ISSN XXXX XXXX © 2018 IJESC

Research Article Volume 8 Issue No.5

Chlorophyll Content Meter Instrumentation Using Raspberry Pi System on Chip & Camera Detector

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Abstract:
Estimation of chlorophyll content in the leaves can be a potential indicator of the plant's vigour and yield. Methods of estimation of chlorophyll in plant leaves through destructive sampling are available, but they are laborious and time-consuming. Devices like Chlorophyll Content Meter (CCM), which measure the chlorophyll concentration of green leaves in a non-destructive manner, using transmitted radiation through the leaf chlorophyll, are available, but are prohibitively costly. Development of a cost-effective, indigenous version of CCM is very promising, keeping in view, its potential utilization in crop condition assessment and yield estimation. Towards achieving this goal, efforts are taken to develop a Chlorophyll Content Meter (CCM) and calibrate the instrument with respect to imported, commercially available device (CCM-200). A comparative analysis of the observations collected from this device with those taken by CCM-200 have shown the calibration results to be in close agreement (R^2 =0.85).

Index Terms: Absorption, assessment, Camera, Chlorophyll, CCI, crop condition , device, embedded, field, greenness, leaf, meter, NIR, pi, raspberry, reflectance**,** transmittance, vegetation.

I.INTRODUCTION

Chlorophyll pigment present in various plant parts (mainly leaves, in some cases stems etc) is essential for photosynthesis, a process that allows plants to absorb light energy from the sun and manufacture carbohydrates. It has been brought out by several studies **(Anatoly A et al)** that the amount of chlorophyll present in the leaves has a direct relationship to the photosynthetic efficiency of the plant and its vigour. Thus, estimation of chlorophyll content can be a potential indicator of the yield. Chlorophyll content is generally measured in lab by destructive methods like chemical analysis of leaf. However, this process is very tedious and takes good amount of time. Devices like Chlorophyll Content Meter (CCM) are available, which measure the chlorophyll concentration of green leaves in a non-destructive manner, using transmitted radiation through the leaf chlorophyll. Chlorophyll Content Index (CCI), computed as a ratio of transmitted radiation in Infra-red and Red regions, indicates the overall health condition of the plant. Currently, in India, Chlorophyll Content Meters (CCMs) are mostly imported and are very costly to be procured by the users. Development of an indigenous version of CCM is very promising, keeping in view, its potential utilization in crop condition assessment and yield estimation. Some studies have shown the feasibility of developing a chlorophyll detector using Camera (**Andrew M. Mutka et al**.). In order to make a handheld device, Raspberry Pi can be used along with camera detector which is very small in size and can be effectively used as a handheld device. The software for computing CCI can be developed using Python, Open source Image processing libraries in Raspberry Pi. The cost reduction can be almost one-tenth of the commercial device. A study was thus initiated to develop a prototype of CCM, using Raspberry Pi SOC (System on Chip) along with NIR camera which acts as the detector. This device is developed and calibrated with respect to imported, commercially available device (CCM-200).

2. PROCEDURE FOR DEVELOPING CHLOROPHYLL METER DEVICE

2.1 Conceptual Stage

Chlorophyll content is a direct indication of plant health and condition. A Chlorophyll meter device uses the light absorbance to estimate the chlorophyll content in leaf tissue. Two wavelengths are typically useful for absorbance determinations due to chlorophyll. One of the wavelength lies within the chlorophyll absorbance range (Red region) while the other has least absorbance and serves to compensate for leaf thickness. CCM measures the absorbance / transmittance in both wavelength ranges and calculates a Chlorophyll Concentration Index (CCI) that is proportional to the amount of chlorophyll in the sample.

