XVII^th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

FOURIER FILTERING FOR WHEAT DETECTION IN A CONTEXT OF YIELD PREDICTION

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CSBE101090 – Presented at Section III: Equipment Engineering for Plant Production Conference

ABSTRACT Prediction of wheat yield appears as a fundamental objective in agriculture for economical and environmental reasons. The use of image processing can be one of the solutions not only with remote sensing tools, but also with “proxy-detection” systems. Nevertheless, to obtain a wheat yield, three components have to be measured and first of all the number of wheat ears per m². The evaluation of this parameter is a two-steps experiment: detection and counting. A colour and texture image analysis method based on the representation of the images in a hybrid space was first developed for a feasibility study to count (semi-)automatically Triticum aestivum wheat ears to simplify manual counting. This new representation was constructed with a priori knowledge about the images (especially the number of classes and training points), providing a better recognition than in the standard RGB space (Red/Green/Blue). Results on a few images gave errors on classification accuracy ranging from 6% to 10%. To improve the image processing, robust and rapid solution has to be found. This paper presents the development and implementation of a high-pass filtering on the Fourier image of the scene coupled to mathematical morphology tools like skeletonization. This method requires low calculation time, is easily to implement and is invariant, in most cases, to illumination constraints. It provides better wheat ear detections than those obtained with hybrid spaces. First experiments on wheat ear counting give errors of 4% between calculated and manual counting which corresponds to classical errors done by the technicians. The first stage of yield prediction is then reached and new experiments are currently conducted on the determination of the number of grains per ear, second component of the yield. Finally, these works will have to be combined with agronomical models of the wheat growth stages to propose a global solution for yield prediction by classical image processing.

Keywords: colour images, Fourier filtering, wheat ear detection.

INTRODUCTION In the general context of precision agriculture, the intraparcellar variability of the fields is highly correlated to a better management of the inputs (fertilizer, phytosanitary products …) so as to optimize, not strictly to increase, the yields with economics and environmental objectives. The development of NTIC techniques has allowed relevant progresses for the estimation of significative parameters of the crops: infestation rate (Zhang et He 2006), Leaf Area Index (LAI) (Richardson et al. 2009), crop density (Saeys et al. 2009), stress (Zygielbaum et al. 2009). Most of the tools utilizes optical or imaging sensors and dedicated treatments, in real time or not, and eventually combined to 3D plant growth modeling or disease development (Fournier et al. 2003 ; Robert et al. 2008). To evaluate yields, the remote sensing imaging devices are often used to complete or replace embedded sensors on the agricultural machines (Aparicio et al. 2000). Even if these tools provide sufficient accurate information, they get some drawbacks compared to “proxy-detection” optical sensors: resolution, easy-to-use tools, accessibility, cost, temporality, precision of the measurement …

A project has then begun in AgroSup Dijon in 2004 to develop image acquisition system and image processing to predict a wheat yield. Since a yield is the combination of three components – number of wheat ears per m², number of grains per ear, thousand-corn weight, our research were focused on the determination of the first component. This objective will help farmers in their optimization of late N application and agronomical technicians for the simplification of the wheat ear counting process currently done manually. Moreover, it could also help French agricultural cooperatives for a better organization of the harvest and storage logistics.

Little research has been done on wheat ear counting. The first contribution is the feasibility study conducted by the Agronomic High School of Bordeaux (Germain et al. 1995) in collaboration with ARVALIS-Institut du Végétal. Although the results found were satisfactory, they were obtained on small area and on a limited number of images. We decided to contribute to this research database by using new technology or methods such as plant or weed recognition. A first technique has then been developed to detect and after count the wheat ears by representing each image in a colour-texture hybrid space and by using mathematical morphology tools (Cointault et al. 2008). Some improvements have also been developed in Cointault et al. (2008).

The whole method gives satisfying results for images taken at all the wheat growth stages even if the ears have a lot of overlapping. However, we can notice that the hybrid space construction method is a supervised one and is again limited by the objectivity of the operator. Moreover, no recurrent hybrid space has been found for all the images, which does not allow automation of the process.

