Development of Sensor System for Estimation of Leaf Water Content

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ABSTRACT

This paper uses the optical properties such as transmittance, reflectance and absorbance for estimation of leaf water content of a plant. Here an optical sensor based set-up is established for measuring these optical properties. Leaf transmittance and reflectance characteristics using different LED light sources are compared in this paper. The objective of this study is to create the relationship between the optical properties and moisture content of the leaf. The experiment with different leaves was conducted. This experiment will infer some accurate results by using LED’s in infrared region between 1300nm to 1500nm since this range of wavelength falls in the water absorption band. Percentage moisture content at every stage of drying of the leaves and their transmittance and reflectance properties are analysed. The conclusions presented could lead to the development of portable instruments for leaf water content estimation and other biological parameters rapidly and non-destructively.

Keywords- Optical Properties, Leaf Water Content, Optical Sensor, Visible Wavelength Range, Infrared Wavelength Range and Water Absorption Band.

1. INTRODUCTION

Leaf is one of the most important parts of a plant whose optical properties help us to evaluate many parameters such as transmittance, reflectance, absorption and scattering. The interaction of electromagnetic radiation with plant leaves depends on the biochemical characteristics of these leaves. Leave optical properties are particularly difficult to simulate, however many experimental measurements of leaves optical properties were still in progress and deterministic approaches on interaction of light with plant leaves were also developed. When a leaf intercepts a light beam, it undergoes reflection, transmission or absorption. But the application of conservation of energy leads to the statement that the sum of the reflectance R, transmittance T, and absorbance A, equals one.

$$R + T + A = 1 \qquad (1)$$

So, one need to fix his/her attitude in finding the accurate values of transmittance and reflectance since absorption can be extracted from that values. Transmittance and reflectance characteristics were different for all the leaves. So, by picking the leaves according to the maturity level of different plant species, we can generate a data for analysing these optical properties. Water stress detection by remote sensing using indices of near-infrared and mid-infrared wavelengths has been performed [1].

In 2012, Qianxuan Zhang *et al.* detect the water content in leaf using the defuse reflectance spectra limited in the VIS/NIR region (400-1100nm) [2]. They conclude that this method can use to determine other biochemical parameters such as chlorophyll and nitrogen content. The correlation between leaf water content (relative water and EWT) and the leaf reflectance spectral index peach tree leaves were observed from a model which performed satisfactorily and which could be used to detect the water content of the peach tree leaves [3].

Reflection of electro-magnetic radiation by non-metallic objects is cause by reflective index differences [4]. Here, the lack of strong reflection in the visible range by most leaves can be attributed to the leaf pigments which absorbed visible light. Leaf thickness doesn't affect reflectance but strongly influence in transmittance especially at some wavelengths. The diffusion of light into the leaf is caused mostly by interfaces between air wet cell walls, but a significant amount remains when these interfaces are eliminated. The measurement of spectral brightness coefficient, the directed reflection coefficients, and the degree and azimuth of polarization of radiation reflected from a leaf were performed at different angles of incidence of radiation on the leaf and different angles of observation [5].

Leaf water content estimation can be achieved by determining the dielectric constant or capacitance of leaves [6]. This estimation was higher at 100 KHz as compared to 1MHz frequency. A terahertz radiation was proposed by Sillas *et al.* for measuring the leave water content [7]. Again a non-destructive method in the field based on terahertz technology is used for determination of changes in leaf water content [8]. Again in 2013, a terahertz time-domain spectroscopic transmission data with an iterative algorithm that calculate the relative volumetric fraction of water present in the tissue [9]. These measurements correlate very well with direct determination of the water content by the well established gravimetric method.

The leaf relative water content in Araucaria Angustifilia leaves were measured by testing the effects of light, temperature and leaf position during imbibitions [10]. A simple set-up using LED's and photo-transistors for measuring the reflectance from the fruit is been developed as an optical chlorophyll sensing system [11]. In another research, the spectral reflectance of leaves from several eucalyptus species was measured over 400-2500nm wavelengths with a laboratory spectroradiometer [12]. The relationship of reflectance with the gravimetric water content equivalent water thickness of leaves was analyzed here.

