Proceedings of the International Conference for Agricultural Machinery & Process Engineering
October 19-22, 1993, Seoul, Korea

Crop-row Detection by Color Line Sensor

S. Hata, M. Takai, T. Kobayashi and K. Sakai
Department of Agricultural Engineering
Hokkaido University
N-9, W-9, Kitaku, Sapporo 060, Japan

ABSTRACT

The purpose of this study is to develop a crop-row detector which can be applied to an automatic row following control for cultivators or thinning machines. In this report, a possibility of new crop-row detecting method was discussed. This detecting method consists of two principal means. One is the hardware means to convert the two dimensional crop-row vision to the compacted one dimensional information. The conversion is achieved by a color line sensor and a rotating mirror. In order to extract crop-row, *R* and *G* signals of RGB color system are used. The locations of two different points on the target row are detected by this means. Another is the software means to estimate the offset value and the heading angle between the detector and the target row which can be assumed as a straight line. As a result of discussion, it was concluded that this detecting method would be accurate enough for practical use.

Key Word : Crop-row detector, Color line sensor, Row following control

INTRODUCTION

In a recent year, the field operations of agricultural machinery have come to be requiring high accuracy with high traveling speed. Cultivating or thinning is not exception. Operator must drive tractor precisely along a row. Since most of field machines are rear-mount type in Japan, operator further bear the burden to drive the tractor looking back frequently. Automatic row following control does not only reduce the operator's burden. This technology also will be the foundation of automatic guidance system for cultivator, thinner or sprayer.

Tillett (1991) widely reviewed about automatic guidance sensors for agricultural field machines and discussed the potential of the various options from an economic and technical point of view. He commented that radio navigation and computer vision would be required in order to provide a general solution to the problems of automatic guidance. Computer image analysis is a powerful technique to obtain guidance information. Reid and Searcy (1988) developed a statistical-based algorithm for extraction of crop row from soil background. They used a DEC PDP 11/73 computer and an image processor which had an intensity resolution of 16 gray levels and a spatial arrangement of 320×240 pixels. They reported that subsampling of 400 pixels out of 67100 had been enough for thresholding row crop images and 113.8 ms had been required to estimate the image distribution.

Gerrish and Stockman (1985) commented on advantages of computer vision as follows;

1) a look-ahead capability which may enable efficient open-loop steering corrections while avoiding busy over-steering which troubles "near-sighted" or tactile systems.
2) no out-board rigging.
3) a potential for adaptation to a number of field crops and operations.

They used VICOM image processor (with a MC68000 based computer) which had 512×512 spatial and 4 bits intensity resolutions. They reported that offset from the row could be known to ±45 mm and heading to $\pm 0.3^{\circ}$ in well defined onion rows. Their image processing routines took several second to run but they projected to be under one second by inexpensive computer and camera.

We projected to develop a crop-row detector which can be driven by an inexpensive one-board 8 bits computer. As two-dimensional image analysis was overload for a 8 bits computer, line (one-dimensional) image sensor was used as a integrator of image intensity. Our method is not detecting individual plants, but detecting a row as a straight line. The advantages of this method are avoidability of mis-detecting caused by missing plants within a row or weeds between rows. The feasibility of this detecting method had been evaluated by computer simulation (Hata and Takai,1992), then the detector using monochrome line sensor was made on trial basis and the stationary field test was conducted (Hata *et al.*,1992). In this paper, an outline of these previous studies are reviewed, and using color line sensor to improve sensibility is discussed.

METHODS OF ROW DETECTING

Considering crop-row as straight line, when two points on the line are determined, the row can be known on the coordinates of which the origin is the detector. Supposing that the camera locates at P_c with tilt angle α_x as illustrated in Fig. 1, the image obtained on retina is shown as Fig. 2(a). P_{v1} is the intersecting point of the first horizontal quadrisector of retina and the target crop-row, and P_{v2} is of the third quadrisection and the target crop-row. P_{v1} and P_{v2} is corresponding to P_1 and P_2 in Fig. 1 respectively. In Fig. 1, the offset ε and heading α_y can be represented by following equations:

$$\varepsilon = \frac{x_1 z_2 - x_2 z_1}{z_2 - z_1} \tag{1}$$

$$\alpha_y = \tan^{-1}\left(\frac{x_2 - x_1}{z_2 - z_1}\right) \tag{2}$$

where x_1 , z_1 and x_2, z_2 are coordinates of P_1 and P_2 respectively, and z_1 and z_2 can be represented by the camera constants as following equations:

$$z_1 = \frac{y_c}{\tan\left(\alpha_x + \frac{\theta_v}{4}\right)} \tag{3}$$

$$z_2 = \frac{y_c}{\tan\left(\alpha_x - \frac{\theta_v}{4}\right)} \tag{4}$$

where y_c is height of camera and θ_v is vertical visual angle of camera.

When the whole image is bisected to near and far vision as Fig. 2(a), and intensity of the each vision is vertically integrated, the luminous signal of each vision is obtained as Fig. 2(b). The peak positions of both luminous signals correspond to P_{v1} and P_{v2} in Fig. 2(a). Therefore x_1 and x_2 can be represented by ε_{v1} and ε_{v2} as following equations:

$$x_1 = \cos\left(\frac{\theta_v}{4}\right) \frac{\varepsilon_{v1}}{h} \sqrt{y_c^2 + z_1^2} \tag{5}$$

$$x_2 = \cos\left(\frac{\theta_v}{4}\right) \frac{\varepsilon_{v2}}{h} \sqrt{y_c^2 + z_2^2} \tag{6}$$

where h is distance from principal point of lens to retina.

In order to integrate intensity, the mirror which vertically rotate in front of lens and the line image sensor which is horizontally equipped on retina position are used. The peak of luminous signal can be detected by hardware comparator.

RESULT OF COMPUTER SIMULATION

The computer used was NEC PC-9801 with i80286 cpu. 3-D graphics technique was used to draw row images. Drawn area is 504×336 pixels. Row width was 60 cm and intrarow spacing was 25 cm. The width of individual bogus crop was 15 cm. The intensity ratio of crop/ground was supposed as 2.0.

As a result of the simulations, detectable limits of the target row were generally determined by the deference of integrated intensity of the target row and neighboring rows. On the conditions described above, the camera height of 85 cm and tilt angle of 18° seemed to be suitable. The offset ε could be known to an accuracy of ±2 cm and heading α_y could be known to ±1° , to an extent of ±20 cm offset and ±12° heading. The theoretical maximum detecting error of offset was calculated as 0.97 cm. The detecting error caused by rolling was able to compensate and the error by pitching was negligible.

EXPERIMENTAL MONOCHROME CROP-ROW DETECTOR

According to the crop-row detecting method described above, a monochrome crop-row detector was made on trial basis (Fig. 3). The horizontal and vertical visual angle were 32.4° and 24° respectively. The detector was equipped with a monochrome CCD line sensor of 2048 pixels and an optical filter of which center wave length was 529 nm. In front of the lens of detector, a rotating mirror which was driven by stepping motor was equipped. The rotating speed was 60 rpm. The interface circuit was also equipped with detector. The interface contained a drive circuit for stepping motor, a synchronous drive circuit for CCD, a comparator for luminous signal, a counter circuit for detecting luminous peak, and a bus controller to one board computer. The one board computer with Z80 CPU calculated ε and α_y within 8 ms according to the Eq. (1), (2), (5) and (6). For the exposure time of CCD line sensor was 33 ms, 41 ms were required to estimate the offset and heading.

Fig. 4 and 5 show the results of stationary field test. Young spinach row was used for the test. Leaf length was 6.5 cm, row width was 60 cm, intrarow spacing was 5 cm. The offset to a row was known up to ±20 cm and heading up to ±6° with the accuracy of ±2 cm and 1° respectively. However, averaging might be necessary for row of grown-up crops, as the standard deviation of detected offsets was more than 2 cm.

Deference in intensity of row and background is essential for detecting. The background was comparatively dark in the test because of adequate soil moisture. In the dry condition, intensity of background may exceed intensity of crops. In such case, crop-row can not be detected. This is unavoidable problem in monochrome system. Moreover, changes in intensity caused by variance of sunshine will become a thresholding problem.