The objective of the current project is then to propose new detection algorithms more rapids, robusts, and invariants according to image acquisition conditions. In the present paper, the new image acquisition system will be first presented, before to develop the associated treatments and the Fourier filtering used for wheat detection. Results on the filtering will be after compared to detection results obtained with the hybrid space technique previously implemented. The yield prediction needing first the wheat ear counting, rather than detection, we will propose some tools currently tested for an automatic counting.

MATERIALS AND METHODS

New image acquisition system Last experiments have shown that the conditions of exposure have a great influence on the future image processing. Difficulties are tied to external conditions (illumination) and to object shapes (2D or 3D). To improve the previous imagery device, we tested different illumination options such as flash, power-leds, natural lighting … combined with the use of opaque protection around the camera to avoid reflection of solar lighting on the soil (Figure 1).

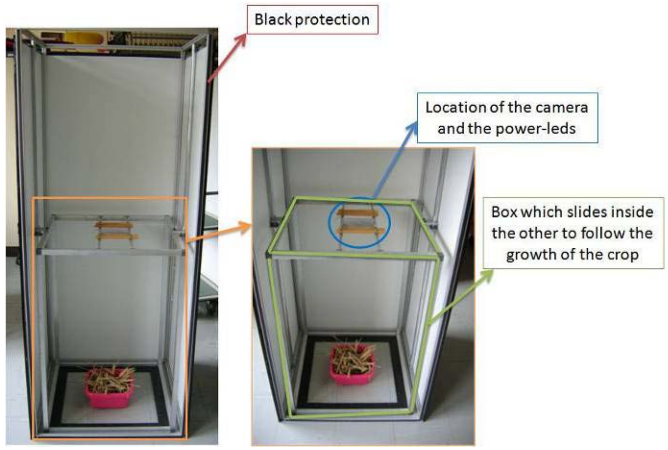

Figure 1. The new image acquisition system in our laboratory.

The use and the control of two 3W power-leds which illuminate directly the scene allows us to obtain perfect images which do not need any image enhancement (Figure 2).

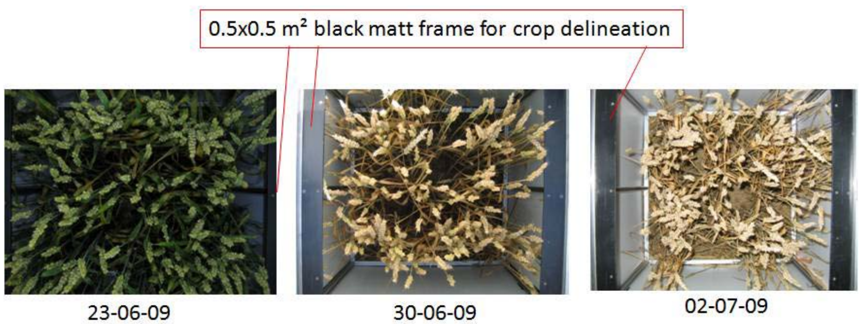

Figure 2. Three wheat images took at three different wheat growth stages.

The use of this imagery system allows to propose then specific image processing as described in the following part.

Image processing by high pass filter Fourier transform This image processing is based on the well known two dimensional discrete fast Fourier transform (FFT) (Cooley and Tukey 1965) and its associated frequency space. This approach includes three important steps: filtering, thresholding, cleaning.

-1: Compute a high pass Fourier filtering: a two dimensional FFT is performed on the target image (equation 1).

$$F(k_x,k_y)=\frac{1}{\sqrt{N_xN_y}}\sum_{n_x=0}^{N_x-1}\sum_{n_y=0}^{N_y-1}f(n_x,n_y)e^{\omega\frac{k_xn_x}{N_x}}e^{\omega\frac{k_yn_y}{N_y}} \quad (1)$$

with $\omega=-j2\pi$.

Based on the centered Fourier image, a high pass filter is applied in order to eliminate low frequencies in the FFT image (Figure 3). The cut off frequency is empirically sized by a 10 pixels width disk mask as it is shown in Figure 3.

