AUTOMATED DIGITAL IMAGE ANALYSES FOR ESTIMATING PERCENT GROUND COVER OF WINTER WHEAT BASED ON OBJECT FEATURES

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Abstract: Percent ground cover of vegetation is an important parameter for crop management. An innovational method based on features of objects was presented to automatically estimate percent ground cover of winter wheat from digital image analyses. Based on the features of wheat and its background components, an algorithm was designed to extract the percent ground cover, and the corresponding program was developed. This method was simple, labor-and time–saving with high classification accuracy about 90%, and the method combined the advantages of ISODATA method and maximum likelihood method. Finally the error source of automatic classification and scope of application were analyzed, and some approaches of improving accuracy of classification were discussed.

Keywords: percent ground cover, image analyses, features extraction, automation classification

1. INTRODUCTION

Percent ground cover of vegetation is an important parameter which both agronomists and ecologists concern about. Not only does it reflect plant's dynamic growth in a long time, but also it is associated with abstraction of photosynthesis available radiation (APAR) of plant. It can reflect photosynthesis and transpiration (J E Adans et al., 1977). With the development of precision agriculture, remote sensing has provided an important tool for retrieving crop's water or fertilizer stress, monitoring crop conditions and offering decision information for the optimized agricultural production management. Percent ground cover of vegetation is closely related to remote sensing spectrum index. Stanhill (1972) pointed out that the differences of spectrum abstraction were due to the amounts of biomass and percent ground cover of vegetation (Stanhill G et al., 1972). Wanjura and Hatfield (1987) considered that the remote sensing crop index was affected by percent ground cover of vegetation more than by dry，fresh biomass or other parameters such as LAI (Wanjura D F et al., 1987). So, estimating percent ground cover of crop is of great importance in agriculture cultivation.

The traditional ways (J E Adans et al., 1977; Armbrust D V; Robert P, 1999) to estimate percent ground cover of crop are as follows: ①Agronomists estimate percent ground cover of vegetation by their experience in field. The main default of the method is the results are too subjective, and different persons may have different judging and values, even greatly. ②A ruler or electronic device can be used to estimate the values based on the theory of light capture around noon. The main default of the method is that it is affected by the weather and the direction when measuring, and it is a labor-consuming method. ③Percent ground cover of vegetation can be estimated by observing the pictures taken vertically and by counting the green elements in the photos.

So the ideal method to estimate percent ground cover of vegetation mainly includes following procedures: ①Cheap and easily manipulated equipment should be adopted. ②The in-situ data should be accurately and objectively treated. ③The method should save time mostly and be restricted the least when measuring in field. ④The process should be scarcely disrupted by the operator (Q Zhou, 2001).

The method to take pictures of crop canopy by digital camera, divide the image to crop and non-crop (soil and residuals) two classes, and calculate percent ground cover of vegetation in two-value image arithmetic could be a good choice among other methods. Along with the expanding market of digital camera, it is widely used because of the stronger space resolution, larger storage capacity and cheaper price. Percent ground cover of wheat has been estimated through alternatively changing contrast and color balance of digital images by Lukina (Lukina E V et al., 2001) using software "Micrografx picture publisher". Percent ground cover of corn has been estimated through alternatively changing the threshold of red, green, blue color, the hue, lightness, saturation or principle component analysis of red, green and blue color by Ewing (Robert P, 1999) using the software "RGBcal DyEye and RootEdge". Percent ground cover of pasture has been estimated through alternatively changing the threshold of tone and saturation by Richardson using software "SigamaScan pro". These research results demonstrate that percent ground cover of crop can be estimated by digital image analysis technology. However the estimation accuracy is affected by sunlight condition, the values are more precise in darkness than in sunlight. Moreover, these methods are labor-and-time consuming with strong subjectivity and frequent interpretation of the operators, so they are not satisfying now.

Winter wheat was chosen as materials in the research. With digital camera to take pictures, the research had adopted relevant analysis technology and put forward an automated extraction method to estimate percent ground cover of crop with more accuracy and objectivity. The aim is to offer a credible and rapid method to estimate percent ground cover of crop.

