# An Investigation Into the Use of a Low-Cost NIR Integrated Circuit Spectrometer to Measure Chlorophyll Content Index

**Nguyen Minh Trang, Tran Khac Duy, Tran Thi Ngoc Huyen, Luong Vinh Quoc Danh, Anh Dinh**

***ABSTRACT--- Crop yield is directly affected by the plant macronutrients, mainly Nitrogen (N) and Phosphorous (P) status. Growers must determine when to apply N fertilizer as the nitrogen deficiency leads to lower yield and economic lost. Chlorophyll meter has been used for years to find the correlation between the leaf chlorophyll content and the plant nitrogen status, hence the demand of N in the field during growing cycle. In general, chlorophyll meters are expensive even these handheld devices are built for ease of use. This work investigates the feasibility of the development of a very simple sensor device which uses extremely low-cost, off-the-shelf optical components to measure chlorophyll content in the leaf. The heart of the device is the AS7263 6-Channel Near-Infrared Spectral ID device made by AMS. The sensor prototype was built and tested. Preliminary results show a promising device which is very low cost, simple, low maintenance, and easy to use in the field to support rice growers to measure and monitor CCI and determine the need for nitrogen in the growing cycle.***

***Keywords- chlorophyll content index meter, near-infrared spectrometer, low-cost sensor***

## I. INTRODUCTION

Chlorophyll (CL) was first isolated and named in 1817 by Joseph Bienaimé Caventou and Pierre Joseph Pelletier. Chlorophyll is a green pigment, present in all green plants. Seen through a microscope, chlorophyll is concentrated within organisms in structures called chloroplasts. The function of the reaction center of chlorophyll is to absorb light energy and transfer to other parts of the photosystem [1]. CL in the leaf is strongly related to the Nitrogen (N) status of the plants. It has been known that monitoring N status of the crop is equivalent to the crop N management. Well nitrogen management, is not only economically benefits to the growers, but also good for the environment and the soils. Measuring and monitoring the chlorophyll in the leaves is very important to the growers as they can schedule fertilizer in the most efficiently way in the growing cycle [2,3,4]. By measuring the absorption of light in the red and far red regions, it is possible to estimate the concentration of chlorophyll within a leaf.

Scientists and growers use chlorophyll meters (CM) to measure CL in the leaf. Most CMs determine relative leaf CL content, called chlorophyll content index (CCI), by measuring absorbance and transmittance, by the leaf, of red radiation, which CL absorbs, and near infra-red (NIR) radiation, which CL transmits [5,6]. Higher value of CM readings are resulted from the increment in absorbance of red radiation by the chlorophyll. Transmittance-based meters are most common in commercial CM and one of them is the SPAD-502 meter (Konica Minolta, Japan). Some other CMs are based on fluorescent principle. Other characteristics of CMs are the wavelengths they use (Table I) and the calibration equations the meters use to convert electrical signals into measurement units.

The red radiation absorption of chlorophylls a and b is approximately at 650 nm as shown in Fig. 1. As seen, the high absorption rate of both chlorophyll a and b is in the 2 regions of the visible spectrum, i.e., the blue color and the red color. The authors in [3] have concluded that for leaf CL estimation, the Chlorophyll Content Index measured with the MC-100 meter was the most effective of the four sensors examined because it had the most accurately estimated leaf CL content and it had no saturation response at higher leaf CL content. The capacity of measuring high leaf CL contents without a saturation response is an important consideration for the practical use of CMs. In general, CMs are expensive even they are built portable and easy to use. Using these type of meters can facilitate on-the-spot accurate N determinations.

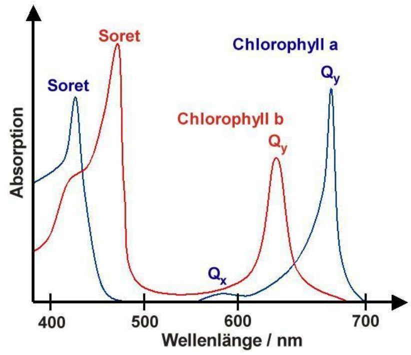


**Fig. 1. Chlorophyll spectrum [7]**

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Fig. 2 shows the principle of Soil Plant Analysis Development (SPAD) system to measure CCI. The SPAD meter determines the relative amount of chlorophyll present by measuring the absorbance of the leaf in two wavelength regions (653nm and 931nm). SPAD is the most popular CMs in the market and it has been used widely in academic and industries [8,9]. Increasing SPAD values indicates higher concentrations of CL per leaf unit area. As shown in Table I and Fig. 1, the transmit spectrum of chlorophyll is in the infrared region, it is not restricted to the 931nm wavelength.

