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LEAVES CURL IDENTIFICATION USING NIR POLARIMETRIC SIGNATURES

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ABSTRACT

We consider passive polarimetric near infra-red imaging systems that measure the three first elements of the Stokes vector and deduce from them the degree of linear polarization and the angle of polarization in near infra-red spectrum for analyzing plant leaves. By using the variance of the angel of polarization from each sample leaf, we identify the curl of the leaf surface and compare it to other sample leaves. The identification will be useful for the next research and application in leaves classification, especially in plant diseases and its level which can be detected by its leaves.

Keywords: leaf curl, NIR-polarimetric imaging, remote sensing, small format sensor.

INTRODUCTION

Imaging polarization of light is now widely used and developed. Our lab have developed polarimetric imaging for some applications such as measurement of fabric surface [1], [2] and also develop high acquisition method in the polarimetric imaging [3], [4] and [5]. And for remote sensing application [6], had reported that passive polarimetric imaging is a potentially promising way in aerial remote sensing.

The leaf curl existent on vegetation, generally indicate the disease existent on the vegetation. The leaf curl disease can be found on tomato, cotton, and tobacco [7], [8], [9], [10], [11] and [12]. The aim of this work is to evaluate our small format sensor [13] as a polarimetric vision system in indicating the curl existent on plant leaves surface. The Stokes vector limited to the three first components is classically named linear Stokes vector [14]. From its measurement, two main parameters can be estimated: the degree of linear polarization (DOLP) and the angle of the principal state of polarization, which we will call the angle of polarization (AOP). The variance of the AOP from each sample leaf is used for identifying the curl of the leaf surface and can be compared with other sample leaves.

POLARIMETRIC IMAGING METHOD

The formalism of stokes

The 4-component Stokes vector S totally describes the light polarization:

$$\boldsymbol{S} = \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ s_3 \end{pmatrix} \quad (1)$$

where s_0 quantifies the total intensity of the light, s_1 is related to the vertical and horizontal polarizations, whereas s_2 is related to the polarizations at• $\pm 45^{\circ}$. s_3 reflects the amount of left and right circular polarizations. From this vector, two relations can be deduced, that show the amount of polarized light:

$$s_0^2 \geq s_1^2 + s_2^2 + s_3^2 \quad (2)$$

$$DOP = \frac{\sqrt{s_1^2+s_2^2+s_3^2}}{s_0} \quad (3)$$

If the light is totally polarized then $s_0^2 = s_1^2 + s_2^2 + s_3^2$ and the Degree of Polarization (DOP) is one, if the light is partially polarized then $s_0^2 > s_1^2 + s_2^2 + s_3^2$and 0 <DOP <1, and if the light is totally unpolarized then $s_0^2 \neq 0$ and $s_1^2 + s_2^2 + s_3^2 = 0$ thus DOP = 0.

In this experiment, we work on the parameters related to linearly polarized components, *i.e.* the first three Stokes parameters, where s_3 remains unknown. The Stokes vector resumes therefore as:

$$\boldsymbol{S} = \begin{pmatrix} s_0 \\ s_1 \\ s_2 \\ - \end{pmatrix} \quad (4)$$

Based on the Stokes parameters and the Mueller matrix, we extract the polarimetric information through four linear polarimetric images with orientation of 0°, 45°, 90° and 135°.

$$\begin{cases} S_0 = I(0) + I(90) \\ S_1 = I(0) - I(90) \\ S_2 = I(45) - I(135) \end{cases} \quad (5)$$

And the Degree of Polarization becomes Degree of Linear Polarization (DOLP).

$$\boldsymbol{DOLP} = \frac{\sqrt{s_1^2+s_2^2}}{s_0} \quad (6)$$

Stokes polarimetric

Stokes Polarimetric means the step to measure the Stokes vector of a reflected wave or transmitted by an object when the polarization characteristics of the light source were not controlled. A polarization states analyzer

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is used to do this (or PSA) (Figure-1). When the polarization characteristics of the light source are controlled using a polarization state generator (or PSG), then one can determine the Mueller matrix of the stage and talking about polarimetric Mueller (Figure-1).