2. EXPERIMENTAL DESIGN AND METHODOLOGY

2.1 Experimental design

When measuring agricultural parameters, the digital image of winter wheat was taken at the Country Precision Agriculture Demonstration Base in the growing season in 2002. The experiment site is located in Changping district (40°10′6″ to 40°11′2″N, 116°26′3″ to 116°27′0″E). The varieties adopted in the experiment were horizontal "Zhongyou 9507", erect "Jingdong 8" and moderate "Jin 9428".

The factors included in the experiment compromised 4 fertilizer applications and 4 water strategies in order to study stress variability. There were 48 plots with 32.4m×30m for each. Four treatments received the following amounts of N at: 0,150, 300 and 450Kg/hm^2. Four water strategies were applied at rates of 0, 225, 450 and 675 m3/hm^2.

2.2 Field data acquirements

2.2.1 Digital pictures acquirements

The winter wheat in the 48 plots was taken pictures of by Sony camera, four times before full crop and twice after that. The first four days were Mar.25th, Apr. 2nd, Apr. 10th and Apr. 18 respectively, leaving the other two days in May. When taking pictures, the digital camera should be positioned erectly 1.5m above the ground between 11 o'clock am 12 o'clock. Because of the weather, some pictures were taken under the shadow of cloud. The pixel size of the photos is 2228×1712, which were stored in the computer in the form of JPEG (joint photographic experts group) and the total number of the image was 192.

As image of the digital camera was derived from the theory of center projection, which contributed to the distorted image when the field view angle grows larger, the image fringe has the most distortion. So only the 1284×1284 pixels in the center of the photos were taken to analyze and compute the percent ground cover of wheat.

2.2.2 LAI index measurements

After the digital pictures were taken of the winter wheat, the corresponding wheat should be collected thereafter. The dry biomass method was adopted to measure LAI in Laboratory. 50 to 100 standard leaves were chosen from each sample to measure leaf area (marked S1) and weigh the dry weight of these leaves (W1) and the rest leaves for each sample (W2). And the LAI of each sample can be calculated by the following equation: $LAI=S1\times (W1+W2)/W1$. The measured values of LAI were revised by CI-203 Laser Area Meter finally.

2.3 Methodology

2.3.1 Background-red, green, blue (RGB) and hue, lightness, saturation (HLS) color space

Digital camera has coupling filters of three different colors, each of the filter corresponds to a special sensitive spectrum band. The three different sensitive band are red(R), green (G) and blue (B) in Descartes color space.

Any color in the nature can be represented a point in the space, ranging from 0 to 255.

Another color space is Munsell system, which depicts color with hue (H), saturation (S) and lightness (L) in accordance to our vision. The space is defined as a two cone body with two vertexes, one is white and the other is black. Hue can be represented by ways of surrounding the vertical axis which itself represents lightness, and the emanative radius along the horizontal direction toward outside represents saturation (Robert P, 1999; Kenneth R, 1996; MEI An-xin, 2001). The colors depicted in either space can be transferred into the other.

2.3.2 Wheat image features

From re-green stage (Mar. 25th) to late jointing stage (Apr. 18th), it is a fast-growing period for wheat and the percent ground cover increases rapidly.

Before the cover reaches 100%, the height of wheat is low and leaves are all green without wilted ones. The hot-spot effect isn't apparent in sunlight. On the other hand, there are lots of bare land and crop residues. In digital image, the soil background and crop residues change greatly and the lightness of certain parts is higher than wheat. From the statistic values of RGB, variances of the two classes of objects are small. After the cover reaches 100%, winter wheat grows high and vertical layer has been shaped. On different layers of wheat leaves, the sunlight conditions vary. Under strong sunlight, the upper layers have strong hot-spot but the lower layers are in the shadow of upper layers. Bare land can hardly be seen in this period. Based on the theory that variances among different objects should be the least, the image can be classified as five classes as follows: ① wheat under sunlight without hot-spot; ②wheat under sunlight with hot-spot; ③wheat in the shadow; ④soil under the sunlight; ⑤soil in the shadow. There is wax on the surface of some wheat. Though only wheat and background need to be considered, however they can't be simply classified as two classes according to a certain program because there are lots of transitions between the two classes in changing sunlight.