**Table I: Characteristics of leaf chlorophyll meters [3]**

| Device | Measuring principle | Wavelengths (nm) | Units |
|---|---|---|---|
| SPAD-502 | Transmittance | 650, 940 | SPAD units |
| atLEAF+ | Transmittance | 660, 940 | atLEAF units |
| MC-100 Chlorophyll Concentration Meter | Transmittance | 653, 931 | CCI |
| MULTIPLEX | Fluorescence | 635, 685, 735 | SFR_R |
| MULTIPLEX | Fluorescence | 516, 685, 735 | SGR_G |

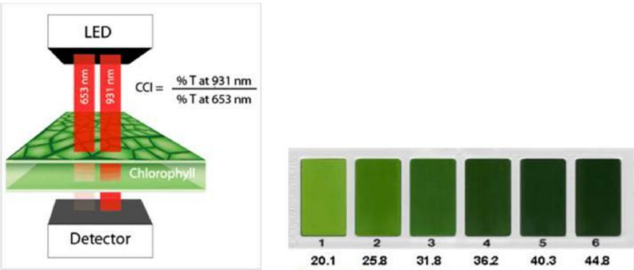


**Fig. 2. CCI measuring of SPAD [4]**

Power supply to the sensor is provided by the Raspberry Pi. As seen in Fig. 3, the white light passes through the leaf sample and enters the opening of the sensor. Optical components in the sensor breakdowns 6 wavelengths which strike on the photodetectors and the photodiode voltages are processed and converted into light intensities.

Raspberry Pi (RP) is a common single board computer. The RP has ample computing power and peripherals for many practical applications including IoT and embedded systems. In this sensor prototype, the third model of RP is used to provide power to the sensor and establish communication link to the AS7263.

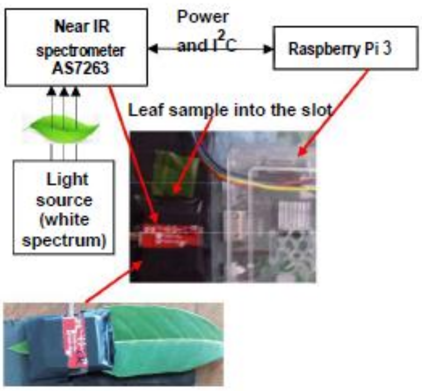


**Fig. 3. System overview and device prototype. Leaf samples are to be placed in the slot between the light source and the spectrometer.**

## II. SENSOR DESIGN

The proposed prototype system consists of two main parts as shown in Fig. 3. Photograph of the designed prototype is also included in the figure. The first section is the sensing and the second is data collection. The most important component of the system is the compact, low cost, advanced technology system-on-chip spectrometer, the AS7263 made by AMS [10]. This highly integrated device delivers a 6-channel multi-spectral sensing in the near-infrared wavelengths from approximately 610nm to 860nm with full-width half-max of 40nm as shown in Fig. 4. An integrated LED driver with programmable current is provided for electronic shutter applications. Control and spectral data access is implemented through either the I²C register set, or with a high level AT Spectral Command set via a serial UART [10]. In this design, the I²C communication between the spectrometer and the Raspberry Pi is used for controlling the spectrometer and data collection. A 3.3V DC

Every second, the VIS spectrometer AS7262 sends 3 sets of 6 numbers representing the amplitude of 6 channels in the NIR spectrum. The RP is programmed (in Python) to receive and save data into a file (in Exel format) while the sensor is in operation. Data files are then transferred to a computer for viewing and processing. Processing data provides 6 levels of the spectrums in NIR which the leaf sample partially absorbs or partially passes through.

The chlorophyll in the leaf sample absorbs red light and passes the NIR spectrum. The white light source provides these spectrums to leaf sample. The useful measurements from the spectrometer are the intensity of "red" and other 5 channels in the NIR region.

## III. EXPERIMEN RESULTS

The prototype was built and tested. A white LED is turn on to provide a wide spectrum of the light, the light passes through the sample and is detected by the spectrometer through its opening. The amplitude of each channels depends on the level of absorption/transmission of the sample to specific wavelengths. The spectrometer measures the intensity of 6 channels and sends data to the RP.