INVESTIGATION ON COLOR LINE SENSOR SYSTEM

Using color line sensor could be one of the solution of the problem in monochrome system. So we investigated a detecting method using a color line sensor instead of a monochromatic one. PIAS 555 digital color image analyzer and NEC PC-9801 computer were used in this investigation. The row images in various soil moisture were taken by a video camera and analyzed by PIAS 555.

In Fig. 6 and 7, (b) shows the integrated intensity of R and G in image of (a) in the same way as Fig. 2. Fig. 6 shows the case of wet soil and Fig. 7 shows of dry soil. In the wet soil condition, both R and G intensity of crop-row is greater than background. But in the dry soil condition, both intensity of crop-row is less than background. In either soil conditions, however, G intensity is nearly equal to R in crop-rows and R is greater than G in background. Therefore, subtracting R from G is effective to detect crop-row in either soil conditions. In Fig. 6(b) and 7(b), normalized $(G-R)$ were also shown.

According to these result, the crop-row detector equipped with color line sensor is under fabrication.

CONCLUSIONS

1. As a result of computer simulation and stationary test by monochrome detector, feasibility of the crop-row detecting method using line sensor was confirmed.
2. The offset can be known to ± 2 cm and the heading to $\pm 1°$. These are accurate enough for practical use.
3. In the dry soil condition, it is difficult to extract crop-row by monochrome system.
4. Using color line sensor, the difficulties in monochrome system can be overcome.

REFERENCES

1. **Gerrish, J. B. and G. C. Stockman.** 1985. Image processing for path-finding in agricultural field operations. ASAE Paper no.85-3037
2. **Hata, S. and M. Takai.** 1992. Crop-row detector equipped with one-dimensional image sensor (Part 1). Journal of JSAM 54(1):81-88.
3. **Hata, S., M. Takai and K. Sakai.** 1992. Crop-row detector equipped with one-dimensional image sensor (Part 2). Journal of JSAM 54(2):83-89.
4. **Reid, J. F. and S. W. Searcy.** 1988. An algorithm for separating guidance information from row crop images. Transactions of ASAE 31(6):1624-1632.
5. **Tillett, N. D.** 1991. Automatic guidance sensors for agricultural field machines: A review. Journal of Agricultural Engineering Research 50:167-187.