2.3.3 Classification theory

The green vegetables appear green because of the strong abstraction in the red and blue spectrum band region and reflection of most of solar radiation in the green spectrum region. So the reflected radiation in the green spectrum is more than that in red and blue spectrum region.

As to the image before full crop, wheat satisfies the form G＞R and G＞B. However, background (soil, crop residues, etc) covers a large portion in the image, and some crop residues appear brown or grey brown which also satisfy the form G＞R and G＞B. The residues characters are that the RGB values have slight differences and the G value is the highest among the values. So it is necessary to eliminate residue pixels. It is a good way to distinguish green and brown objects with saturation when the RGB color space is transferred into HLS color space. In the HLS color space, saturation 60 degrees is kelly and 240 degrees is bottle green. The saturation value of crop residues is 0-20 degrees and 340-360 degrees, and that of wheat is 60-240 degrees.

As far as the image after full crop, wheat cover is above 80%, mainly around 90%. So wheat in the period can be classified as three sub-classes. (1) Wheat with hot-spot, it is strongly shined in the daytime and many lightness values are high even above 0.9. Part of soil under sunlight is relatively lighter, but the lightness value is less than that of wheat with hot-spot as the soil is lower than wheat. As a result, the threshold of L values is x＜L＜1, in which x stands for the highest value of soil or a value above the highest one, in the paper it is set at 0.9. (2) Wheat under sunlight, the color of it turns from olivien to bright green, and the corresponding saturation values range from 90 to 240 degrees. It can't be misclassificated as soil. (3)wheat in the shadow, the color of it is green and it satisfies the form R＞G and R＞B. In order to avoid the effects of soil, 60＜H＜90 is added as the limitation factor. Maybe there are overlapped parts between the first and the second part, but the soil has been separated successfully. Finally the wheat image can be got by combining the three subclasses: (1), (2) and (3) together.

2.3.4 Automated extraction algorithm on percent cover of wheat

According the automated extraction theory, the arithmetic is as follows:

(1)automated extraction arithmetic image before full crop

If the pixels satisfy the following form :｛R＞G and R＞B, 60≤H≤240｝, they can be classified as wheat, or else as soil (R, G, B represents red , green, blue value respectively, and H represents saturation of pixel).

(2)automated extraction algorithm image after full crop

A. Transfer RGB color space into HLS color space, H ranges from 0 to 360 (0 represents red , 120 represents green, 240 represents blue), L and S range from 0 to 1 (2002).

B. If the pixels satisfy the form 90≤H≤240, they can be viewed as wheat and belong to class one as mentioned above correspondingly. The color turns from olivine to bright blue and covers the corresponding part.

C. As to the pixels left, if they satisfy the form x≤L≤1, they can be viewed as wheat and belong to class 2 mentioned above correspondingly (x is the highest value of soil or the value over the highest one, and it is usually set at 0.9).

D. For the rest pixels that are excluded from the above two classes, if the pixels satisfy the form: R

R＞G and R＞B, 60≤H≤90, they can be viewed as wheat and belong to class 3 as mentioned above.

2.3.5 Automated extraction program on percent cover of wheat

Based on the algorithm mentioned above, automated extraction program on percent cover of wheat is developed in IDL Language (MEI An-xin, 2001), which compromises three steps as follows. The first step is to read all the digital images and files in the same directory by calling READ_JPEG in the batch processing. The second step is to transfer RGB values to HLS values by calling COLOR_CONVERT. Using the extraction algorithm of wheat, digital image before and after full crop can be differentiated pixel by pixel and classification results (value one represents wheat and value zero represents background) are stored into array. The third step is to call IMAGE_STATISTICS to statistically classify the frequencies of one and zero in the array. Then figure out percent cover of wheat and export the value into files.