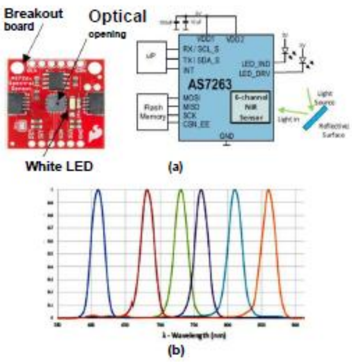


**Fig. 4. (a) The NIR spectrometer AD7263: breakout board and block diagram to be used with Raspberry Pi, (b) AD7263 typical optical characteristics (normalized intensity) [10]**


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Fig. 5 shows an example of the measurement results (absorption/transmission) of the tests on leaf samples. As seen on the "No sample" plot, without the leaf sample in the slot, the spectrometer receives the full intensity of its NIR spectrum. After the leaf sample was inserted into the slot, chlorophyll and other substances inside the leaf partially absorb these spectrums and the spectrometer values are much lower. Higher absorption by the leaf results in lower number of photons strike on the photodetector. Now the experiments focused on the absorption of the leaf samples to all the 6 channels. From the collected data, transmission rates and CCI were calculated using the following equation:

$$\frac{\%}{\%} \quad (1)$$

where T is transmission rate:

$$\% \quad \frac{}{} * 100 \quad (2)$$

In each type of the leaves, the number of data was 400, averages were used and listed in Table II. Standard division was also examined to see the distribution of the collected data to ensure the data were valid.

**Table II. CCI at 5 different wavelengths on 7 different types of leaf sample**

| Type of leaf samples (Series) | CCI | | | | |
|---|---|---|---|---|---|
| | 680nm | 730nm | 760nm | 810nm | 860nm |
| 1. old leaf | 0.28 | 1.17 | 0.28 | 1.21 | 1.07 |
| 2. full grown leaf | 0.29 | 2.02 | 1.33 | 2.41 | 2.05 |
| 3. juvenile leaf | 0.25 | 0.74 | 0.44 | 1.27 | 1.20 |
| 4. full grown rice leaf | 0.24 | 0.96 | 0.50 | 1.37 | 1.23 |
| 5. juvenile rice leaf | 0.18 | 0.21 | 0.25 | 0.91 | 1.17 |
| 6. old leaf (red color) | 0.26 | 0.07 | 0.07 | 0.58 | 1.06 |
| 7. full grown (same tree with red color old leaf) | 0.10 | 0.22 | 0.22 | 0.92 | 1.19 |

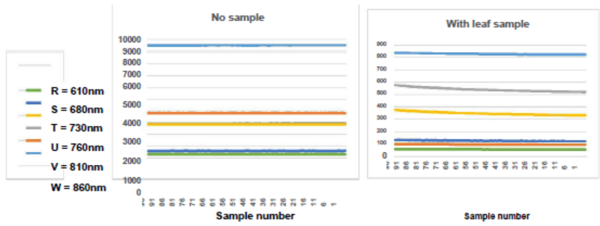


**Fig. 5. Absorption/transmission NIR spectrum of no-sample and of leaf-sample showing partial spectrum are absorbed by the leaf sample**

Fig. 6 displays the measurement results listed in Table II. By observation, the 810nm wavelength provides the highest CCI. The 680nm wavelength has very low CCI because chlorophyll a absorbs this spectrum as shown in Fig. 1. The wavelength 760nm also has a low CCI because there are certain substances in the leaves absorbs the energy in this spectrum. The last wavelength 860nm doesn't provide the consistent trend for all the leaves.

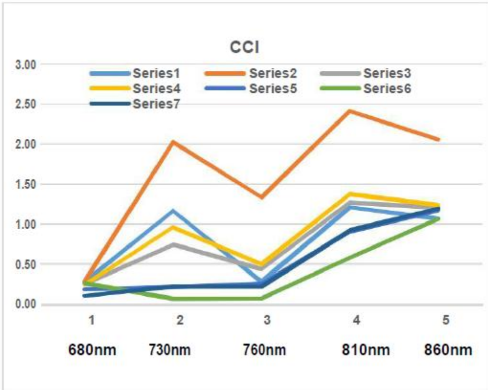


**Fig. 6. CCI measurements of 5 different wavelengths on 7 leaf samples**

## IV. CONCLUSION AND FUTURE INVESTIGATIONS

The results from the work confirm the feasibility of using low-cost near-infrared spectrometer to measure chlorophyll content index in the leaf. The results also indicate that the wavelengths used for absorption/transmission of the meter are not restricted to the wavelength longer than 900nm as it is used in commercial devices. For the AD7263 spectrometer, the proposed wavelength used is the V wave (810nm) for transmission and the R wave (610nm) for absorption in equation 1 to calculate CCI. This highly integrated device can be easily interface to smart phones or embedded systems to measure CCI. The conversion from CCI of this device is to be investigated in the future to make it comparable to the SPAD units.

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