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A low cost sunlight analyser and data logger measuring radiation

M.J. Oates, A. Ruiz-Canales*, M. Ferrández-Villena, A. Fernández López

Engineering Department, Miguel Hernández University of Elche, Ctra. Orihuela-Beniel, Km 3.2, Orihuela 03312, Spain

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ABSTRACT

Growing conditions in the early stages of crop development can be critical to eventual yield. This is true for a wide variety of crops such as lettuce, maize and rice. These conditions include not only soil quality, moisture and temperature, but also the quality and duration of available sunlight. A simple measure of 'brightness' is however not a good indication of the true 'quality' of the sunlight available. Research has shown that the presence or absence of specific wavelengths of light (particularly infra-red (IR), red and blue) can significantly affect photosynthesis and hence crop growth. Further, over exposure of plant tissue to high levels of ultra violet radiation can prove damaging. IR radiation is known to be scattered by weak levels of cloud and haze, and is significantly absorbed by moderate cloud conditions, resulting in lower levels reaching the ground. Ultra violet radiation is capable of penetrating even moderate levels of cloud. The total amount of quality sunlight received by an immature plant can affect its later yield, determining whether a crop is worth harvesting, or influence the later use of fertilizers or the real time control of supplementary, wavelength specific illumination. This paper discusses results from a low cost, real time, stand-alone LED based sunlight analyser and data logger capable of making both quantitative and qualitative measures of specific wavelength bands, and distinguishing sunlight conditions ranging from direct sun, through light haze, moderate cloud and even moonlight. The unit costs less than 10 Euros and can give in excess of 4 months unattended monitoring and logging using 3 alkaline AA batteries, storing to an internal 32Mbit Flash EEPROM and transmitting via a 2.4 GHz RF link.

1. Introduction

There is a wide range of technologies applied to low cost new sensors in agriculture for different purposes. In the scientific literature, several examples can be found. Kim et al. (2017), have been employed different combinations of chromium carbide with two polymers for made high performance linear humidity sensors. The fabricated sensors are cheap, easy to fabricate, and are ideal to be used in high end environmental and health monitoring applications. Stajanca and Krebber (2017), evaluated the performance and potential of commercial perfluorinated polymer optical fibers (PF-POFs) for radiation monitoring applications. In the cited work was demonstrated that a cheap and disposable sensor can be used for distributed detection of radiation with doses down to tens of grays. A low-cost biophotonic sensor shaped by way of cheap processes as hybrid silicon/silica/polymer resonators was developed by Li et al. (2017a). This device is capable to detect biological molecule gel/fluid phase transition as lipids at very low concentration. This is an adequate low thermal resonance method for substituting the expensive technologies of electron-beam lithography. A case study of providing to farmers a tool for monitoring the crop state in TV screen using a low cost device with temperature, solar radiation, soil moisture, pH and wind was presented by Villarrubia et al.(2017). In this way, a cheap intelligent system for measuring temperature and humidity using the based in RF wireless transmission was implemented by Rusia et al. (2016). For the study of the heterogeneous household air pollution (HAP) concentrations and exposures factors influencing them, a relatively inexpensive a suite of relatively inexpensive, rugged, battery-operated, microchip-based devices has been developed. This suite includes two generations of particle monitors; data-logging temperature sensors to assess time of use of household energy devices; a time-activity monitoring system using ultrasound; and a CO_2-based tracer-decay system to assess ventilation rates. (Pillarisetti et al., 2017). Cheap devices for analyzing the air quality, using a set of gas semiconductor sensor and an IR particulate matter sensor have been designed by Gugliermetti and Garcia (2017). Moreover some Big Data tools are integrated for harvesting, storage and data analysis that were generated by a sensor's network based in Arduino's kits (Ríos and Diéguez, 2016). A new smart voltage and current monitoring system (SVCMS), using an Arduino® platform with a cheap microcontroller for data gathering by means of a wireless sensors was designed by Mnati et al. (2017).