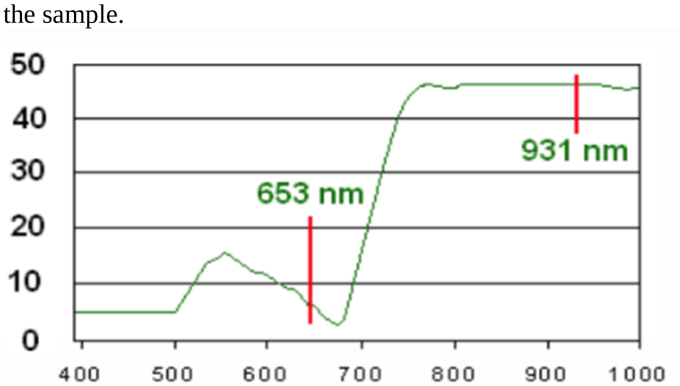

Figure.1. Transmittance Curve of Chlorophyll

Raspberry Pi System on Chip along with the LED in (IR and

Red region) acting as a monochromatic light source and Sony IMX219 NIR camera as detector can be used to measure the transmittivity of light in these regions from the leaf . This can then be linked to the relative chlorophyll content by taking a ratio of the Red and Infra Red transmittance which is popularly known as Chlorophyll content index (CCI). The camera is having 8M Pixel CMOS Image Sensor with High sensitivity, low dark current, no smear, Excellent anti-blooming characteristics and Variable-speed shutter function.This provides lower noise, high quantum efficiency with less saturation and an excellent night vision.

2.2 Design Stage

A Top Down approach of Hardware Software Co-design has been carried out to select the optimum solution for develoing the aforementioned system. At first the macro level system requirements are defined and taken into consideration which are – NIR Camera Detector, Software for Image processing, Operating system, Storage Space, Processor etc. Then a detailed analysis is performed to achieve the required system architecture. A Pareto optimal solution with the variety of existing solutions suggetsed to go for lowest cost and lowest area chip with highest suitable set of components. The cost versus area specifications for the various solutions available to the given problem is given in Table -1. The Pareto optimal set consists of Banana Pi and Raspberry pi with lowest area and lowest cost respectively. Since the difference in area is not much, so the lowest cost solution is selected which is Raspberry Pi. Additionally Raspberry pi provide NIR camera support with API libraries.

Table.1. Cost versus Area Specification of various System on Chip Boards

Name of the Board	Cost(in Rs)	Area (mm^2)
Raspberry Pi	2888	4760
Banana Pi	3600	4225
Beaglebone Black	4999	10914
LinkSprite pcDuino	8855	7865

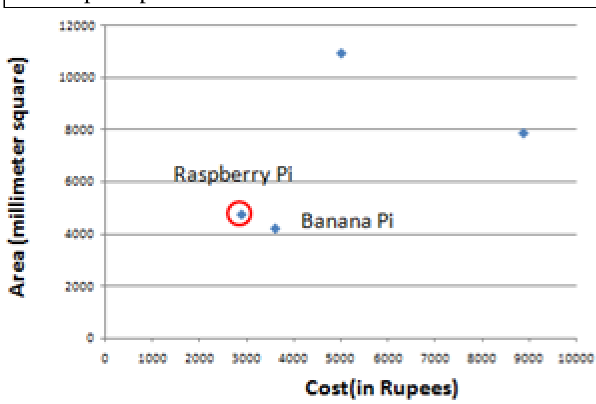

Figure.2. Pareto Optimal Solution

The Raspberry Pi is a System on Chip which can be loaded with a variety of Operating Systems which aids the learning of programming and computing (*RaspberryPi.org*). It is also a fantastic starting point for the development of the IoT devices. The low cost with multiple ports for USB, camera, ethernet and GPIO of Pi makes it a board that is accessible to all types of components with numerous connectivity options. Pi is the perfect experimental tool, whether to use it as a desktop computer, media centre, server or monitoring/security device. Linux based Operating system can be installed on Raspberry Pi which allows plenty of software installation possible like Python and OpenCV for Image processing.

