. Robots will optimize inputs used by farmers (fertilizers, pesticides, insecticides) and reduce the impact on soils and water tables.

1.1.5 Current challenges of PA sensing applications :

Crop infestation, biotic and abiotic stresses and lack of the adequate monitoring tools, are responsible for affecting negatively yield prediction, consequently leading to low productivity, crop quality and safety. For this reason, a framework in which smart sensors are combined with intelligent decision support software should be developed in order to enable efficient agricultural production management through real-time error detection technology, crop condition monitoring, automation and product quality assessment. Moreover, the combination of sensor fusion and novelty detection provides situational awareness and automation in several types of monitoring.

The central milestones for automation and crop sensing monitoring include:

1. Determination of fault detection architecture, algorithms requirements and specifications for the development of monitoring systems in decision-making support and automation frameworks that meet the principles of PA.

2. Development of situational framework recognition based on information fusion for agricultural production.

3. Development of technical innovation in detecting abnormal situations in several agricultural processes.

4. Health oriented crop-monitoring application by using non- contact optical sensors for achieving online continuous operation.

5. Agricultural products monitoring through non-destructive detection for guaranteeing quality or measuring yield.

6. Implementation, evaluation and decision support systems applications for an efficient control at early stage.

To address the above challenge there have been introduced a number of sensor technologies specialized in aiding and contributing into several agricultural conditions which affect a variety of factors, including crop yield, soil properties and nutrients, crop nutrients, crop canopy volume and biomass, water content, and pest conditions (disease, weeds, and insects), consequently concerning crop status and management.

These sensor technologies are given as follows:

1.Sensors for Soil Analysis and Characteristics. 2.Yield Sensing. 3. Sensors for crops and fruits assessment. 4. Sensors for weed management. 5. Sensors for disease detection and classification.

1.2 Sensors for soil analysis and characteristics:

There are several sensing methods investigated for soil nutrients and other characteristics assessment such as Near Infrared Radiation (NIR) and Raman spectroscopy, spectral libraries, electrodes, thermal imaging, fluorescence kinetics, and electromagnetic radiation (microwaves).

1.2.1 Visible (VIS)/NIR Spectroscopy:

Advances in the spectroscopy field have brought about novel approaches for determining the chemical elements concentration. Ultraviolet (UV), VIS and NIR reflectance spectroscopy belong to the most common techniques. The main advantage of these techniques lays on their ability to assess soil properties in a fast and non-destructive way.

Soil organic matter (SOM) is one of the initially investigated soil properties soil fertility due to its strong correlation to soil fertility and high affection to crop production.

Bowers and Hanks (1965) have also reported that soil moisture is inversely proportional to the reflectance and can be possibly assessed through reflectance measuring.

Soil organic carbon (SOC) content is regarded also a prominent constituent of SOM. Linear and PLS regression models (Vasques, Grunwald, & Sickman, 2008), NIR and fluorescence approaches (Rinnan & Rinnan, 2007), and spectral features (Bartholomeus et al., 2008) belong to the most common techniques utilized for determining SOC. Soil mineral-N was also investigated. Ehsani, Upadhyaya, Slaughter, Shafii, and Pelletier (1999) utilized PLS and principal component regression (PCR) models together with soil NIR reflectance for assessing soil mineral-N content in the range of 1100–2500 nm. The calibration models were proven quite robust. However, a site-specific calibration was essential when the models had not included some other interfering factors.

A soil moisture content determination approach using a NIR calibration equation has been reported Slaughter, Pelletier, and Upadhyaya (2001). High correlations between soil moisture content and NIR absorbance data were indicated when the calibration set and the unknown samples were of the same soil type and particle size. However, the model correspondence appeared to be low for unknown soil samples whose particle size differed. Moisture content is another important soil property. NIR spectroscopy is considered suitable for estimating soil water content due to the fact that there are concrete water absorption bands (960, 1410, 1460, and 1910 nm). Mouazen, Karoui, De Baerdemaeker, and Ramon (2006) presented the soil water content effect on other soil properties estimation with VIS and NIR spectroscopy. Three different classifiers off limited texture and color variation were utilized in order to form the validation data sets for assessing water content on soil, reaching an accuracy of 95%. Shibusawa et al. (1999) used a handheld spectrophotometer for estimating in real-time the underground soil reflectance in a range from 400 to 1700 nm. After being revised, the same soil spectrophotometer was used for collecting soil reflectance data in a paddy field in order to predict soil moisture, SOM and NO3-N content, EC, and pH. The R2 values between 0.54 and 0.66 were reported to form the validation samples.