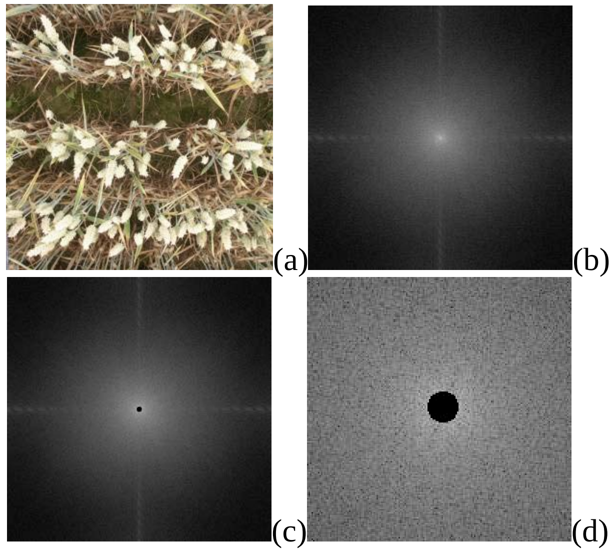

Figure 3. Exemple of wheat image (a), (b) its associated FFT projection, (c) cut off disk, (d) zoom of cut off disk.

-2: Thresholding the resulting image: Inverse FFT is performed and a predetermined threshold is applied in order to eliminate low pixel values which do not correspond to wheat objects (ground, leaf,…) (Figure 4).

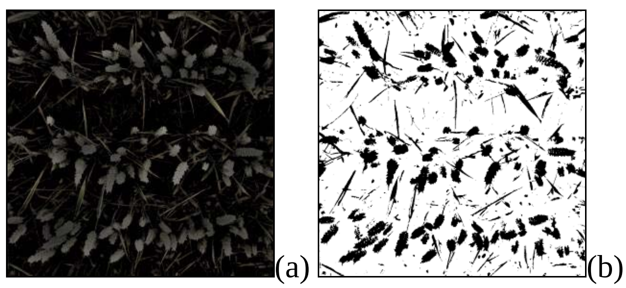

Figure 4. Image after inverse FFT(a) and threshold image (b).

-3: Cleaning: Cleaning step aims at eliminate remaining “non wheat” pixel groups, which are small and scattered. It lies on mathematical morphology operation (Serra 1982) and is performed with three sub steps:

- First, a dilatation, which aims at making bigger and closer pixel groups in the image.
- Then a blurring convolution with a Gaussian smoothing operator, followed by a thresholding, which eliminate too small groups of pixels. These small groups are considered as miss. This step makes smaller the pixel groups that correspond to wheat and then justify a third step.
- Finally, another dilatation is performed which aims at regenerate size of pixel groups corresponding to wheat ears (Figure 5).

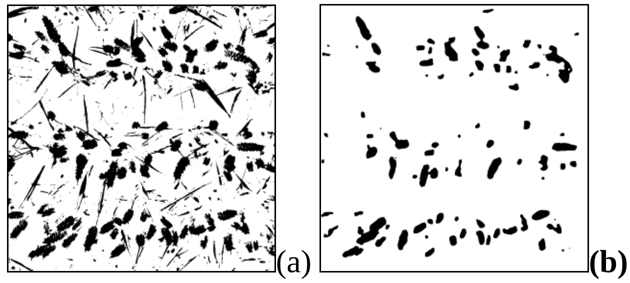

Figure 5. Threshold image (a) and cleaned image of wheat detection (b).

Wheat ear counting estimation The first image processing by high pass Fourier filtering gives a binary image, composed of several pixel groups. Each group represents one or more wheat ears to be counted. In order to estimate this number we analyze the shape of each group considering two possible configurations:

- Pixel group presents a convex or nearly convex shape pattern: it is considered that only one ear is present in this kind of group (Figure 6a).
- Pixel group presents a concave shape pattern (Figure 6b): it is consider that several ears are presents.

