

A method for plant leaf area measurement by using stereo vision

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Abstract

This paper presents a method for the measurement of LAI of wheat *in situ*. By using stereoscopic images a 3D map was computed. One colour image was segmented to identify plant regions and the 3D leaf area was computed on these regions. The result showed that the precision was about the same as for the reference measurements but required a lesser workload.

Key words: Leaf Area index, stereo vision, 3D.

1. Introduction

The leaf area index (LAI) is an important property of vegetation, for plant growth assessment and for crop models parameterisation. The reference measurements are usually destructive and involve the picking of plants from a given field area and the measurement of the leaf area by machine vision. This way to proceed is however destructive, tedious and expensive. To be accurate the sampled surface must be sufficient. Indirect values have thus been developed, based on canopy transmittance or on the reflection in specific wavelength such as the simple ratio, the normalized difference vegetation index (NDVI, Aparicio, 2000). The inconvenient of those methods is to be influenced by the chlorophyll content or the soil type and to saturate when the soil is completely covered.

Field image acquisition devices have been used to monitor coverage ratio or its complement, the gap fraction, but the saturation problem obviously remains.

The emergence of three dimensional acquisition devices and algorithms opens the possibility to determine the leaf area index more quickly in comparison to the traditional methods and might overcome the saturation problem of the monocular camera system. The average leaf angle (ALA) is another related parameter of interest which could be determined using the same techniques.

This paper presents a non-destructive and low cost method using a stereo-vision cameras set-up, describes the employed algorithms and gives an insight of the first results.

2. Material and Method

2.1. The crop and the reference measurements

This experimentation concerned wheat (*Triticum aestivum*, L.) and was part of a more complex set-up. The seed density was of 250 grain/m². The stereo images were acquired in an experimental field with plots subjected to different nitrogen application organised in complete random blocks. For this applications doses of 0 or 180 kg/ha applied in three contributions were considered. Two blocks were installed in different soil conditions (loamy loam and sandy loam). There were four repetitions for each soil and nitrogen conditions and thus 16 plots were studied. Measurements were made between end of March and end of

April. The different fertilisation, soil or dates were not relevant for this study but were useful by ensuring a variety of LAIs at the different growing stages. These are thus here together called the treatments.

The reference measurements for the LAI were computed by harvesting and measuring the area of leaflets in 0.5 m of a line in each plot and then extrapolating the result for a square meter. The area considered here is half the total leaf area, i.e. the area of one face of the leaves. The plots and the acquisition device are illustrated in Fig. 1.

2.1. Acquisition device and image analysis

The devices used in the experiments are twin colour CMOS cameras model STH-MDCS2-VAR-C from Videre Design. These were observing the culture from around 0.75 m from two points of view distant of 115 mm. The focal distance was 6 mm. Vergence of 8° was applied to the system to maximise the area inspected simultaneously by the two cameras. The cameras were observing the plant with their medium optical axis vertical. The device is shown in Fig. 1. The field stereo images were acquired, saved in "tiff" files and processed off line. The camera drivers were the CMU 1394 Digital Camera Driver from the Robotic institute, Carnegie Mellon University. The treatments were based on the OpenCV libraries.

The 3D system calibration was carried indoor, before or after the acquisition. A chequerboard with 10 columns, seven rows and squares sides of 24 mm was used. The calibration consisted in acquiring images of the pattern at different distances and orientations. The internal parameters (camera linked such as focal distance or distortions) and external parameters (distance between camera, vergence, ...) were computed by using the appropriate OpenCV libraries.

The processing of the field stereo images comprised several steps : the three dimensional position estimation for each pixel of the image relatively to the camera, the plant vs soil segmentation, the scanned area dimensions measurement and the computation of the 3D areas of leaf pixels.