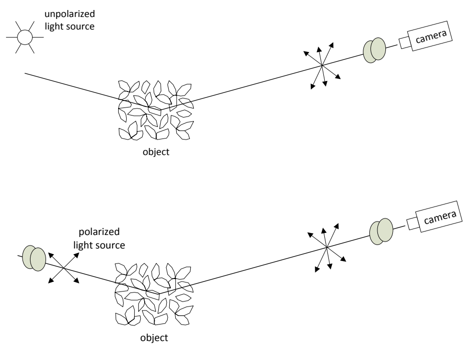

Figure-1. Imaging stokes polarimetric (top), and Meuller (bottom).

Static methods for partial Stokes polarimetric using an element of variable polarizing (in rotation or birefringence) to a fixed polarizer (for accuracy and / or speed, it can motorize the plate rotation) matrix of Mueller $M_{Pol\,(0^\circ)}$.

$$\mathbf{M_{Pol(0^\circ)}} = \frac{1}{2}\begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (7)$$

We can take generally without loss of our model to a variable element of θ orientation phase plate and φ delay, the Mueller matrix is expressed as:

$$\mathrm{M}_{(\varphi,\theta)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2(2\theta) + \sin^2(2\theta).\cos(\varphi) & \cos(2\theta).\sin(2\theta).(1-\cos(\varphi)) & \sin(2\theta).\sin(\varphi) \\ 0 & \cos(2\theta).\sin(2\theta).(1-\cos(\varphi)) & \sin^2(2\theta) + \cos^2(2\theta).\cos(\varphi) & -\cos(2\theta).\sin(\varphi) \\ 0 & -\sin(2\theta).\sin(\varphi) & \cos(2\theta).\sin(\varphi) & \cos(\varphi) \end{bmatrix} \quad (8)$$

The angle of polarization

From Equation. (5) S_0 represents the total intensity of the image, S_1 and S_2 represent the linear polarimetric characteristic of the image. By having S_1 and S_2, we could find the angle of polarization (AOP) to the plane of incidence:

$$\Psi = \frac{1}{2}\tan^{-1}\left(\frac{s_2}{s_1}\right) \quad (9)$$

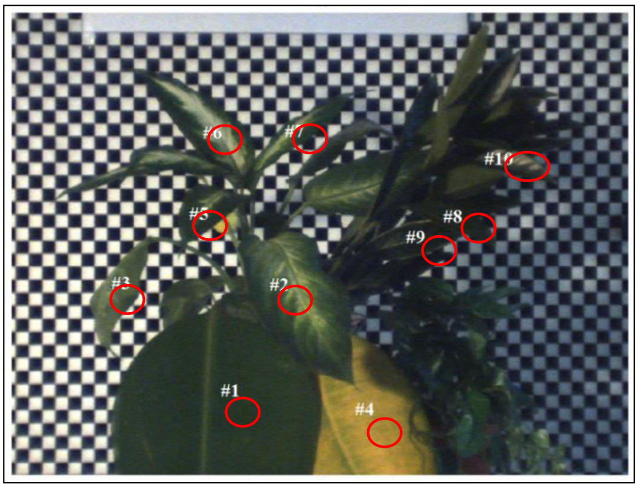

Figure-2. The ten object leaves.

THE LEAVES AND INSTRUMENT SETUP

The sample leaves we used are presented Figure-2. Leaves #2, #3, #5, #6, and #7 are from Dumb Cane plant, leaves #1 and #4 from Ficuselasticaplant and leaves #9, #8 and #10 are from Zamioculcas Zamifolia or the ZZ plant.

The optical setup used for this experiment is presented Figure-3. Rotating this half-wave plate retarder generates the four different Stokes used as successive inputs. And a rotating linear polarizer oriented at 0°, 45°, 90°and 135° guarantees a the linear polarization orientation input to camera sensor.

Figure-3. The optical setup.