A project work has been done by Chung Qi Joy *et al.* to study how the reflectance spectra of leaves were affected by water content [13]. Here the reflectance spectra is been measured using a portable field spectrometer. In 1974, Rechard *et al.* performed a rapid estimation of relative water content [14]. This relative water content technique, which is formerly known as relative turgidity, was originally described by Weatherley [15][16][17] and has been widely accepted as a reproducible and meaningful index of plant water status. Another technique known as beta ray gauging technique for measuring the changes in leaf water content, leaf thickness and moisture status of plant was proposed [18][19][20].

Many methods and models like FSM (Foliar Scattering Model) [21], BDF (Bidirectional Surface scattering Distribution Function) model [22], 3D FDTD (3-Dimentional Finite Difference Time Domain) method [23], Plate model [24], PROSPECT model [25], etc. were proposed for analysing these optical properties.

Jim Reeb and Mike Milota conduct an experiment to determine the moisture content by the oven-dry method for industrial testing [26]. And this can be used as validation of data. So, in different ways these properties are measured and used in the inversion models to estimate leaf biophysical properties. This knowledge is nevertheless crucial to develop more accurate relationships between these properties and important leaf functional characteristics, or to improve models which are directly used to interpret remote sensing data when coupled with canopy reflectance models.

2. MATERIALS AND METHODS

A simple set-up is made for measuring the transmittance and reflectance of the leaves using different wavelength LED's so that the effect of different LED sources could be studied. Fig.

1 shows a simple set-up for measurement of transmittance and reflectance of the leave using different wavelength LED (460nm, 520nm, 585nm, 620nm, 780nm and 1300nm) sources and photo-transistor.

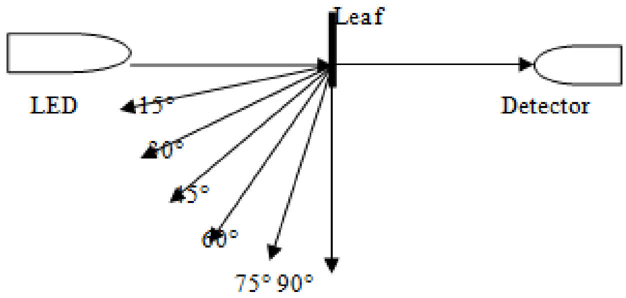

Fig-1: Set-up for transmittance and reflectance measurement.

Phototransistor for transmittance measurement is kept along the axis of propagation of light. Reflectance is measured by putting the phototransistor at every 15° with respect to the source till 90° along counter clockwise direction.

The effect of water content on leaf optical properties was investigated for two plants species: papaya and devdaru. Young leaves, half-matured leaves, and matured leaves from different position of different branches were collected. The leaves are cleaned by a soft brush in such a manner that the leaves won't get destroyed. The reading has been taken in three different positions of each leaves and the average is taken as the data for analysis. The experiment was carried out in a dark room so that no external lights can disturbed the operation. Transmittance and reflectance characteristics were compared with different wavelength ranges for all the leaves.

In the second set-up, reflectance is measured only at 45° other than various angles. The phototransistor for transmittance measurement along the axis is kept as it is.

Also, oven dry method can be use for validation of moisture content. Oven-dry test can be a useful tool not only for verifying the readings from electronic moisture meters or sensor system, but also for understanding what is happening inside of the sample as it dries. Moisture content (MC) of a leave can be calculated as:

$$MC = \frac{(\text{initial weight of the leave} - \text{dry weight of the leave})}{\text{Initial weight of the leave}} \times 100\% \quad \ldots\ldots\ldots\ldots (2)$$

Leave moisture content has been observed for papaya and devdaru leaves at various drying stages. We took 3 different leaves (young, half-matured and matured) each of papaya and devdaru plants and cut them with equal shape and size. We took the initial weight after half an hour of plugging and then measure the transmittance value using the prepared set-up for mid infra-red (1300nm) LED's. Once the initial weight and transmittance is taken the leaves begin to dry and there is no going back. So we need to keep a good record at every step of observation. We put the leaves in open air at room temperature for one and half hour and took the readings (weight and transmittance). Same process is executed twice for every 1 and half hour difference and then we put the leaves in an oven for drying. The oven is set at a constant temperature of 60°C for 24 hours. After that we take the dry weight for all the leaves. Since water absorption takes place between the wavelength ranges 1300nm to 1500nm, we prefer a 1300nm LED.