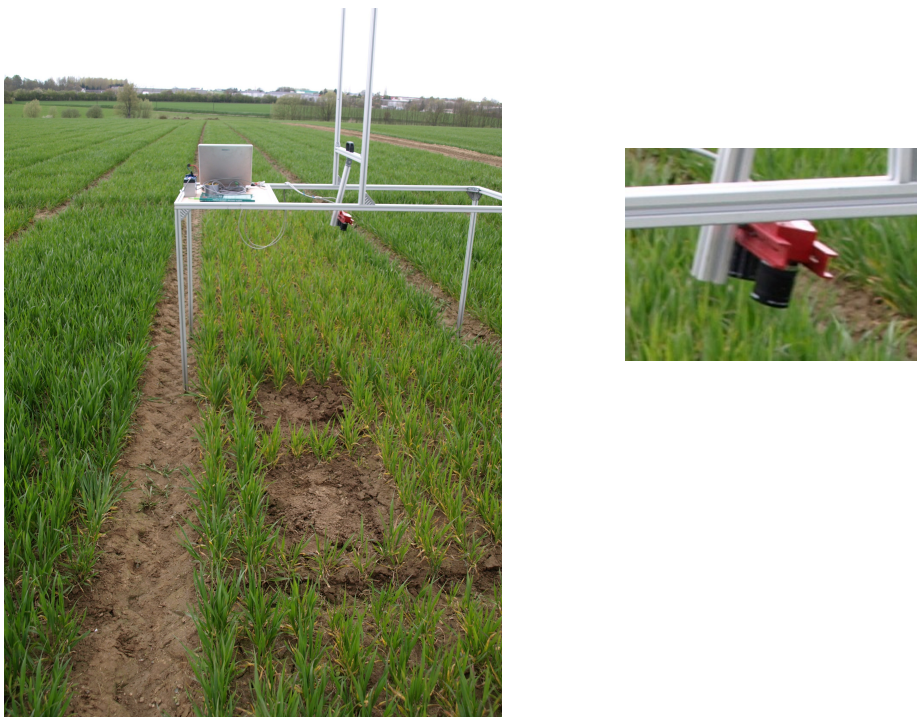


FIGURE 1: Experimental set up showing one plot with the pickings of March and April, and the acquisition device (camera couple and portable computer to record the images).

For the 3D part, the first treatment was a geometrical rectification so that corresponding pixels were on a same horizontal line on both images. This correction is visible in the two upper images of Fig. 2. The disparities, that is to say the horizontal distances between points in the right image relatively to the corresponding points in the left image, were computed by using Hirschmuller's algorithm (2008). For several parameters the default values were not the best ones because the objects in this application (leaves) were of small size. The "matched block size", the size on which the matching of the disparities was computed, was fixed to 3 pixels. The "uniquenessRatio", a parameter used to detect doubtful matches between the left and right images was fixed at 5 percent and the "speckleWindowSize" was of 50. For the other parameters defaults values were adopted. A rectangular region of interest including all the pixels common to both images was determined. After a suitable calibration, the pixel disparities were converted in camera linked three dimensional metric 'xyz' referential with the origin centred on the sensor, the 'z' coordinate pointing to the camera (all z values were thus negatives).

In a next stage, the plants were segmented from the soil in the left image by linear discriminant analysis applied on the RGB colour parameters of the pixels. The discriminant function was computed and thresholded (Fig. 2 bottom right). The analysis was based on a sampling of plant and soil pixels. The chlorotic leaf pixels were considered as soil pixels because the LAI only includes the photosynthetically active areas.

