Chapter 15

Plant Optics: Counting Photons to Inform Plant Productivity, Stress, and Resilience

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Agriculture has played a significant role in the development of civilization. The agricultural industry produces food, beverages, clothing, and building materials used in the home. In traditional farming methods, substantial manual labor is required to cultivate crops, and this method is unable to meet the ever-increasing demands of mankind. Therefore, it is imperative to investigate the possibility of implementing cutting-edge technologies in agricultural production, particularly in crop cultivation and harvesting. The effectiveness of technologies related to optics and photonics has been demonstrated in this regard. Plant tissues are studied using optical spectroscopy, and crops are diagnosed and biotic and abiotic stresses are investigated with optical spectroscopy. The physiology of photosynthetic biofilms can also be assessed remotely and without invasive methods such as spectral methods. A further benefit of these methods is that they can be used to examine the impact that various plant species have on biodiversity and ecosystem stability from a distance. The field of plant science and agriculture has recently received a great deal of attention with regard to optical spectroscopy. This is primarily due to the development of high-throughput plant phenotyping technologies and the demand for quick and non-contact productivity evaluations. This chapter discusses the scientific and technological foundations of optical spectroscopy, as well as the main applications and techniques. Light-based spectroscopy will be affected by all of these factors in the future.

Keywords: *Agriculture, spectroscopy, plant species, biodiversity*

INTRODUCTION

Light constitutes a collection of particles known as photons, propagated in the form of waves [1]. In physics, light often relates to radiation in the entire electromagnetic spectrum, encompassing X-rays, ultraviolet, visible light, infrared, and microwaves among others [2]. The unique electromagnetic properties of light have intrigued academics across the globe and the earliest study can be traced back to the early 17th century [3]. As time passes, the accumulation of knowledge and technological advancement have gradually shaped the canvas for light-related research, leading to the establishment of the field of optics and photonics.

Optics can be defined as a branch of physics that studies the behavior and properties of light as well as the interaction of light with other matter [2]. Meanwhile, photonics can be regarded as the application of light through the systematic generation, control and detection of photons [2,4]. Despite the distinction between optics and photonics, both terminologies have often been used interchangeably in the literature to collectively represent the science and application of light [1].

Optics and photonics have influenced various engineering applications, transforming the landscape of various fields and improving the lives of mankind. One of the main applications of optics and photonics can be seen in the field of communications. Knowledge of optics and photonics has been used to develop optical fibers which help to cater for the needs of broadband Internet service in this “data hungry” era. Furthermore, optics and photonics have been used in the manufacturing of modern displays such as liquid crystal display (LCD), organic light-emitting diode (OLED), flexible display and such. Solar cells for energy harnessing too illustrate another application of optics and photonics. Not least, optics and photonics have also been applied in more sophisticated areas such as security surveillance, medical imaging, quantum computing and more [1]. Amidst the modern and complex solutions discussed earlier, it often slipped our minds that optics and photonics can be readily integrated into the field of agriculture. The simplest examples would be the adjustment of plantation direction for optimum sunlight exposure, as well as the usage of incandescent light bulbs in egg incubation and hatching [5,6]. Over recent decades, academics have been alerted to the potential of optics and photonics in the agricultural industry. This has led to progressive developments that utilize optics and photonic techniques in maximizing the quality and productivity of agricultural products.

This chapter aims to review some of the most popular optics and photonic techniques in agriculture, namely imaging, spectroscopy and spectral imaging. In addition, existing applications of each technique in the agricultural industry will also be compiled. A comprehensive discussion will also be made to gauge the potential of exploiting optics and photonic techniques in the agricultural sector with the intention of improving the quality and productivity of the agricultural products at a reduced labor cost.

2. A BRIEF REVIEW OF OPTICS AND PHOTONICS IN AGRICULTURE

From our knowledge about the photosynthesis process, and the miniaturization of laser diodes, light emitting diodes (LEDs), and photodetectors, selected wavelength light sources and the associated photodetectors can be used to find weeds [7], to control the growth rate of plants [8], and to inspect the teat [9].