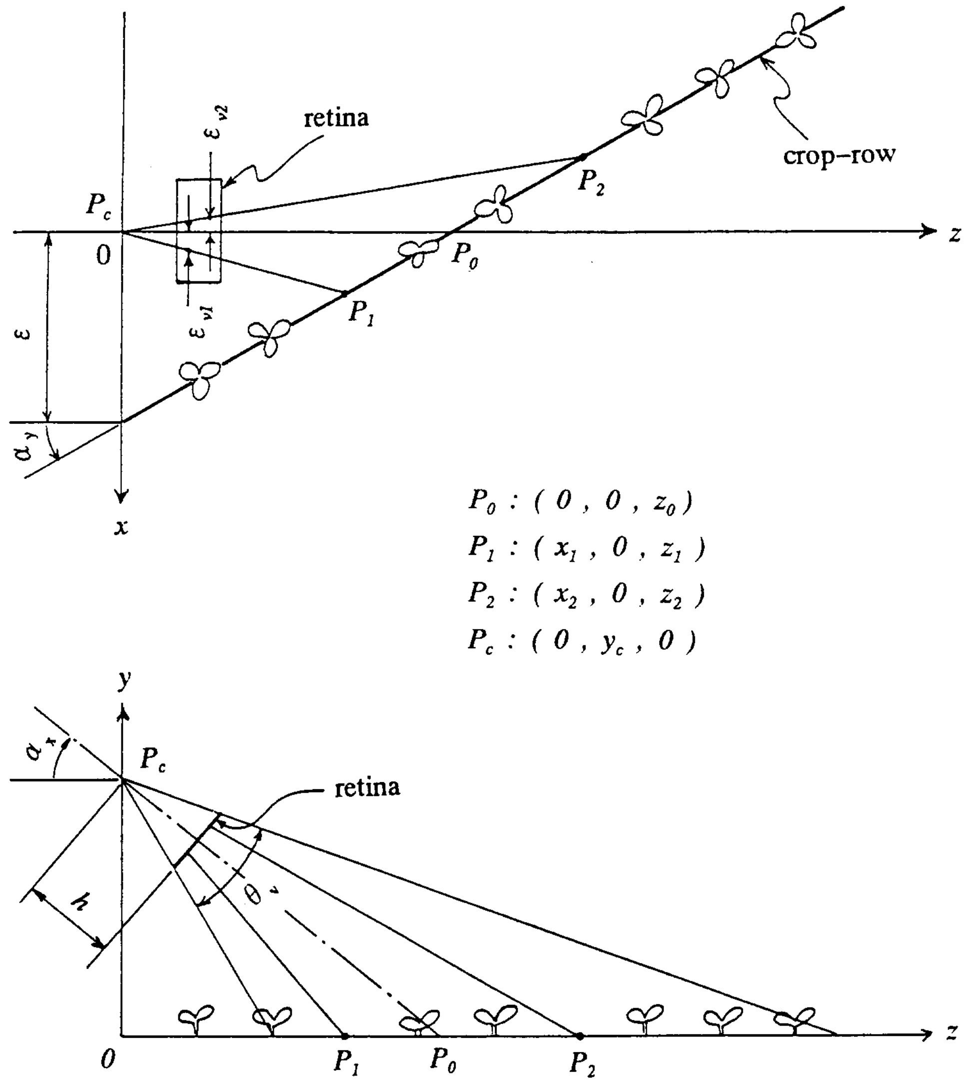


Fig. 1 Geometry of crop-row detection

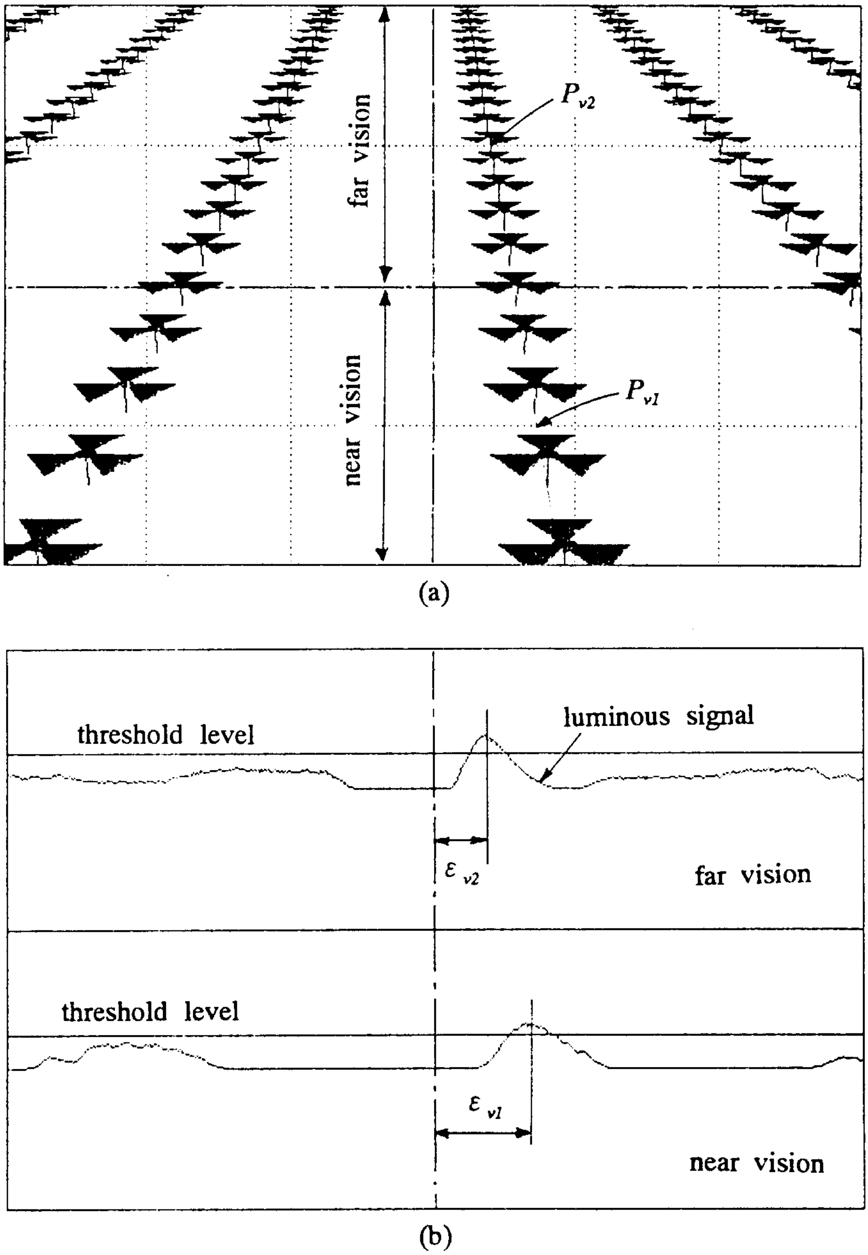


Fig. 2 Visual field and output signal of monochrome crop-row detector (by simulation)

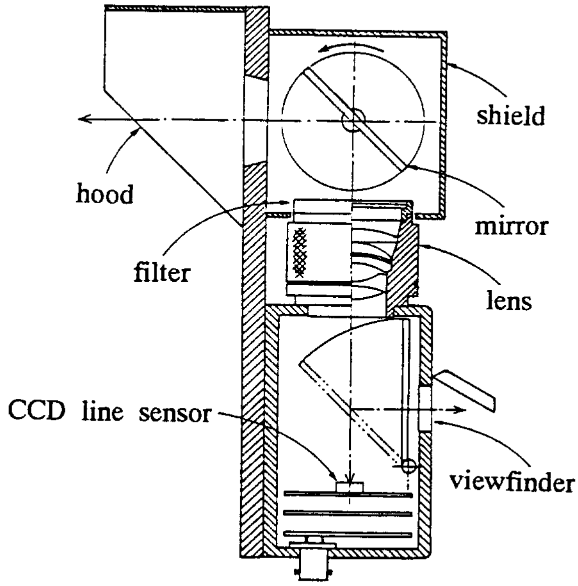


FIg. 3 Monochrome crop-row detector

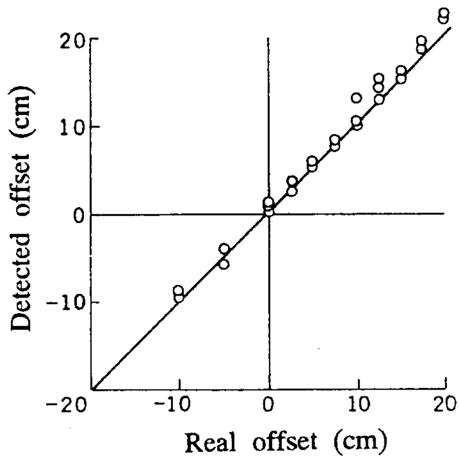


Fig. 4 Results of detection of *offset* on spinach rows (y_c=90 cm, α_x=20°, row width=60 cm, intrarow spacing=5 cm, leaf length=6.5 cm)

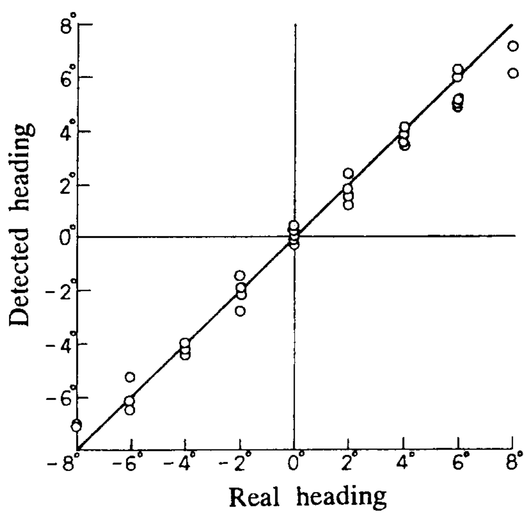


Fig. 5 Result of detection of *heading* on spinach rows (y_c=90 cm, α_x=20°, row width=60 cm, intrarow spacing=5 cm, leaf length=6.5 cm)