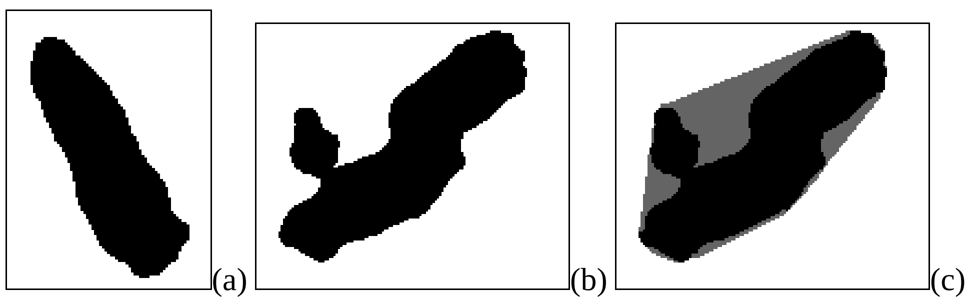

Figure 6. Pixel groups with nearly convex (a) and concave shapes (b), convex hull of a concave shaped pixel group (c).

In order to quantify the number of wheat ears, we estimate a shape indice based on two features extracted from each pixel group:

$$Q = \frac{S_c - S}{S} - 1 \quad (2)$$

With S the surface and S_C the convex hull surface of the pixel group (Figure 6c).
Coming from this indice, a number X of ears is attributed for the group, considering this interval :

$$(X - 1)/10 < Q < X/10 \quad (3)$$

RESULTS AND DISCUSSION

Wheat ear detection results For the first experiments, here are principally presented the qualitative results on wheat ear detection by high pass Fourier filtering.

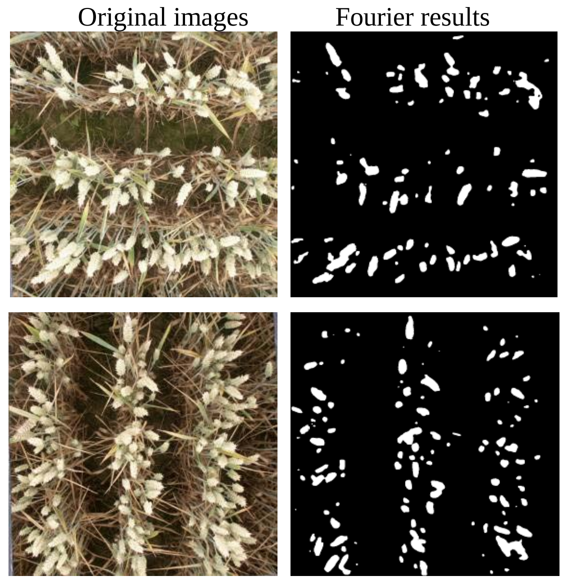

Figure 7. Results of wheat ear detection using high pass Fourier Filtering.

A fast visual observation (Figure 7) shows that only a small amount of groups corresponds to non-wheat things in image. More precisely, the biggest wheat ears are well detected and well separated from surrounded leaves. Ears that lie the nearest of the ground, that are partially hidden or that are a little bit over exposed in the image are not well detected. Small amount of very big leaves also remain after cleaning step.

In order to test our image processing we performed algorithm on 40 images and compare the results with the mean of manual counting done by several experts. For the example, five images sample have been randomly chosen (Table 1). Results are represented in figure 7:

Table 1. Specifications of five experimental drying runs used for validation.

Image	Counting		Difference (%)
	Manual	image processing	
1	139	142	2,11
2	36	34	-5,88
3	90,5	94	3,72
4	116,5	122	4,51
5	136,5	142	3,87

Within the image set, a high variability of ear's number can be observed. With most of the images, high pass Fourier filtering method returns slightly higher counts. Based on the whole image sample, absolute difference between manual counting and image processing counting is contained under the value of 6%. The mean error obtained is 4,02% for this set of images.