Development Environment: The following table-2 shows the development environment:-

Table.2. Development environment

Operating System:	Jessie OS
Programming Language:	Python, Bash scripts
GUI:	TKInter
Additional dependencies:	OpenCV

2.3 Software Development Stage

The sequence of user interactions with the device are specified for the field instrument as follows (**Figure 3** shows the System sequence diagram):

- ➢ User switches on the device and opens the application.
- ➢ User puts the leaf in between the light source and camera module. Then he selects to capture the CCI. A success message comes back to user.
- ➢ User clicks on calculate CCI and software calcultaes the transmittance of leaf in IR and Red bands and converts it into Chlorophyll content index.
- ➢ The output is displayed on the screen.
- ➢ User saves the results.

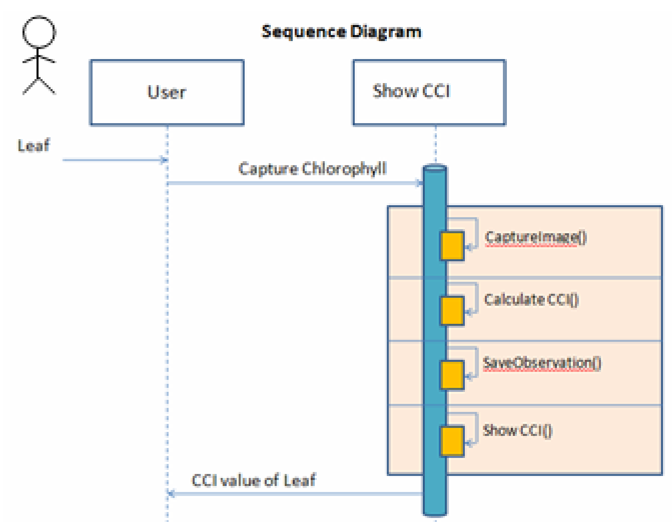

Figure.3. System Sequence Diagram for the device

2.4 Bread board testing

The electronic components for this device are procured and tested in breadboard with appropriate ballast resistance calculated using Ohm's Law:-

V=RI

Where:

V=Voltage applied

R-Resistance

I-Current

	
Figure -3	**Figure -4**

With the help of jumper wires the device is tested for its conceptual workflow. Figure – 3 shows the testing of the camera with the LED as light source. Figure -4 shows the image captured of NIR Light source (LED) which can only be detected by NIR camera Detector.

2.5 Instrumentation Stage

The bread board testing is followed by integration and soldering to develop the chlorophyll meter device with proper encasing designed to make the device handy in a cost effective manner. Figure 5 shows the devloped device.

Figure.5. Chlorophyll meter device developed.

3 EQUATIONS

The Chlorophyll Content Index is the ratio of the amount of InfraRed light to the amount of Red light transmitted through the leaf.

$$\textbf{CCI} = \frac{\textbf{\% Transmittance in IR region}}{\textbf{\% Transmittance in Red region}}$$

The above mentioned method of determining chlorophyll is non destructiv. However, in laboratory the chlorophyll concentration is calculated using molar analysis of the leaf's chlorophy which is a destructive analysis. The CCI is similar to the molar attenuation coefficient which is a measurement of how strongly a chemical species attenuates light at a given wavelength. It is an intrinsic property of the species. The SI unit of molar attenuation coefficient is the square metre per mole (m2/mol). The molar attenuation coefficient is also known as the molar extinction coefficient and molar absorptivity (See Wikipedia, Bluebook, https://en.wikipedia.org/wiki/Red_edge (describing definition and application of the Red_edge) (as of Mar. 12, 2018, 20:50 GMT)).

The absorbance of a material that has only one attenuating species also depends on the pathlength and the concentration of the species, according to the Beer–Lambert law

$$\mathbf{A = \varepsilon\, c\, \ell}$$

where

- **ε** is the molar attenuation coefficient of that material;
- **c** is the amount concentration of those species;
- **ℓ** is the pathlength.