1.2.2 Soil sensing using airborne and satellite imaging:

Airborne and satellite images have been utilized widely in several studies for the assessment of different soil properties. Baumgardner, Silva, Biehl, and Stoner (1985) managed to detect different soil properties via airborne and satellites based soil reflectance measurements. In this study, GIS has been surprisingly referred to a georeferenced information system instead of “geographic information system”. At this time, GIS was considered a newly introduced technology for soil data recording and monitoring. Soil P, soil organic matter and soil moisture (Muller & Decamps, 2000; Varvel, Schlemmer, & Schepers, 1999) have been indicated with the help of aerial imagery. Barnes and Baker (2002) utilized multispectral aerial and satellite imagery for soil textural class mapping development. The differentiation between field properties appeared to be responsible for worsening the spectral classification results. On the other hand, after spectral classification performed field-to-field, reasonable accuracy results were achieved. Later, Barnes et al. (2003) presented a soil properties assessment approach including electrical conductivity (EC), soil compaction, SOM and N levels by using both ground and remote sensing data. The synergy between physical and empirical models could form a highly sophisticated and effective method for collecting soil property information via airborne reflectance data. Moreover, the near infrared reflectance analysis was proven an useful approach not only for soil properties assessment but also for facing remote sensing challenges when different sensing methods are employed. It was also stressed that multispectral imagery integration and ground-based sensing data have the potential to provide soil maps of better accuracy. Ben-Dor (2002) demonstrated the soil quantitative remote sensing techniques, the sensors of high spectral resolution (HSR), the Soil-radiation interactions processes and the main factors that affect remote sensing.

1.2.2.1 Electrodes :

Electrodes use is regarded a relatively newly introduced method for soil properties detection. 1990s, Adsett and Zoerb (1991) measured nitrate levels in soil by using a ion-selective electrode technology. It has been reported that the filed nitrate content can be automatically monitored but the calibration process fails in case that the operating environment or the electrodes is not fully balanced. A different ion-selective electrodes (ISE) application for phosphate assessment was performed by Kim, Hummel, Sudduth, and Birrell (2007). Cobalt rod-based electrodes appeared to be more sensitive when the typical soil phosphorus concentration range increased. Kim, Hummel, Sudduth, and Motavalli (2007) expanded the previous study for measuring simultaneously soil macronutrients including N, K, and P. The NO3 ISEs demonstrated almost the same results to those from standard laboratory analysis (R2¼0.89). However, the standard laboratory analysis results demonstrated 50% than K and 64% higher concentrations than PISEs.

1.2.2.2 Microwaves:

Passive and active are two different techniques in microwave soil moisture sensing. Both methods remain unaffected by cloud cover and deliver highly trustworthy results when soil is barren or soil has low vegetation cover. The active technique is used for soil properties assessing, and has higher spatial resolution than the passive technique. A radar is required as a microwave source. The active technique is characterized by its high sensitivity to soil water content, surface, vegetation structure and soil geometry, making consequently soil water content hard to estimate. It is not affected by atmospheric conditions, solar radiation, cloud presence and rain spraying. Sensors in agriculture 9 The passive technique, it is more often used than active microwave sensing technique, due to its lower sensitivity to soil surface roughness and geometry, and vegetation structure. There is no signal source needed as microwave source. Moreover, it provides higher temporal resolution than the active method. Njoku and Entekhabi (1996a, 1996b) described basic principles of soil moisture passive microwave remote sensing. It was proven that the soil thermal microwave radiation emission was closely connected to soil moisture content.

1.3 Yield sensing:

Yield maps are useful for depicting the overall yield variability, consequently offering useful insights for improving management practices. The mapped variation in yield and crop quality depicted by yield maps envisages to the optimal profitability. For avoiding profit loss from unexpected events and optimizing inputs in intensive agricultural systems, the administration of inputs such as water, fertilizers, and pesticides for plant protection is required to be optimally controlled according to the crop needs. A useful tool for estimating the crop needs regarding nutrients and water content is Vis-NIR reflectance spectroscopy, which is used for mapping plant growth progress indicated by plant biomass, the levels of chlorophylls. Crop yield is regarded the most valuable information in precision agriculture. It is a fusion of several factors with complex dynamics including soil properties, terrain features, crop intensity, and nutrient and health plant status. A yield map can be used for deriving site-specific management practices combined with crop stress information (Searcy, Schueller, Bae, Borgelt, & Stout, 1989). Remote sensing maps obtained during growth, enable both with-in and after-season management. Vegetation indices (VIs) resulting from multispectral remote sensing are already used as a standard method for crop yield mapping (Yang & Everitt, 2002). These VIs result from ratios of visible and near-infrared (NIR) narrow wavebands. eNIR/Red ratio and normalized difference vegetation index (NDVI) are two standard VIs (Rouse, Haas, Shell, & Deering, 1973). A common index with wide applicability is soil-adjusted vegetation index (SAVI) (Huete, 1988). Other Vis such as NIR/Green and green NDVI (GNDVI) have been employed for yield prediction (Yang, Wang, Liu, Wang, & Zhu, 2006). Without doubt, there is wide remote sensing research on several annual crops; however, in the case of specialty crops (fruits and vegetables) remote 10 Intelligent data mining and fusion systems in agriculture sensing finds limited use due to the discrete crop character and the complex crop geometry. Koller and Upadhyaya (2005a, 2005b) developed a model for predicting processing tomato yield utilizing. Leaf area index (LAI) and a modified NDVI. Their results demonstrated similar tendencies between the actual and the predicted yield maps. Partial least squares (PLS) regression models were utilized by Ye, Sakai, Manago, Asada, and Sasao (2007) for yield prediction in citrus trees. In this study, canopy features were extracted from airborne hyperspectral imagery and they were compared with vegetation indices. The hyperspectral features, combined with PLS models successfully predicted citrus yield (R2 ¼0.51–0.90). Ye, Sakai, Asada, and Sasao (2008) also correlated particular canopy features obtained by airborne multispectral remote sensing to the yields of citrus trees. They found a significant correlation between the spectral responses of mature leaves and the yield of the current season.