3. RESULTS AND DISCUSSION

Different colours of LED's like blue (460nm), green (520nm), yellow (585nm), red (620nm) and infrared (780nm) were taken for transmittance and reflectance measurement. Each wavelength measurement analysis will extract some useful results. Figure 2 shows the transmittance characteristics of young, half-matured and matured leaves at different wavelength ranges. Minimum transmittance reading is observed at 520nm (green LED) and maximum transmittance is observed at 780nm (infrared LED). Here, transmittance characteristics of all the leaves are almost equal except for young leave where transmittance for papaya leave is pretty much higher than the devdaru leave.

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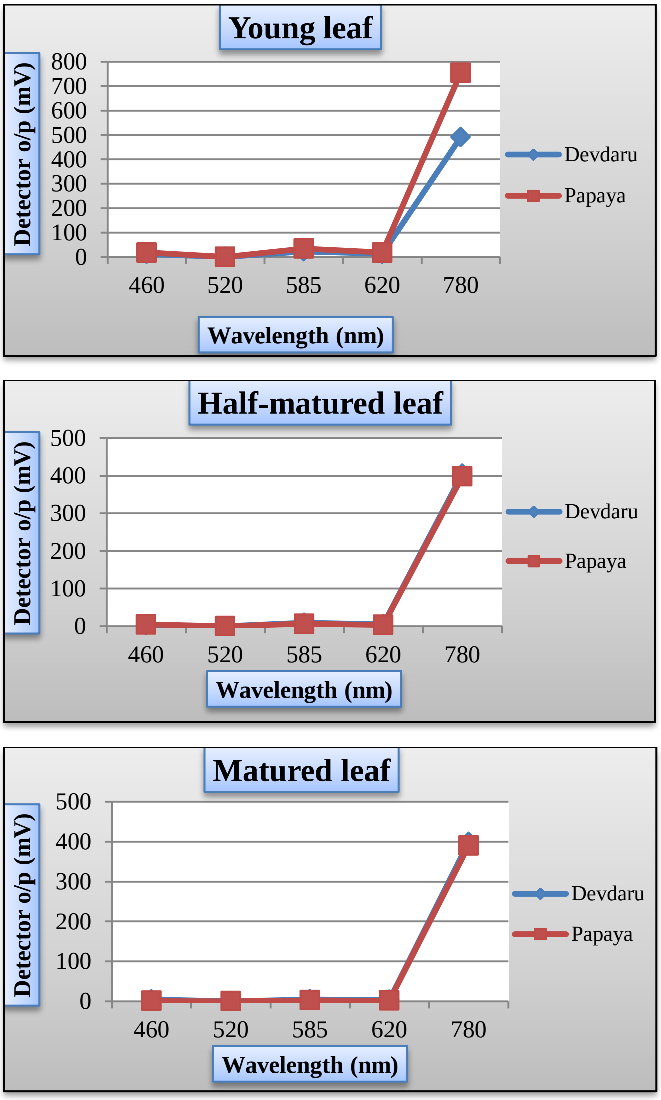
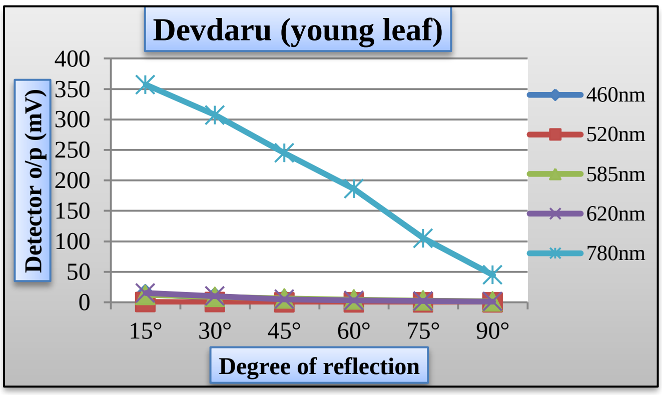
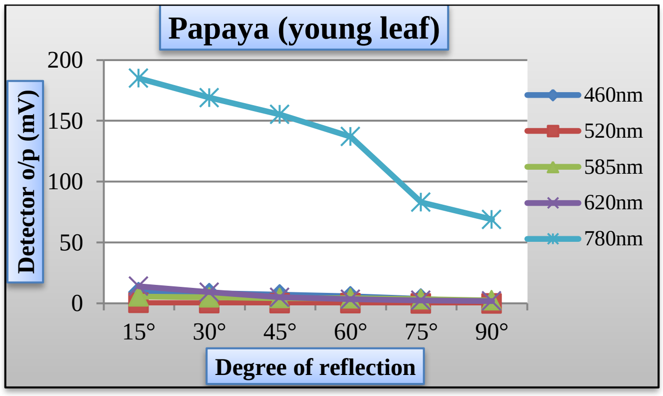
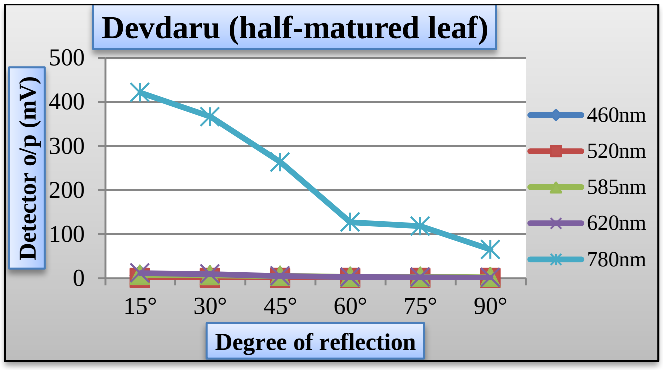
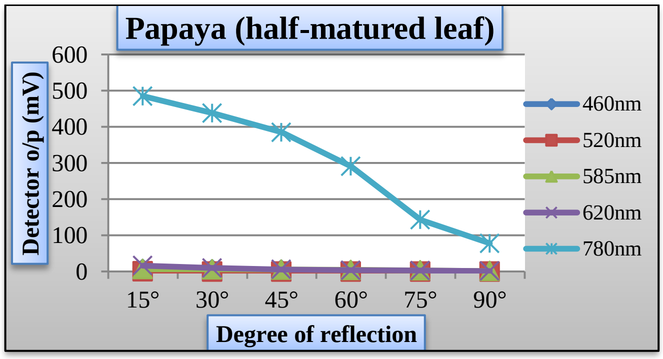