Comparison with hybrid space results The development of a high pass Fourier filtering approach method aims at creating an easily usable and adaptable method while obtaining a best wheat ear detection. Therefore, it is essential to compare this approach with previously used methods such as hybrid space method (Cointault et al. 2008). For a visual comparison, high pass Fourier filtering has been applied onto images that have been previously treated with hybrid approach (Figure 8).

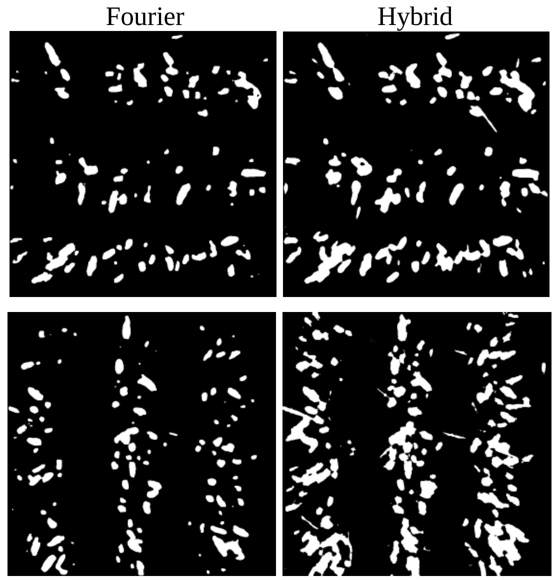

Figure 8. Visual comparison between Fourier and Hybrid approach results for two different images.

Visual comparisons with hybrid space results show that high pass Fourier filtering approach eliminate more non wheat objects within the images. Fourier approach separates more efficiently ear groups. Calculation time for Fourier approach is few sec per image while its few minutes for hybrid space, with the same operating system.

Discussion High pass Fourier filtering gives global satisfying results. Although a close range of settings has been determined, inverse FFT remains a parameter that has to be adjusted according to input image. An empirical value has been found and gives good results for most of images but it could be optimized with an automatic threshold selection such as k-means methods (MacQueen 1967).

In the context of wheat detection, it has been observed that some ear objects are eliminated after cleaning step. These non-detections mainly correspond to near ground ears or ears massively hidden under leaves, hence, it should be relativized as too low ears may have development problems and may not be considerate within wheat yield. Ears that are located in over or under exposed part of image are not well detected but it is not due to the algorithm but to the quality of the acquisition, which is limited by the natural conditions. Small amount of very big leaves also remain after cleaning step and eliminate these artifacts constitute a further axis of development, including shape analysis in cleaning step.

In the context of wheat ear counting, it is observed that counting error percentage decrease with number of ears in images, hence, best results may be obtained with images representing more area and yet, more ears. Actually, worst error, 5,56%, is obtained with only 36 wheat ears in the image.

It is important to note that in most cases, Fourier approach returns slightly higher counts than manually counts. It should be due to missing detection, such as remaining leaves or over exposed part of images. Counts should be more precise with the including of shape analysis in cleaning step.

CONCLUSION To predict wheat yield, remote sensing tools are not the only solution. Proxy-detection systems allow to acquire high resolution images to be treated by robust algorithms such as high pass Fourier filtering. Before to predict yield, the number of wheat ears has to be determined and is the resultant of a detection and a counting step. Detection has been done using colour-texture hybrid space in older work and classical image processing based on Fourier filtering, according to the frequential information included in the images.

In this paper, we have presented the high pass Fourier filtering technique which gives satisfying and robust wheat ears detection with lower computing time. Moreover, we have compared the detection results with those obtained by representation in a hybrid space. Even if we obtain satisfying results for this qualitative experiment, some improvements should be done such as including an automatic threshold determination after the inverse FFT and an efficient shape analysis in order to obtain a finer wheat ear detection and better artefacts elimination.

In the case of Hybrid/Fourier comparison, we have limited voluntarily our study to a qualitative and visual analysis. In further work, we should improve the analysis by using a quantitative approach and measure accurately the difference between the two methods.

Acknowledgements. Special thanks to Richard Martin for the conception of the acquisition apparatus.

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