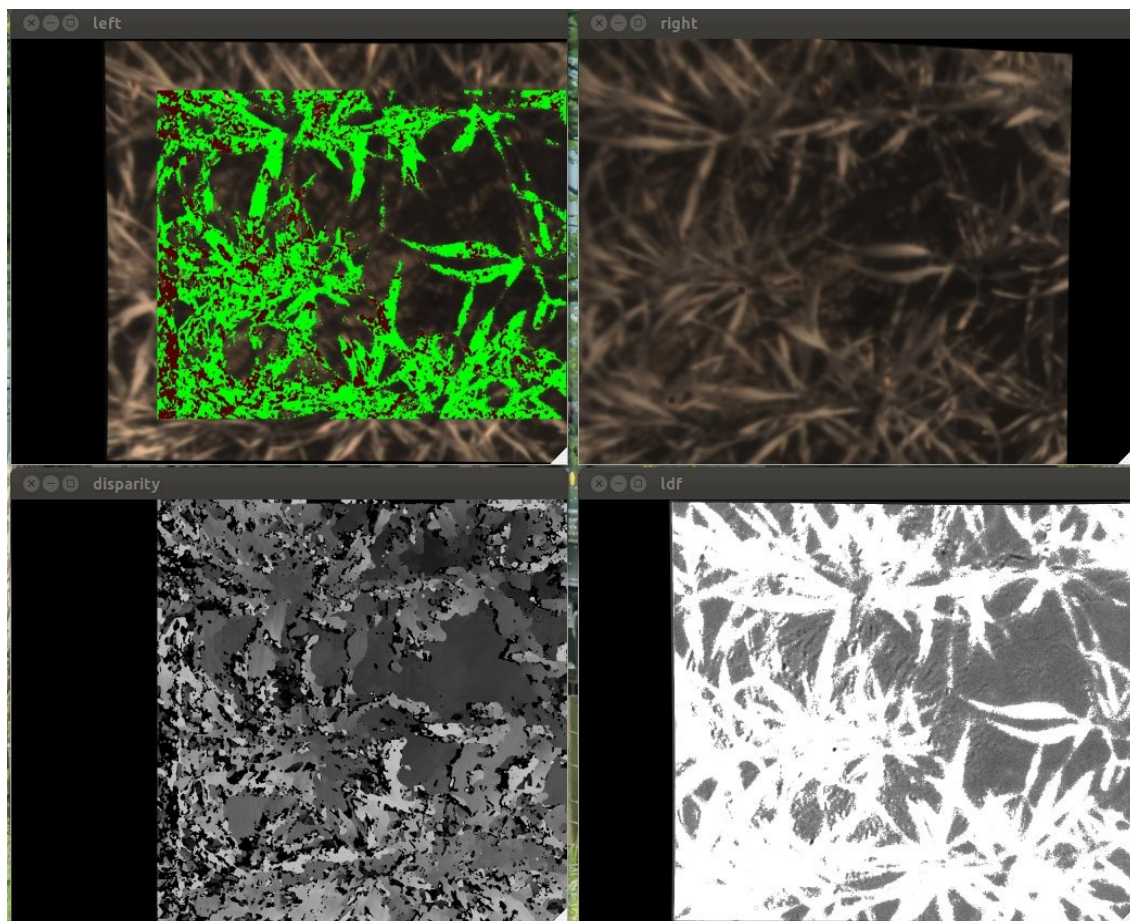


FIGURE 2 : Example of images acquired and result of the treatments. Above left, left images after geometrical rectification with superimposed in the region of interest, on the plant pixels a green colour where the 3D computation was possible and a red colour where occlusions occurred (corresponding to the black pixels on the bottom left image). Above right, the right image after geometrical rectification. Below left the disparities, the pixels closer to the camera being lighter grey. Below right, the soil plant discriminant function output.

The real dimensions of the observed area were computed based on the mean distance from the camera to the leaves, from the focal distance and from the sensor dimensions. Because the leaf density was not homogeneous in a dimension perpendicularly to the plant rows, it was essential to limit the y dimension of the region of interest (perpendicular to the plant rows) to an entire number of inter-row distance. This area was used as soil area reference for the LAI and was around one tenth of a square meter. It is shown in Fig. 2.

The leave area was evaluated for each triplet of adjacent pixels. This includes the computation cross product (CP) of two vectors joining the summits of the triangle in the xyz coordinate system. The direction of the perpendicular to the local leave plane was given by the resulting vector and the area was given by half its module. The total area of plant leaves was computed by summing the local areas over the region of interest. The ratio of this sum to the reference soil area gave directly a measurement of the leaf area index.

The angle between CP vector and the z axis was given by :

$$\alpha = \arccos\left(\frac{CP_z}{|CP|}\right)$$

The mean of this angle for the ROI gave the ALA.

The coverage ratio (CR) defined as the ratio of a projection of the leaves on a horizontal plane occupied by leaf pixel for a given area was also computed.

