MACHINE VISION FOR ON-LINE WEED IDENTIFICATION

Maniak, S. - Mesterházi P.Á. - Neményi M. - Milics G.

University of West-Hungary,
Institute of Agricultural, Food and Environmental Engineering
H-9200 Mosonmagyaróvár, Vár 2, Hungary
Tel./Fax.: +36 96 566 - 635
e-mail: nemenyim@mtk.nyme.hu

Abstract: To compensate the existing difficulties in case of machine vision based weed recognition more and more complicated systems are applied. It means a demand of significantly increasing investment and extra cost for the farmers. However, the complexity of the field conditions and the morphological variability of the plants still make weed identification complicated. The typical barrier of the practical application is the insufficient efficiency caused by the limited viewing angle of the optical devices and the long computation time. The authors review their optical sensor based weed monitoring system operating with CCD and infrared camera, and a special solution – a special optical device with an optical angle of 360º - trying to eliminate the limitation of the optical instruments concerning to their view angle. *Copiright® 2005 IFAC*

Keywords: DGPS, weed monitoring, machine vision, on-line image processing, infrared camera, Panoramic Annular Lens (PAL)

1. INTRODUCTION

The weed control based on machine vision and spectroscopy is a very popular but complex research field with special limiting factors, thus more and more new experimental tools came in to light, but they haven't been yet put into the practice.

In case of weed detection some typical trends can be observed. These methods can be separated basically as spectral characterisation and shape or texture analysis. A distinction can also be made corresponding to the place of detection, namely local and remote sensing. Under field circumstances, cultivated plants and a wide variety of weeds are mixed present. Therefore, the first step must be the separation of plants and soil. In the most case it can be done with high confidence by means of the reflectance differences. The next step is the dissociation of the green part into weeds and cultivated plants. For this task the reflectance properties can be taken into account too, but in the most case other techniques are (also) required. Shape- and texture analysis is also known methods for this aim.

The most shape analysis based system working with predetermined parameters, thus they can – theoretically – identify the weed species, which they have information about. But not any other. To increase the capability of these systems, there are efforts to employ spectral features together with shape- and texture analysis (Zhang and Chasaittapagon, 1995). Perez et al. also (2000) introduce a near-ground image capture and processing system using the colour information to distinguish the vegetation from the soil and shape analysis to discriminate the weeds. As an advanced form of this method, such experimental recognition system is also under development, which takes into consideration not only the characteristics of the leaves but also their relative spatial position (Manh et al., 2001). Hemming and Rath (2001) reported their system using statistical analysis and fuzzy logic.

Nevertheless, there are still many difficulties in the field of weed recognition. However much pointing ahead these systems the low working speed and consequently poor efficiency restrain the real field application. This goes among others for the robotic weed control system elaborated by Slaughter et al. (2000) too, which has the capability of on-line

operation at a speed of only 1 m/s. For reaching a satisfactory on-line operating speed, a sufficiently powerful computer system is requested (Philipp and Rath, 2002). In many cases controlled lighting conditions are also required to eliminate the effect of the varying ambient illumination.
Nonetheless, further problems may arise from the overlapping of certain plant parts (Hemming and Rath, 2001) and from their movement too. Despite the intensive research and new experimental results, several experts are sceptic corresponding to the practical application of this technology. Referring to Manh et al. (2001) in spite of using more and more sophisticated systems taking into account more and more parameters weed identification still remains difficult. According to the authors, the complexity of the real field conditions and the morphological variability of the plants are mainly to be blamed for it. Godwin and Miller (2003) also believe that the automated weed monitoring systems based on either spectral reflectance characteristics and/or image analysis methods will not be available for the agricultural practice within the foreseeable future. A very consonant viewpoint is expressed in Feyaerts and van Gool (2001) as well; they also state that the techniques based on shape and texture analysis are currently too slow to be implemented in a real-time evaluation system, due to the mathematical complexity to characterize and recognize the plants.
What can be so the solution? A compromise or a breakthrough is required. As a compromise, such devices, which discriminate only the soil and plant parts may be fast enough for the practice. The provided information may be considered less valuable, however it is still adequate for weed control between the rows or for stubble analysis. The principle of recognition may also be altered – it is probable the field crop(s), which is to be identified and everything else should be handled as weed. Particular solution should be needed only in case of weed species requiring specific (herbicide) treatment.
The other possibility is to break through the limiting factors such as the slow operation and low efficiency. This development may – theoretically – be achieved by speeding up the recognition process and/or by enlarging the observation area. Unfortunately, the speed increase has been proved to be unaccomplished yet (Mesterházi, 2004). The system reported in this article follows these mentioned lines intending to eliminate the typical difficulties of the optical instruments.