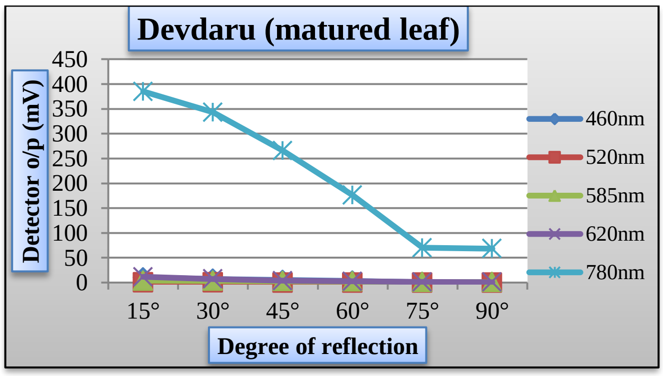
Fig-2: Transmittance characteristics for young, half-matured and matured leaves with respect to different wavelength ranges.











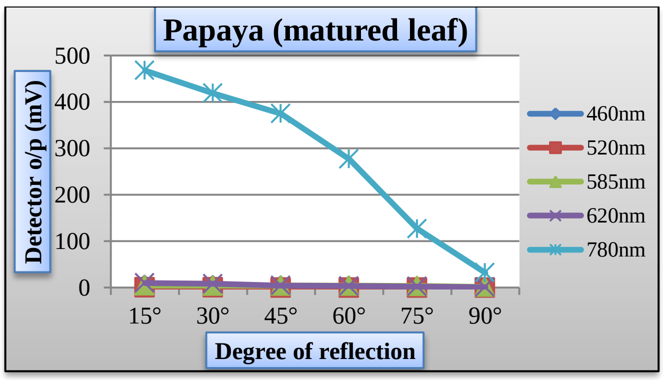
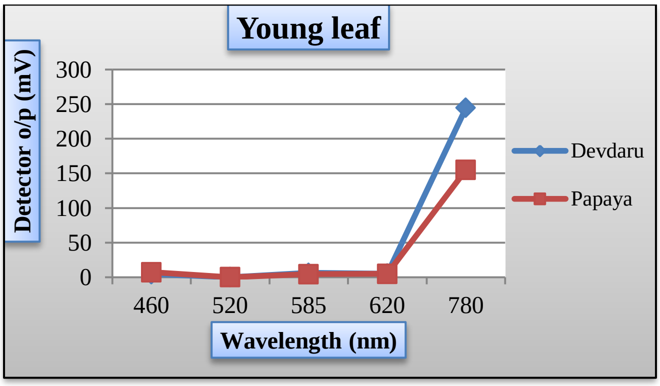
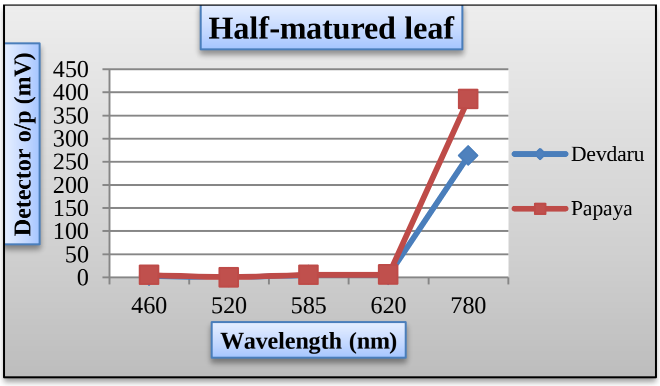


Fig-3: Reflectance characteristics for young, half-matured and matured leaves at different angles with respect to different wavelength ranges.

Figure 3 shows reflectance characteristics for young, half-matured and matured leaves of devdaru and papaya tree at different angles with respect to different wavelength ranges. Reflectance is highest at 15° and decreases gradually till 90°. Here in the graph, a distinct variation is observed for each leaves that reflectance is extremely higher in infrared region i.e. at 780nm wavelength. And achieve the lowest reflection at 520nm (green) wavelength.

From the above observations we got to know that the average reflectance takes place nearly at 45°. So, finally, the reflectance is measured by fixing the phototransistor at 45°. This will reduce system complexity and will make the measurement more easier. Figure 4 shows the reflectance measurement for young, half-matured and matured leaves at 45° reflectance angle. The reflectance characteristics are almost same besides for young leave, devdaru has higher reflectance than papaya at 780nm wavelength and reversed for half-matured and matured leaves at the same wavelength.





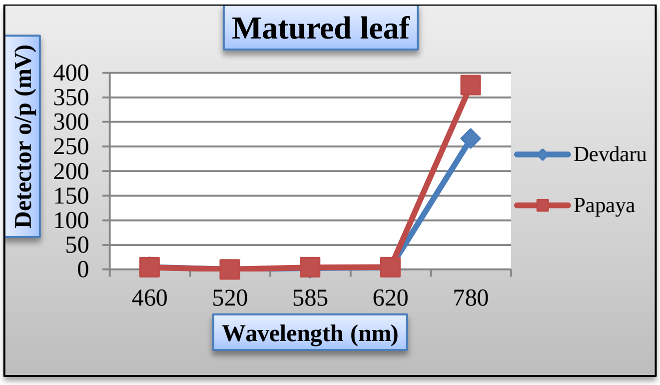
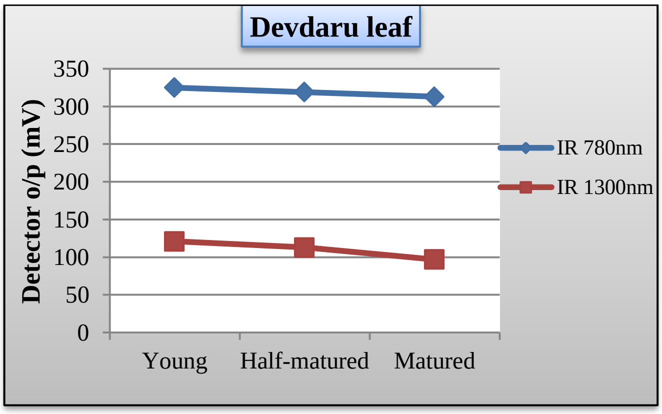