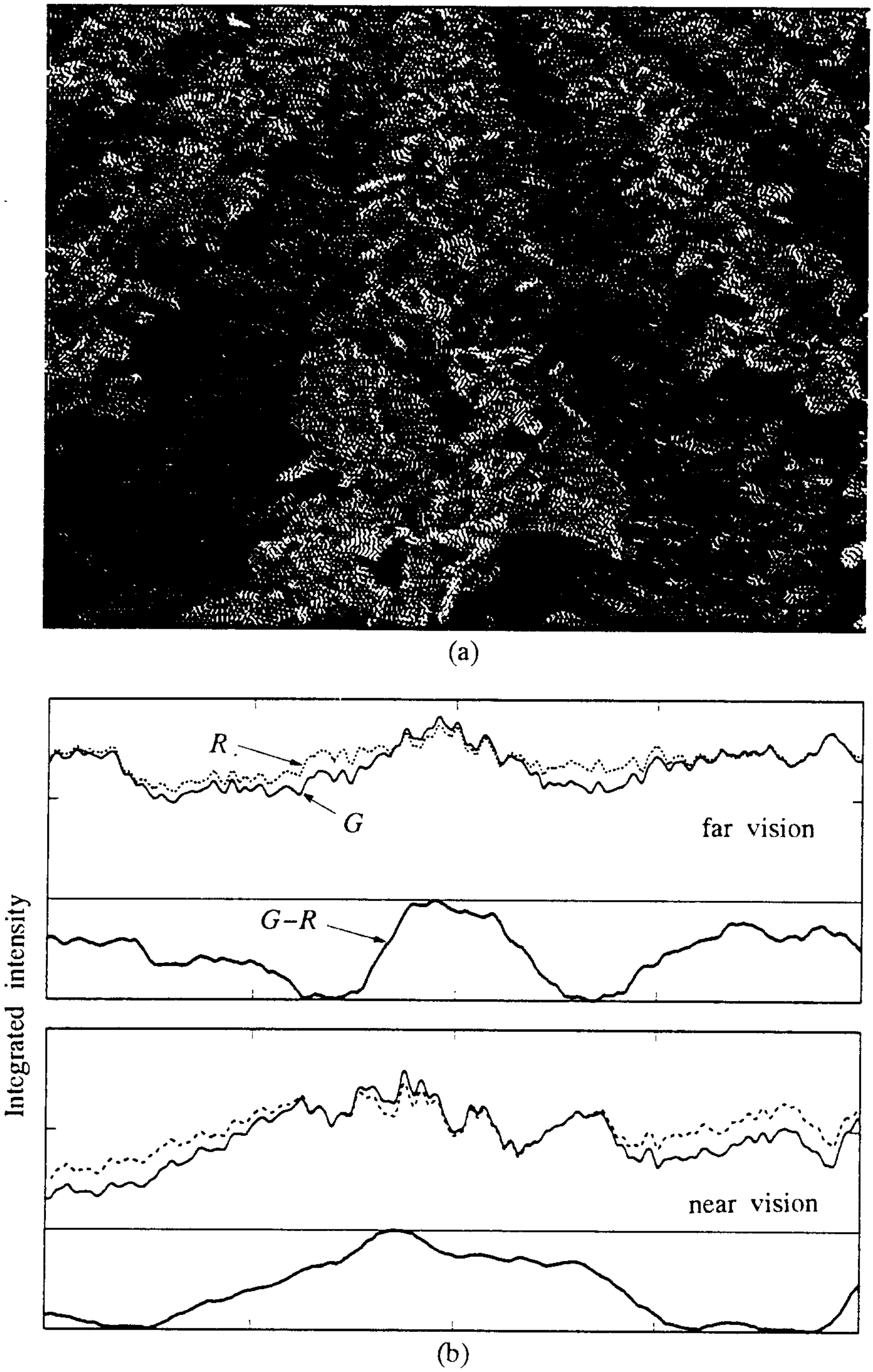
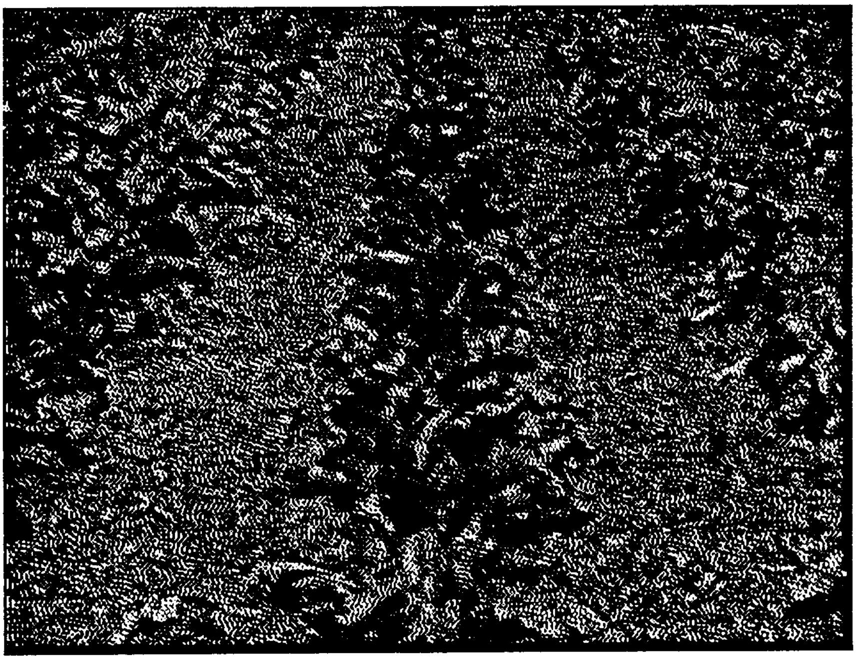
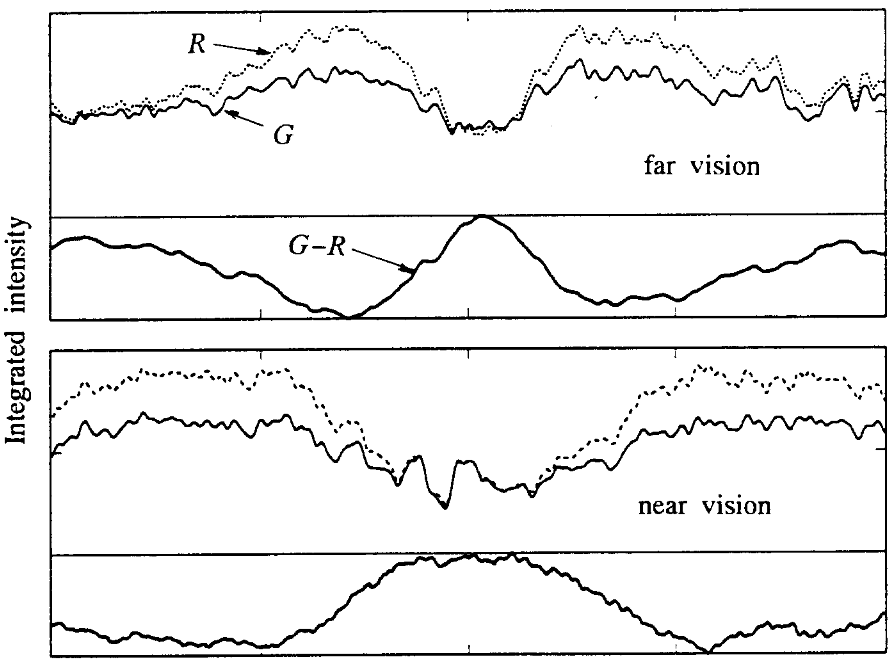


Fig. 6 Row image in wet soil condition and integrated intensity by RGB analyzer



(a)



(b)

Fig. 7 Row image in dry soil condition and integrated intensity by RGB analyzer