As highlighted in Fig.2, moving the wavelength light toward near infrared and infrared spectra leads to the analysis of fruit quality [10], soil nutrient contents [11], and heat stress management for poultry and viticulture [12-13]. One of the technical issues we have received from Thailand's sericulture industry is to identify the gender of the silkworm in order to help improve the breeding rate. Optical penetration-based silkworm sex identification that is suitable for silkworms in the pupa state [14-15]. Its current performance offers a high 95.6% accuracy. Another important issue is the way to efficiently count the number of tiny good eggs of silkworms. This process will help in analyzing the breeding process as well as in fairly selling the silkworm. The results of the silkworm eggs being counted based on image segmentation and centroid detection [16]. Current performance has reached 87.9% accuracy for 8,558 silkworm eggs under test.

It have also applied fluorescent imaging and spectral imaging analysis to non-destructively identify Thai jasmine rice (KDML105 rice species). The current developed system utilizes high energy light sources in the UVC spectrum and analyzes only the fluorescent spectral image at 545 nm wavelength via an artificial neural network, featuring a moderate accuracy of 80%.

It is not surprising now that the market of the smart mobile devices in the forms of a cellular phone and a tablet has been grown very rapidly. By realizing that the smart mobile device is actually a notebook computer equipped with additional sensors and communication components, it would be highly desirable if we could extend its functionality for agriculture. In this section, we will highlight some of our achievements. A digital microscope is an important tool in agriculture. It can be used to look for small pests and observe symptom of some plant diseases. The pecifically designed lens module that can be placed in front of any cell phone or tablet in order to convert it into a digital microscope [17]. Our lens module contains a molded 4-mm focal-length plastic convex lens located at the center of a transparent plate. With this simple tool, a small pest (e.g., thrips) moving inside an orchid can be easily observed and the density of leaf stomata can be analyzed. In today precision agriculture, the estimation of the ripeness level on any part of the fruit is necessary, leading to effective yield and logistics management. It is spatially analyze two broad spectral images of the fruit under white light and ultraviolet illumination [18]. With our proprietary algorithm, we can spatially and specifically classify the green fruit into three ripeness levels: immature, ripe, and overripe.

3. Classification of Photonics Systems in Agriculture

Quantity and quality have always been the primary foci in the field of agriculture. The governing of these attributes is anticipated to be more crucial in the upcoming years. This prediction is based on the constant increase in global population as well as heightened expectations for healthy food sources. However, the agricultural field faces great pressure under globalization. The transformation of the global economic landscape makes agricultural activities seem less profitable in contrast to other industrial activities. The outflow of the workforce makes it increasingly expensive and difficult to meet the demands of agricultural activities. As a result, modern technology has been integrated into the agricultural field to maximize output efficiency at minimum labor force. Similar to other industries, automation systems have been applied in stages of agricultural activities to reduce a dependency on manual labor [6]. These systems require optics and photonics techniques to complement them, providing the required ‘sight’ for operations. These vision requirements have been fulfilled by optics and photonic techniques such as imaging, and spectral imaging. These techniques provide machine vision at high dynamic range, high resolution and high accuracy in a non-destructive, non-contact and robust manner [5].

3.1 Imaging Technique

The imaging technique is analogous to the function of the human eye. It captures the image of the subject for necessary calculations and measurements before performing the final evaluations [19]. The imaging technique is essential for collecting spatial, color [6] and even thermal [20] information of the subject of interest. Therefore, imaging techniques are typically operated in an active manner. The active imaging technique involves image acquisition under two major light sources, namely visible light and infrared sources. Images under visible light can be easily acquired with any standard camera modules. On the other hand, images under exposure to infrared can be acquired with special infrared camera modules [20].