3. Result and discussion

Figure 2 shows an example of couple images and their treatments. These images were form 23rd of March. The result of the geometrical rectification was responsible for the skewed top and bottom borders of the images. It can be seen on the upper left image that the height of the region of interest covers two plant rows.

The sensibility of the LAI measurement to variation of the parameters was tested. Only the threshold had a significant impact.

Analyses of variances were carried out to compute the variability between images of the same plot, between plots for the same treatment, and between the different treatments (AV1 for reference data, hierarchical AV2 for the 3D data). The means, the standard deviations, and the variances are given in Table 1.

3.1. Analysis of the variabilities

The variabilities between treatments were close for both methods (Tab. 1). For the reference method the variability at plot stage was high, close to the variability between treatments.

Table 1 : General LAI means, standard deviation and variances (between parenthesis) at different stages (in leaf m² / soil m²).

Source of variations	Reference	3D estimate
General averages	1.35	1.14
Treatments and dates	0.39 (0.155)	0.36 (0.131)
Plot	0.36 (0.13)	0.13 (0.017)
Between images		0.27 (0.074)
Total	0.52 (0.27)	0.45 (0.21)

One reason was that the picking dates were early in the growing season and the variability between treatments (including dates) would grow as the season goes by (and as plant grow). This could also be understood by looking at Fig. 2. The central row in Fig. 2 presented a gap corresponding to missing plants. This particular gap was of around 20 cm, which was wide but not unusual. On the contrary, the bottom row was densely populated. Eventually, the plants around the gap would produce more tillers and the gap would be filled. But this had as consequence that the variability in the reference measurements could be high. For the reference measurement the residual variability (at plot stage) included the measurement variability, the “in line” variability and the “between plots” variability while for the 3D images this variability was decomposed. It can be seen on this latter that the residual variability (between images) was more important than the variability between plots.

The destructive reference measurements were made on a distance of 0.5 m, which cover 0.073 m² while the 3D data represent around 0.1 m². The bigger area measured by vision could account for the lower residual variability.

3.2. Estimation of the reference LAI

Table 2 gives the correlation data for the estimation of the reference LAI based on the 3D-LAI measurement and on the covering ratio, at different stages while Fig. 3 shows the corresponding scattering diagrams (at image stage, represented in Fig. 3a and c by blue dots and at plot stage, Fig. 3b and d).

It can be seen from Table 1 (mean values) and from the lines in Fig. 3b that the 3D-LAI underestimated the reference LAI. This was expected due to the leaves overlapping and justified the estimation of the real value by regression on the 3D-LAI.

Dispersion in data at image stage and in graphs a and c Fig. 3 included the high local variability while those at treatment level reduced significantly those variations. Accordingly the correlation at treatment stage was much better but to the price of acquiring 20 couples images. More generally the standard deviation of the estimated values (Table 2, $S_{y,x}$) at stage level was around 0.15 *i.e.* a coefficient of variation above 10%. By acquiring five images, as in these experiments, the LAI could be estimated with a standard deviation of 0.07, that is to say a coefficient of variation around 5% which should be accurate enough of agronomical and modelling applications.

When comparing the coverage ratio and the 3D-LAI, the advantage of the latter on the former was not obvious at that date. Contrarily to the LAI, the coverage ratio is limited to the unity and the relation between the LAI and the CR is known to present a saturation phenomenon. At that moment of the season, it remained to be seen how the 3D-LAI could overcome this problem.

The average leaf angle was 58° in March and 54° in April. This measurement was strongly influenced by the wind conditions.

Table 2 : Determination coefficient and standard deviation of the estimated LAI for different estimators (in leaf m² / soil m²).