RESULT AND DISCUSSIONS

The AOP image from the scene presented Figure-4, show the different orientation of each point of light reflected from the leaf surface will produce the different AOP. A relatively wavy leaves (curly) will have a lot of differences in the orientation of reflection point of light, so it will make much difference AOP as shown in the AOP

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image, charts and table from each leaf (as presented Figure-5, Figure-6, Table-1). By calculating the statistic variance value of the AOP on each leaf image, then we will get the

Figure-4. Angle of polarization from the scene.

relationship between variations in leaf curl surface with the variance value of AOP the leaf: the greater the AOP variance, the more curl/wavy the surface of the leaves.

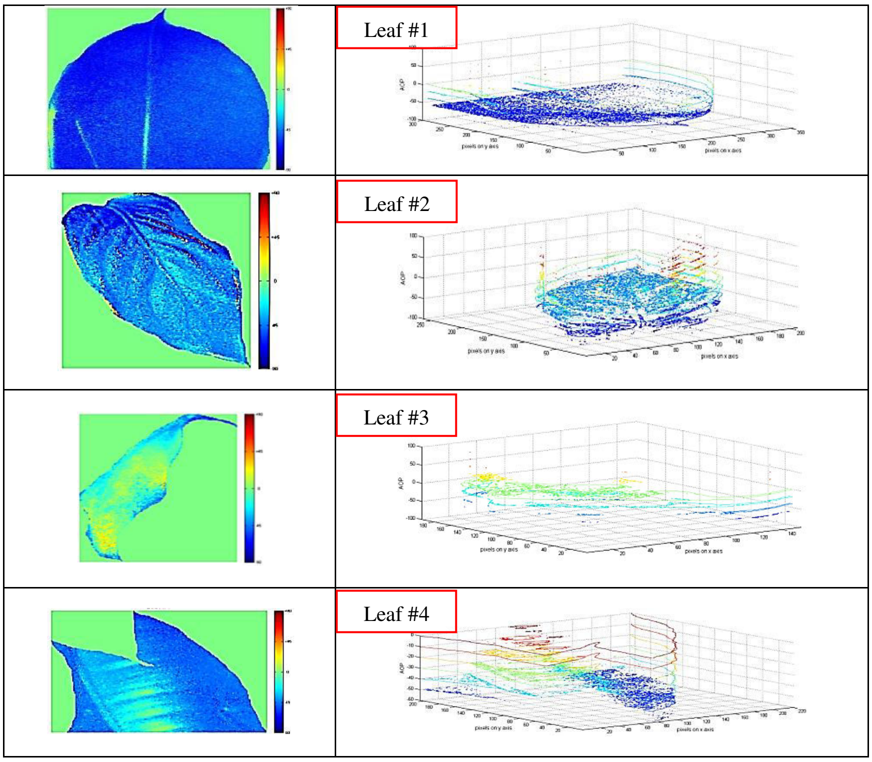
Having the variance value of AOP on each leaf and compare it with the variance value of AOP on another leaves, will give us a method for identification the leaf curl existent from the object scene. This identification method will be test and use for aerial remote sensing applications on plantation. And to have the AOP variance in the real remote sensing application on a plantation, a high-speed portable polarimeter using a ferroelectric liquid crystal modulator[3] which need a high-speed acquisition and processing [4] [5] is a challenging research in the next.

Table-1. Variance of AOP of the leaves.

Leaf #	pixels	mean	variance
1	79994	-41,3451	872,3352
2	32439	-25,2606	1018,127
3	8538	-2,24175	320,7197
4	27692	-23,7756	738,8698
5	7080	-14,2661	1929,161
6	15095	-11,2966	1102,096
7	6172	-6,05788	885,2962
8	5107	-17,3272	1399,42
9	7685	-23,4222	788,8686
10	4822	-10,7899	853,7134

CONCLUSIONS

From the experimental results of NIR-Polarimetric imaging, AOP image from the sample leaves showing the relationship between thelevels of the leavescurl surface with the AOP variance. Thus the AOP on NIR-Polarimetric can be used for identification of the curl of the leaf surface.