Fig-4: Reflectance measurement for young, half-matured and matured leaves at 45° for various wavelengths.

In the above observations, strong transmittance and reflectance is observed at 780nm wavelength i.e. at infrared region and much less transmissions and reflections were observed at visible region. This lack of strong reflection in the visible region by the leaves can be attributed to the leaf pigments which absorb visible light.

From the results obtain from the above observations we got to know that infrared LED's will interpret a more distinct output regarding the moisture content of the leaves. Since 1300 nm wavelength falls in the water absorption range, it will be the most accurate way for determining the leave moisture content. 780 nm wavelength LED is also use to compare and see if there is any difference in the result obtain from using the 1300 nm wavelength LED.



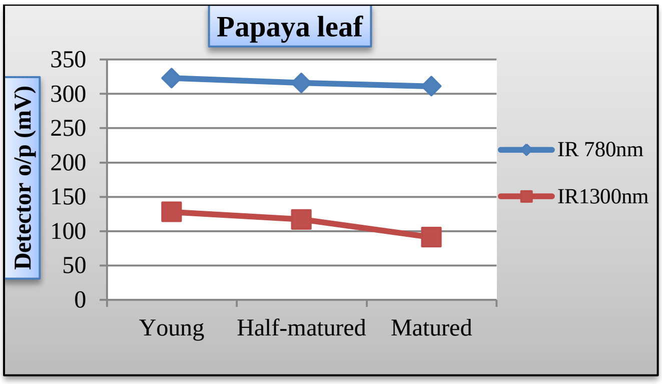


Fig-5: Transmittance characteristics for LED are of wavelength 780 nm and 1300nm.

Figure 5 shows the corresponding graph for the above table which illustrate the comparison between 780 nm and 1300 nm wavelength LED's. Here in the figure above, we compare the photo-detector outputs of IR 780nm LED and IR 1300nm LED. IR 780nm LED gives high output voltage but the absorption spectra is very less and changes in output are not much satisfied with the acquired moisture content. But a unique trend of variation is observed for IR 1300nm LED. Although IR 1300nm LED gives a lower output voltage than the IR 780nm LED, IR 1300nm is a matter of concern. And since we are talking about moisture content, IR 1300nm LED which falls on the water absorption band is more preferable as compared to IR 780nm LED.

Weight of the leaves reduces at every instant of time due to evaporation from the leaves. And with this moisture content variation in the leaves, the optical properties also changes. Here, we take observations of the leaves for every one and half hour difference with 1300nm LED by keeping the leaves in open air. Weight of the leaves and transmittance and reflectance readings are observed simultaneously for every time interval. The final dry weight is measure by keeping the leaves in an oven which is fixed at temperature 60°C for 24 hours. We make a circuit in such a way that the total amplification gain is 5090.4 to make the output feasible for operating the microcontroller 8051.