The program uses figure-user interface which can be easily manipulated, and the main procedures include: (1) put the image that needs to be treated with in the same directory; (2) run the program and input directory name; (3) the program will be automatically searching for all the images in the directory and classifies them individually; (4) export the results, each image will engendering a chart that contains classification results information and the percent cover of wheat data in all the images will be exported into a file.

3. EXPERIMENT RESULTS AND EVALUATION

3.1 Automated extraction accuracy on percent cover of wheat

Computer digital image classification includes supervised classification and unsupervised classification. Supervised classification firstly needs to choose training sample from manual work and the accuracy is closely correlated with the amounts and the degree of representation of the samples chosen. The unsupervised classification needn't choose training sample because it combines and classifies the pixels by their similarity, so it is an automated method.

The most popular methods in the research are unsupervised classification—ISODATA method, supervised classification-maximum likelihood method (ML), and the automated extraction method suggested in the paper. And six images were randomly chosen in the experiment to classify wheat and extract the percent cover of wheat, the accuracy of the three methods were evaluated by the observing the digital pictures visually. Among the pictures, the former four were taken of before full crop and the two latter pictures are after full crop, which are shown in Figure 1.

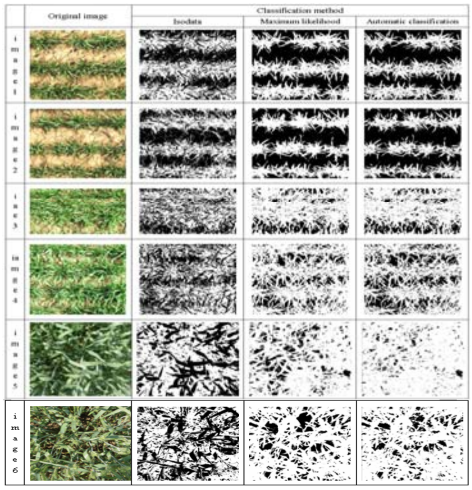

*Fig.1:*Six cases of three classification results and their comparisons

ISODATA method and maximum likelihood method were run with software packet ENVI3.5 (2002). Before applying the maximum likelihood method in the whole image, the evenly distributed training samples of wheat and soil background should be chosen manually and respectively.

The classification results of the six images applying the three classifications mentioned above are shown in Figure 1.

One hundred pixels randomly chosen in the six images were judged visually and classified as wheat and soil then compared the results of the three methods with the visual judgment. Rusesll's error matrix (Russell G Congalton, 1991) provides reference to assess the accuracy of the three methods in the paper. The error matrix for accuracy assessment as Table 1.

Table 1 The error matrix for classification accuracy assessment

	Reference data (from eye judgment)		
Classification data	wheat	soil	total
wheat	a	b	number of wheat
soil	c	d	number of soil

Note: a: the number of wheat pixels that have been classified as wheat in the reference data; b: the number of wheat pixels that have been classified as oil in the reference data; c: the number of soil pixels that have been classified as wheat in the reference data; d: the number of soil pixels that have been classified as soil in the reference data. The overall classification accuracy can be calculated by the form: (a +d)/ (a + b+ c+ d) ×100%.

The classification accuracy of the six images with three different methods is shown in Table 2, respectively.

Table 2. Overall accuracy(%) of six image with three classification methods

	Isodata	the maximum likelihood	the automated extraction method
image 1	63	90	87
image 2	55	91	95
image 3	54	89	88
image 4	48	91	85
image 5	68	85	93
image 6	45	92	93
average	55.5	89.7	90.2

Table 2 indicates that ISODATA method has the lowest classification accuracy (45%-68%, 55.5% on average), and the maximum likelihood method and the automated extraction method both have high accuracy with little difference.