In the other hand, maximising the efficiency of photosynthesis is critical to the enhancement of crop yield and the improvement of crop

* Corresponding author.
E-mail address: acanales@umh.es (A. Ruiz-Canales).

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characteristics such as colour and flavour (Davis and Burns, 2016; Ilic et al., 2015; Cao et al., 2014; Neocleous et al., 2014). To optimize photosynthesis requires a detailed understanding of the process, monitoring of current growing conditions and real-time management of both the quality and timing of supplementary illumination. By using sensors able to measure the strength of specific wavelength components of the available sunlight, it is possible to determine in real time which wavelengths of supplementary illumination are required to optimise specific crop characteristics. Photosynthesis process is characterized by relating the use of water, carbon dioxide and sunlight energy, in order to produce carbohydrates and oxygen. Simply, natural photosynthesis is the process by which sunlight is absorbed, transferred and converted into the energy of chemical bonds of organic molecules that are used for building up the body of all living organisms (El-Khoulya et al., 2017; Janka et al., 2016).

Photosynthesis occurs in two stages. In the first stage, light-dependent reactions or light reactions capture the energy of light and use it to make the energy-storage molecules Adenosine triphosphate (ATP) and Nicotinamide adenine dinucleotide phosphate (NADPH). During the second stage, the light-independent reactions use these products to capture and reduce carbon dioxide.

In the light-dependent reactions, one molecule of the pigment chlorophyll absorbs one photon and loses one electron. This electron is passed to a modified form of chlorophyll called pheophytin, which passes the electron to a quinone molecule, starting the flow of electrons down an electron transport chain that leads to the ultimate reduction of Nicotinamide adenine dinucleotide phosphate (NADP) to NADPH. In addition, this creates a proton gradient (energy gradient) across the chloroplast membrane, which is used by ATP synthase in the synthesis of ATP. The chlorophyll molecule ultimately regains the electron it lost when a water molecule is split in a process called photolysis, which releases a dioxygen (O_2) molecule as a waste product.

The overall equation for the light-dependent reactions under the conditions of non-cyclic electron flow in green plants is (1):

$$2H_2O + 2NADP^+ + 3ADP + 3Pi + light \rightarrow 2NADPH + 2H^+ + 3ATP + O_2 \quad (1)$$

Not all wavelengths of light can support photosynthesis. The photosynthetic action spectrum depends on the type of accessory pigments present. For example, in green plants, the action spectrum resembles the absorption spectrum for chlorophylls and carotenoids with absorption peaks in violet-blue and red light. In red algae, the action spectrum is blue-green light, which allows these algae to use the blue end of the spectrum to grow in the deeper waters that filter out the longer wavelengths (red light) used by above ground green plants. The non-absorbed part of the light spectrum is what gives photosynthetic organisms their colour (e.g., green plants, red algae, purple bacteria) and is the least effective for photosynthesis in the respective organisms. In summary, there are several light-dependent reactions in the Photosynthesis. The measurement and control of the sun light can help the monitoring of the crop during all the growing seasons.

This has been shown to be at least a three step process. The photosynthesis process is primarily performed by two kinds of Chlorophyll: 'a' and 'b', which absorb violet-blue and red light respectively. However neither absorbs photons with wavelengths between about 500 and 600 nm, which are reflected as green. Chlorophyll *a* is the main photosynthetic pigment and is the only pigment that can act directly to convert light energy to chemical energy. In Photosystem II, the absorption peak is approximately 680 nm, whilst the absorption peak of Photosystem I pigments in plants is 700 nm. These two photo-systems work together to carry out a non-cyclic electron transfer. When the rate of photosynthesis is measured using two light beams of different wavelengths (one red and the other far-red), Emerson and Lewis (1943) demonstrated that the rate was greater than the sum of the rates using individual beams of red and far-red light. This is called the enhancement effect. Thus it is clear that it is the combination of different wavelengths that is critical for efficient photosynthesis (Senol et al., 2016; Baba et al., 2012). Westlake demonstrated a wide range of factors affecting plant productivity (Westlake, 1963). For some crops it is not optimal to irrigate during full sunlight conditions. For others, especially those grown under glass and when ripening, it can be beneficial to ensure minimum brightness levels by artificial means when natural light conditions are insufficient. Conversely, it may be beneficial to provide artificial shade to some crops when natural light conditions become too intense or persist too long. For some crops, the presence of moonlight (Aissaoui et al., 2016; Bayani and Watve, 2016) can be either beneficial or harmful due to increased likelihood of pollinators or their predators (for example bats and moths) (Lewanzik and Voigt, 2017; Proctor et al., 1996; Buchmann and Nabhan, 1996). Detection of such conditions can lead to more efficient application of pest control and pollinator support systems (Xiao et al., 2017; Shepherd et al., 2003), be these chemical, auditory or mechanical.