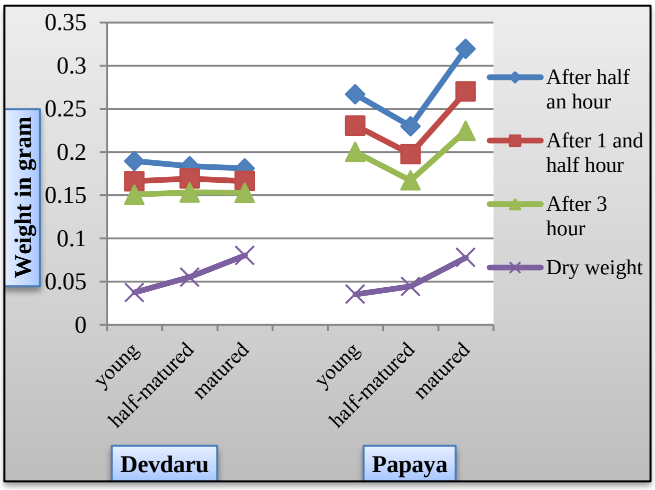


Fig-6: Plot for various weighing stages of devdaru and papaya leaves.

Figure 6 shows the graph plotted for various weighing stages of devdaru and papaya leaves. From these values we can calculate the moisture content of the leaves at every stage of drying. With decrease in weight of the leaves, moisture content of the leaves also decreases respectively. The percentage moisture content and their transmittance and reflectance values for devdaru and papaya leaves at various time intervals were observed. The transmittance trend is quite good for both devdaru and papaya leaves. But the reflectance characteristics were almost stays on a value and increases a bit but the increase is not distinct. And it's hard to extract any useful observations from the reflectance values. So we will prefer transmittance values for our last presentation of result. Figure 7 and 8 shows the plot between amplified transmittance and moisture content at different instant of time for 1300 nm LED. And the flowchart to display the result in the LCD is shown in figure 9.

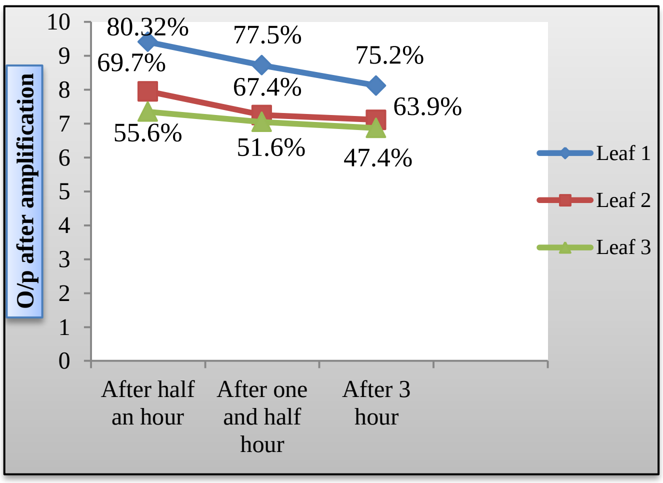


Fig-7: Amplified transmittance values with respect to moisture content for devdaru leaves at different time interval for IR 1300nm LED.

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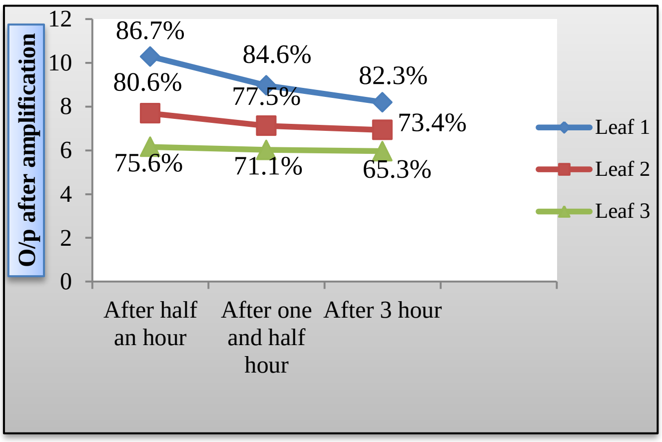

Fig-8: Amplified transmittance values with respect to moisture content for papaya leaves at different time interval for IR 1300nm LED.