The spectral characteristics of the younger leaves were correlated to the yield of the next season. Airborne images can be fused effectively with sampled ground truth information providing interpolated reference data and Machine Learning models providing a statistical an alternative for yield mapping and prediction.

The timing of remote Sensing for predicting yield is important because growth stages at which the estimation can bear a faithful and trustworthy model depends on the growth dynamics of each individual type of growth. Yield variability patterns and homogeneous management zones with a similar yield tendency as correlated to spectral features from airborne remote sensing are useful at different stages during growth and after harvesting. The yield prediction of specialty crops is still at an early stage of development and there is a need to carry research on new techniques based on remote and proximal sensing. Research results indicated that hyperspectral remote sensing features carry more information than multispectral features as related to yield prediction.

1.4 Sensors for weed management:

Weed identification can be a result of proximal sensing obtained from ground vehicles and remote sensing from unmanned aerial vehicles (UAV) or satellites. Sensors combined with Machine Learning algorithms can provide a real-time platform detection for identifying and mapping crop type, land cover, and particularly weed patches in order to enable targeted chemical or mechanical treatment in a site-specific management regime. Sensors in agriculture Detection and identification of weed species via machine imaging systems is applied simultaneously with crop-health sensors based on fluorescence, thermal infrared cameras and ultrasonic mapping. Advances in imaging spectroscopy has been further expanded to the detection of fungal infection in arable crops, enabling selective harvesting, and contributing to the concentration of harmful mycotoxins reduction (Gebbers & Adamchuk, 2010).

1.5 Sensors for disease detection and classification:

For sustainable intensive crop production, inputs are required to follow certain environmental regulations. Pesticides are applied in uniform dosages in fields, whilst most diseases appear in patches. Large ecological and financial benefits are expected to occur if site-specific management treatment would be applied only to the infected areas and adjusted to the specific plants nutritional need.

Based on the effect of disease and nutrient stresses on spectral plant properties, an optical sensor would recognize and control disease symptoms and nutrient demands. There are sensor system including multispectral, hyperspectral sensing and chlorophyll fluorescence kinetics, capable of providing high-resolution data about crop condition (Mahlein, Oerke, Steiner, & Dehne, 2012).

The effective combination of sensor equipment with advances in Machine Learning and GIS systems offer new prospects to precision agriculture, are the requirements for early stage recognition and identification of different types of pests .

The data quality and quantity derived from crop sensing has radically increased. They are not predicting physiological responses directly, but obtain a spectral feature, which is combined of several biochemical and structural properties for the plant and environmental circumstances often related to lighting conditions and leaf geometry. These sensor data are highly intercorrelated, depend on several heterogeneous factors so their interpretation necessitates the utilization of advanced Machine Learning, and signal processing techniques. The spatial distribution of disease symptoms and stresses can be obtained by UAVs.

The Current commercial satellite sensing is too coarse in terms of spatial resolution since most disease symptoms are very fine grained to allow early detection. On the other hand, satellite images can be useful by detecting relatively large infected or nutrient stressed areas, which can then be inspected by the farmer. However, several constraints related to availability of satellites at certain places and the invisibility due to meteorological conditions variability could lead to intermittent of remote sensing information. Airborne systems are more effective for obtaining remote sensing information compared to satellites due to customized availably.

Canopy spectral characteristics are affected by nitrogen status and other stress factor like diseases and water stress, which can cause a spatial variation of spectral characteristics. Crop diseases affect not only crop appearance and its nutritional content, but also is capable of decreasing crop quality in such an extent that can consequently induce health problems. There has been an increasing occurrence of fungal disease spread, degrading global food production and safety due to related mycotoxin risks (Fisher et al., 2012). Since mycotoxin presence depends on the species of fungus, the fungus mapping can be used to obtain a map of mycotoxin risk. By mapping the fungal presence in real-time based on symptoms detected by sensors it is possible to allow the construction of application map. More specifically, in arable crops, leaves or ears of grain show symptoms of senescent, which are symptoms of fungal infection. These symptoms develop earlier on infected plants compared to healthy plants. However, the differences are clearer between an infected and a green canopy, while at later stage of disease progress the causal relation between disease and the senescent is not evident. This situation leads to the need to obtain more specific information related to the temporal development of symptoms in order to recognize the context of the health status in order to obtain custom multisensory or meteorological information to facilitate decision support for optimal crop handling according to real inflection risk