Thus the CCI value should increase with increase in chlorophyll concentration and also with the thickness of the leaf (equivalent to path length).

In order to calculate the transmittance of light through the leaf, a pair of Red and IR LED can be used as light source to impart the corresponding spectrum to the leaf. Then the amount of light captured by the camera will correspond to the transmitted radiation from the leaf structure which passes through leaf after undergoing reflection and absorption.

Since

$$\mathbf{R+A+T = 1}$$

$$\mathbf{A = 2 - \log(T)}$$

Where

R- Reflectance

A-Absorbance

T-Transmittance

The absorbance in Red band is directly proportional to chlorophyll concentration. This also implies that the transmittance in Red band will decrease with increase in chlorophyll concentration (inverse proportionality).

4. RESULTS

4.1 Calibration

The calibration of the device's camera sensor response is done in reference with Commercial device i.e., Apogee CCM-200 chlorophyll meter. The results have shown close correlation of the device measurements with the commercial device observations (R^2 =0.85).The result of calibration is shown in **Figure 6**.

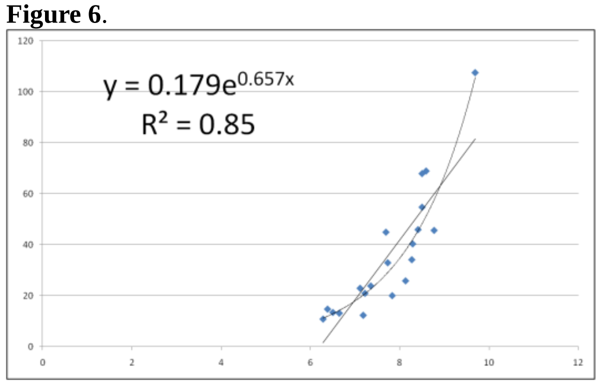

Figure.6. Results of Calibration

Table.3. Verification of leaf samples

Our Device	CCM200	Relative error
18.63	22.6	3.97
21.9	29.3	7.4
42.3	46.6	4.3
16.8	21	4.2

A verification of the calibrated deivce is done to check for relative errors in observations. This is shown in **Table 3**.

5. CONCLUSION

A very cost-effective method is established to build a Chlorophyll content meter using raspberry pi and NoIR camera. The cost is reduced by one tenth of the commercial device (the cost of developed device is Rs 25,000 whereas cost of commercial device is Rs 2,50,000). It can be used for crop condition assessment and linked to various damages occuring due to disease/ Drought / nutritional content since the reliabilitiy of the device is found to be quite satisfactory (R square value of 0.85 for calibration).

6. LIMITATIONS

The device works well for various types and thickness of leaves but it is not sensitive for very small or very thick leaves due to insufficient light reaching the detector. As the chlorophyll varies across the leaf at various points, small leaf may capture diffused light. Also, it can't be used for very thick leaves since the LED intensity will not be appropriate to provide enough luminiscence which is required for chlorophyll detection.

7. ACKNOWLEDGMENTS

I express my deep sense of gratitude to our respected General Manager, Dr. S V C Kameswara Rao, RRSC-Central, Nagpur for providing directions and for permitting me to utilize all the necessary facilities of the center. I am also thankful to Shri Vinod M Bothale, Group Director, Sci/Eng G, NSRC, Hyderabad and Dr D S P Rao, Sci/Eng – 'SF', RRSC-Central, Nagpur and Faculty of BITS-Pilani for their kind co-operation and supervision in my M Tech Dissertation on the same topic. Lastly, I would like to express my deep appreciation towards Chief General Manager, Regionl Centres, National Remote Sensing Center, ISRO for providing us the moral support and encouragement for always doing our best in scientific and technological frontiers. The authors wish to thank Director, NRSC for his encouragement and overall guidance. This work was supported in part by a grant from Regional Remote Sensing Centre –Central (Nagpur), National Remote Sensing Centre.

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