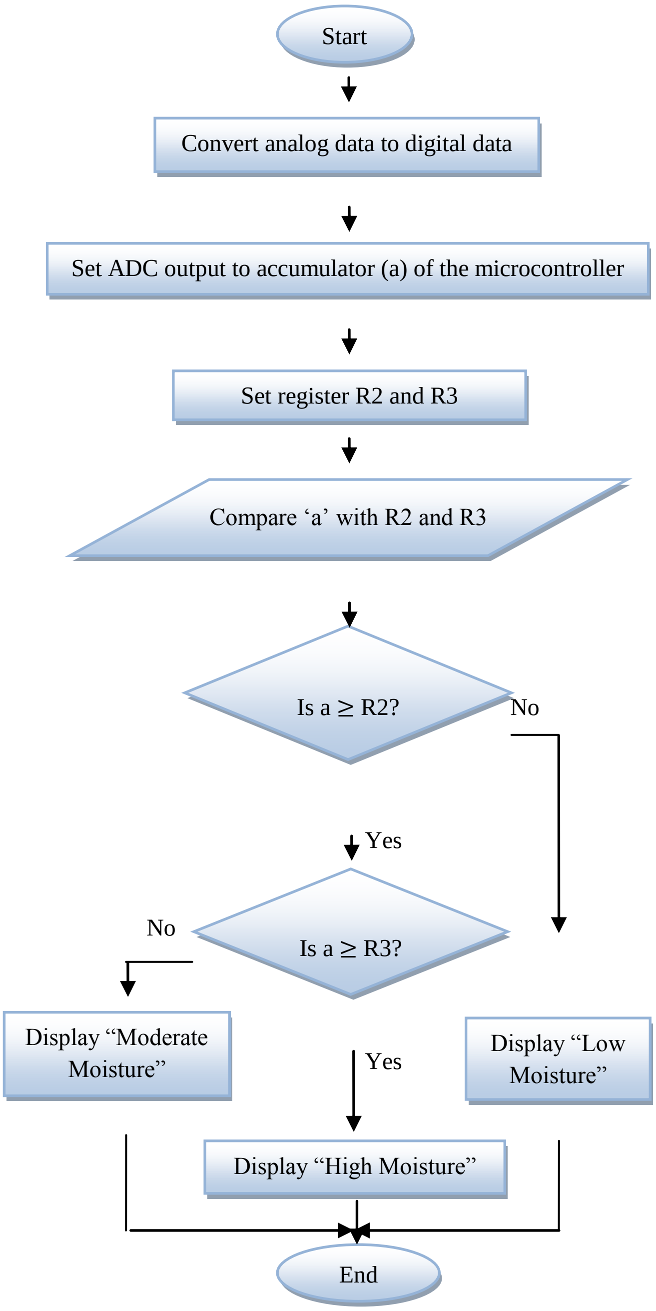

Fig-9: Flowchart for microcontroller programming.

So, first we have to convert the analog data into digital form since microcontroller doesn't accept any analog value. For that we have given the amplified output to the ADC channel of the development board. After conversion, the digital output from ADC channel is sent to the microcontroller where this value will be compared with the values which are already set to the microcontroller.

So, we will set two values: 6 volt at register r2 and 8 volt at register r3. The microcontroller program is written in such a way that if the amplified output (i) is greater than 8 volt, the LCD display will show "High Moisture", (ii) lies between 6 volt and 8 volt, the LCD display will show "Moderate Moisture", and (iii) is less than 6 volt, the LCD display will show "Low Moisture". So, by analysing the transmittance values from the sensor output, we can easily demonstrate the moisture content of a leaf.

4. CONCLUSION

In this paper, a simple technique suitable for non-invasive measurement of leaf water content has been suggested. The proposed model reduces the system complexity, made the model more stable, and extracted the most efficient information of transmittance and reflectance properties. Devdaru leaves have smooth surfaces and papaya leaves has rough surfaces. So, study of optical properties of these two different leaves can conclude to a very good result and this analysis can be applied to all other leaves for moisture estimation. LED's of different wavelength ranges from 460 nm to 1300 nm were used for transmittance and reflectance measurement. And 1300 nm LED gives better performance as compare to the LED's of other wavelength ranges. So, an LED of 1300 nm wavelength which falls in the water absorption band is found out to be the most efficient source for leaf moisture content estimation.

The research done in this paper overcome some of the pending operations and has several applications in the field of agriculture and irrigation systems. In future laboratory experiment, these measurements will be more precise by increasing the wavelength range in order to get more accurate information.

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