Further, specific weather and temporal conditions also exhibit individual distributions of light spectra (Deng et al., 2016; van Ieperen, 2016; Sanchez et al., 2015; Rodionov et al., 2015) and thus recognition of these distributions can lead to real time, optimized use of crop management resources such as irrigation, artificial illumination, heating and shade management.

Yield prediction techniques (Amodio et al., 2017) are an increasingly important tool in Agronomy. Unexpected crop failure or poor harvest can have devastating effects on subsistence communities, and have severe financial impact to commercial growers. This in turn leads to greater risk and uncertainty, increasing agricultural insurance premiums (Castañeda-Vera et al., 2015), affecting futures markets (Theurl et al., 2017; Zhang et al., 2017), as well as encouraging over-use of fertilizers, pesticides and irrigation (Wagner, 2004). Many yield prediction algorithms are based on remote sensing data obtained from NDVI data from satellites (Bai et al., 2016; Tatsumi et al., 2015; Soria-Ruiz et al., 2004), which whilst useful at estimating biomass and crop health over large areas (Ul-Haq et al., 2017), are subject to noisy data based on climatic conditions, in particular cloud cover (Wu et al., 2015; Huang et al., 2013). Growth models tend to be based on early stage crop development such as 'R1' silking in corn (Mourtzinis et al., 2013) or plant height at V6, V10, and V12 (6-, 10-, and 12-leaf, respectively) growth stages (Battilani et al., 2013; Yin et al., 2011) in which yield is extrapolated based on specific growth in the first few weeks after germination.

Such models incorporate a range of factors including soil types, terrain, climate, farming practices, meteorological data and statistical models (Coopersmith et al., 2014; Lobell and Burke, 2010). However as photosynthesis is critical to plant growth, and meteorological conditions are on the whole uncontrollable, it is often the amount of usable sunlight that is crucial to healthy crop development and prediction accuracy (Agarwal et al., 2001; van Straten et al., 2000). Photosynthesis has been shown to be at least a three-step process (Teal, 1990) involving specific wavelengths primarily in the IR sub-spectrum (Senol et al., 2016; Raven and Johnson, 2001). The combined levels of these wavelengths can significantly affect plant growth (Emerson and Lewis, 1943). Further, the daylight conditions also play a crucial part in the development and activities of pollinators and pests (Bankestad and Wik, 2016; Shepherd et al., 2003) which also have a strong influence on crop yield (Zhang et al., 2015; Buchmann and Nabhan, 1996). A simple, broad spectrum measurement of light intensity does not provide sufficient information to be able to determine specific daylight conditions as different wavelengths of light are affected in different ways by climatic conditions (Janka et al., 2016; Wiscombe et al., 1984). For example, IR light is dispersed by haze and light cloud (Dursun and Ozden, 2014; Bantges et al., 1999) whilst UV light can penetrate even moderate cloud conditions (Romer et al., 2011; Li et al., 1995; Hayasaka et al., 1995). Many crops (for example Soya bean, pea, spinach, etc.) do not thrive well if over exposed to either intense or prolonged sunlight conditions