Image acquisition under visible light is similar to our daily photography. The image acquisition process under this light source is straightforward and images captured are usually rich in details and colors. However, complexity often arises while performing analysis on these images due to illumination variations. For instance, images captured outdoors vary under sunny and cloudy conditions. Meanwhile, images captured indoors is categorized by natural light, incandescent and fluorescent conditions [19].

The acquired image will then undergo pre-processing to convert it into an appropriate format before further analysis. Pre-processing tasks may include exposure correction, color balancing, noise reduction, sharpness increase or orientation change. Next, the process of feature detection and matching as well as segmentation is performed on the pre-processed image to extract the object or region of interest. Finally, the subject of interest is analyzed with proper analysis algorithms in the respective area of application [21].

The imaging technique can be easily applied in the simple analysis of static-positioned objects or even in more complex areas which involve moving targets, such as visual navigation and behavioral surveillance. These achievements were made possible by utilizing the spatial information acquired through the imaging technique for position triangulation and motion guidance [19,21]. In image processing, the computer imaging technique has been employed to create, edit, and display graphical images, characters, and objects. The computer image analysis technique is a broad field which consists of computer domains and applications in food quality evaluation [24,25], grading and the sorting of agricultural products [26,27], as well as harvesting the crops [28], and estimating moisture content in the drying stage for the storability of the food product [29]. Computer imaging contributes to the development of digital agriculture. For instance, weed detection and fruit grading systems with digital imaging techniques are cost effective systems in achieving ecological and economically sustainable agriculture [30].

3.2. Spectroscopy Technique

In contrast to the imaging technique, the spectroscopy technique enables the ‘sight’ of properties that are invisible to the naked eye. The spectroscopy technique functions by extracting spectral information from the sample of interest. The spectral information is obtained when light interacts with the composition of the sample. This interaction leads to changes in the intensity or frequency and wavelength of the initial light source, ultimately defining a spectrum which acts as the fingerprint of the sample [31].

Similar to the imaging technique, variations do exist for spectroscopy. These variations are categorized by the nature of interaction between the light source and the sample when the spectroscopy measurement is conducted. In the agricultural field, the commonly adopted spectroscopy techniques are ultraviolet-visible (UV-VIS) spectroscopy, fluorescence spectroscopy, infrared (IR) spectroscopy, and Raman spectroscopy [31].

4. Use of optical sensors combined with a GPS receiver to create maps

Maybe one of the most interesting applications for optical sensors in agriculture is to be able to use geographical coordinates to create maps from reflectance measurements. But why do that? Precision Agriculture is based on the fact that all fields have variability. Understanding this variability is first step to make decisions about investments in Precision Agriculture. Many procedures may be used to characterize and treat spatial variability on yield aiming profit for the farmers, but a wide and safe vision about the impact of the variability in a production system requires an accurate measurement of this variability.

Soil variability is caused by climate, topography, vegetation, soil forming processes and also management. These factors can influence the variability in different scales and cause great variability on nutrient availability in the soil. Then, when using uniform rates of fertilizers it is almost certain that excessive rates will be applied to some parts of the field and inadequate rates in others. Precision Agriculture can be defined as a management system that considers spatial variability that is present in a production field, independently of the size and treats locally this variability. It is well proved that quality and yield are spatially variable and systems are being developed to explore these variations and increase profit [32]. The variable rate application of fertilizers is one of the options to manage variability, and creating maps from optical sensors can help to realize variable applications with nitrogen.

An optical sensor connected to a GNSS (Global Navigation Satellite System) receiver is able to register reflectance values with a pair of coordinates (latitude and longitude), and when the file is imported to a GIS software (Geographic Information System) it is possible to represent the measurements and its distribution in a field with maps. Depending on sensor system used, that information can be stored in different ways and types of files. Some systems installed in agricultural machinery allow using a laptop with software that will store the sensor readings and coordinates. Other systems use their own data logger or a pocket pc. a raw data collected in a field. Each strip is around 24 meters from each other, but what looks like a line, actually are many dots very close to each other due the frequency used to collect the data in the field.

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