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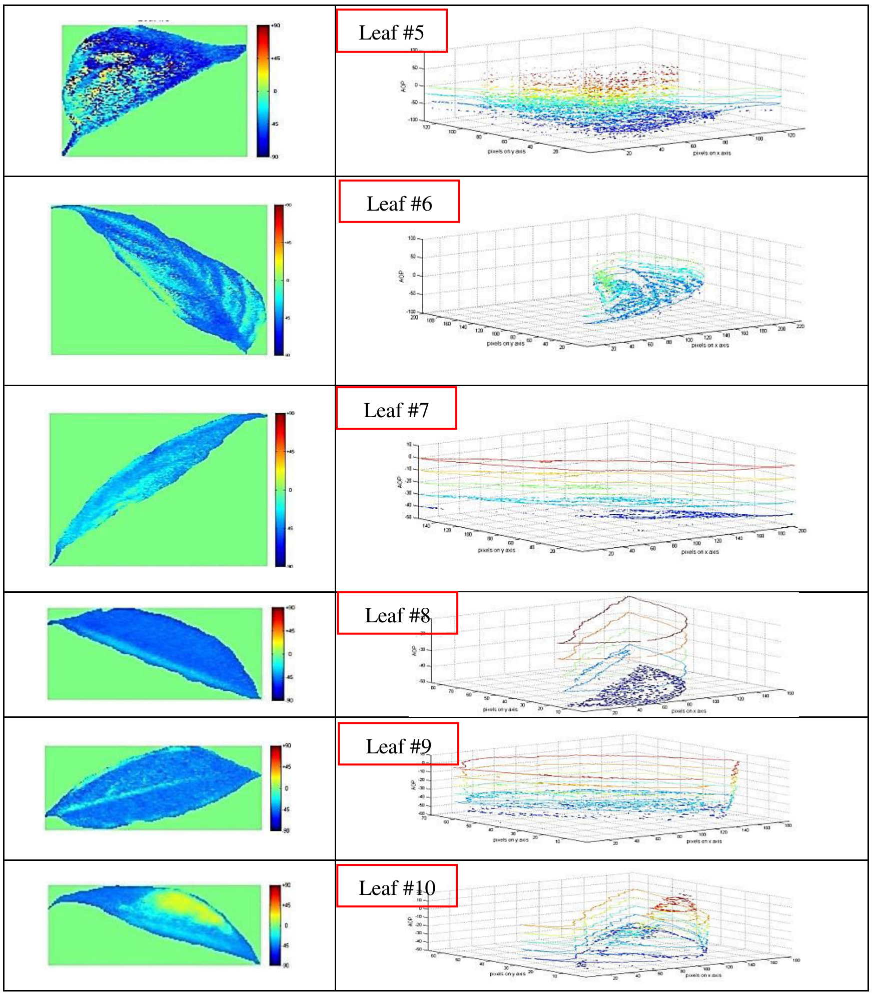

Figure-5. AOP from each numbered of the leaves.

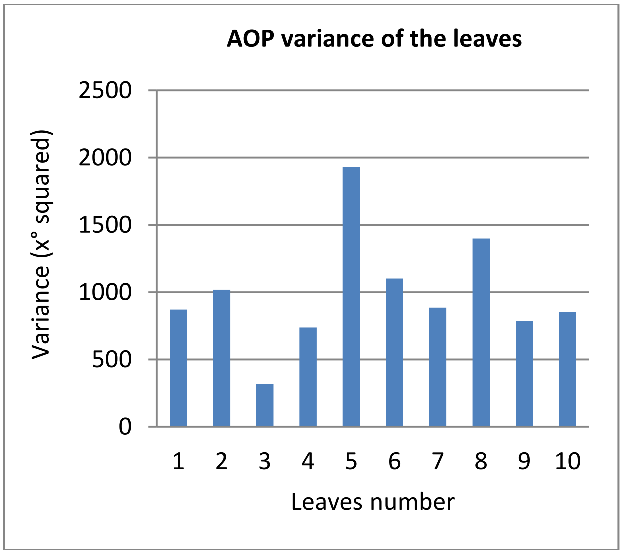

Figure-6. The variance values of AOP for each leaf.

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