The comparisons of the three methods are shown in Table 3. The theories of them are different. In terms of choosing training samples, objectivity, batch processing, work amounts, processing time and individual participation of the three classifications, automated extraction method and ISODATA method are very similar, simple and fast. However the maximum likelihood method is labor-and-time consuming. With respect to classification accuracy, the maximum likelihood method and automated extraction method have higher classification accuracy than ISODATA method. So the automated extraction method based on the digital image features combines the advantage of ISODATA method and maximum likelihood method, it can provide the estimation rapidly with the least work amounts and high accuracy.

Table 3. The compare of advantage and disadvantage with three classification methods

	ISODATA method	maximum likelihood method	automated extraction method
theory	the overall statistic based on a whole image RGB, the iterative unsupervised classification by its average value and dispersion	the RGB statistic based on the training sample, classify the parts out of training samples in the image according to maximum likelihood principle	classification based on the characters of wheat and soil, their features in the RGB and HLS color space, and the sunshine effect on imaging
Choosing training sample	unnecessary	absolutely necessary, every image has its corresponding training sampl	unnecessary
objectivity	strong objectivity	strong subjectivity, correlated with training sample	strong objectivity
Batch processing	enable	unable	enable
Work amounts	small	heavy	small
Processing time	short	long	short
Individual participation	occasionally	Frequently	occasionally
accuracy	very low	high	high
General evaluation	bad	fine	fine

3.2 Evaluation of the error and applicability of the automated extraction method

As to the digital photos, a small part of wheat may be easily misclassificated as soil because of the strong similarity between soil and wheat in color and brightness, especially most of the pictures were taken in sunlight. In addition, the transition from wheat to background can easily be confused due to the mixed pixels in a digital picture.

Were there absolutely not hot-spot effect on wheat leaves (under obscure sunlight or cloudy whether), the classification accuracy would increase somewhat.

As to the digital picture after full crop, the bottom wheat was covered by the top wheat and received less sunshine. Probably some of the leaves can be misclassificated as soil background due to the dark environment.

The accuracy of the latter two images after full crop was higher than that of the former four images before the full crop. Soil received less sunshine after full crop and it can be distinguished from wheat easily because they were very different from each other by the color and lightness.

The soil type in the research was alluvial soil. With different soil moisture and under different sunlight the soil appeared grey, French grey, filemot, buff and khaki in the digital image. The research results can be applied to wheat grown on soil types of black, grey, khaki etc. series. Further discussion and validation of the applicability of the red or other soil types were still necessary.

By adjusting some parameters, the automated extraction method can be applied to extract percent cover of soybean, clover, cotton, corn and rice and to monitor crop dynamic growth.

3.3 Estimation of leaf area through percent cover of wheat

When regressed against percent cover of wheat before full crop extracted by using digital image and the measured LAI , it is found that the two showed exponential relationship, which reached highly significant level, and the multiple correlation coefficient was 0.743. It is consistent with Toby's research result (Toby N, 1997).

4. DISCUSSION

This paper brings forward the automated extraction method of wheat percent cover using digital image analysis technology to process the pictures taken with digital camera. The method eliminates operator's subjectivity and it has high classification accuracy and satisfying results. In addition, as the estimation accuracy is affected less by the sunshine conditions, the satisfying results retain whether in sunshine or in shadow.

Furthermore, the LAI before full crop could be estimated by percent cover of wheat from the digital image.

As to the wheat image before full crop, part of it may be misclassificated as soil due to strong sunshine and hot-spot phenomenon. Part of the pixels of the transition between wheat and background may be misclassificated because of mixed pixels. The bottom leaves received less sunshine as the top leaves, may be misclassified after full crop.

The new algorithm in the paper is based on single pixel in wheat digital image without considering its relationship with surrounding pixels and prior knowledge, such as that wheat was planted along rows, wheat is composed of many pixels while the isolated pixel indefinitely isn't wheat, and provided there was hallow hole on the physical surface of wheat leaves (generally the hot-spot part), the hallow hole would be wheat. In conclusion, in order to improve estimation accuracy, physical morphologic algorithm should be combined with and prior knowledge should be added for further research.

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