Correlation between	r ²	S _{y,x}
LAI _{3D} – LAI _{Ref} at image stage (Fig.3a)	0.41	0.155
LAI _{3D} – LAI _{Ref} at treatments stage (Fig.3b)	0.87	0.028
CR – LAI _{Ref} at image stage (Fig.3a)	0.45	0.145
CR – LAI _{Ref} at treatments stage (Fig.3a)	0.83	0.037

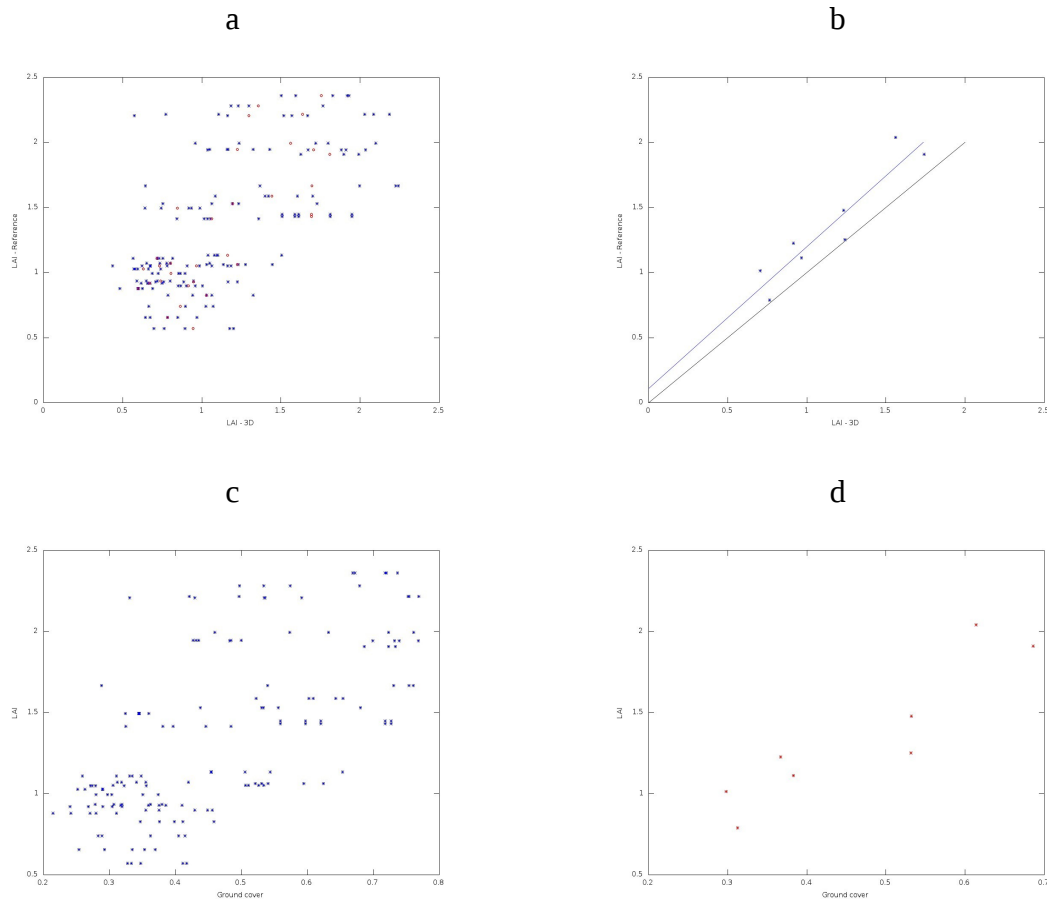


FIGURE 3 : Scatter diagrams of the reference LAI against the 3D-LAI (a, b) and the coverage ration(c and d) for the image level data (a and c) and treatment data (b and d).

4. Conclusion

A method to evaluate the leaf area index by using stereoscopic images was presented. The early results showed that the 3D-LAI could be used to estimate the real LAI but the advantage on the measurement of the covering ratio was not obvious at that moment of the season (April).

As for the reference method, due to the high variability of the LAI into the field, it was necessary to acquire images at several places, in consideration of which the precision of the method was higher than that of the reference and thus efficient enough for agronomical or modelling applications. This means that for a real time application a wider inspected area seems necessary, which means to consider the use of a sensor with more pixels. For sampling applications, the cost of the measurements in term of human time is much lower than the reference method, which could permit more samplings and more frequent samplings.

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