To increase the operation speed significantly only the soil and plant parts are divided from each other, and it is not taken into consideration whether those parts are weeds or not, or even that what species. Besides, a special optical device, a so-called Panoramic Annular Lens (PAL) is employed to extend the view angle of the optical tool.

2. MATERIALS AND METHODS

The investigations took part in an experimental plot of 1 ha belonging to the Institute of Agricultural, Food and Environmental Engineering. The area was a fallow with a (natural) heterogeneous coverage of weeds, which are parts of the typical field flora. The soil surface was also heterogeneous, the clod size varied from 0,5 to 10 cm.
Our aim was to build a system for the practice. Consequently, a quick on-line one is required, which can be the foundation of a VRA weed-control unit for both map and sensor based applications. For positioning, both of the DGPS receivers (CSI Wireless, DGPS MAX,) can be applied, which are available at the institute as parts of the RDS and the Agrocom ACT yield monitoring systems, respectively.
For image capturing a CCD camera (Hitachi KP-C550) was used, the images were digitised on-line by means of a PCI Frame Grabber card (Hauppauge WinTV Go) installed also into the portable computer (KP-5212T/A) mounted in the cab of the tractor (Fig. 1).

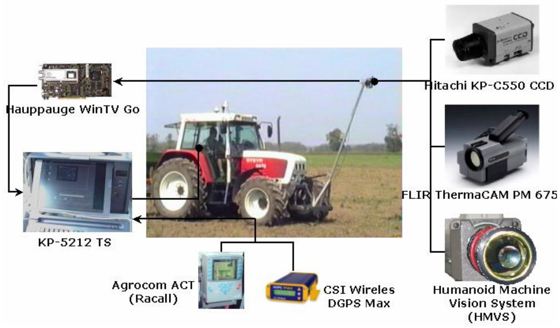

Fig. 1. Components of the GPS system

On the portable computer self-developed software was run to capture and process video images, which were stored in a database. While the analysing process runs, the weed density in each image (721x584 pixels) is calculated in real-time and is also saved in the database. The CCD camera is mounted at a height of 4 meters and provides images that show a field area of approximately 4 square meters. The quality of these images is sufficient enough for dividing ground and plants. The algorithm for this purpose was established based on the former analysis of several histograms of captured images. Figure 2 shows an average histogram of 50 CCD images. There are two conspicuous minima at 127 and 169 in the histogram.

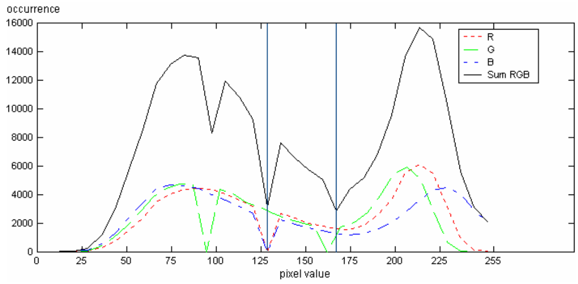

Fig. 2. Average histogram of 50 CCD images for measurement of weed density

In order to get the weed density of the CCD images the ratio between the number of pixels above a threshold and the total number of pixels in each image has to be calculated.

To find the optimal threshold for dividing ground and plants, the weed density of a set of captured images is measured manually. This reference measurement is compared with computer measurements by using all thresholds from 0 to 255 of all three colour components. As expected, the best threshold for dividing weed from ground was discovered at 127.

To get the weed density, each pixel in the blue colour component of the captured image is scanned and compared with the threshold. The ratio of the number of pixels, which are lying under the threshold and the total number of pixels result in the weed density in percent. Moreover, the software described above can export data to different Geographic Information Systems (GIS) (Neményi et al., 2003; Maniak, 2002; Maniak 2003; Mesterházi et al., 2002/a and b) in order to build a weed density map.

As it is well known, a CCD is sensitive to the red - green – blue and near infrared (NIR) spectral range. But over its capability, the infrared range can be also usefully applied for the same task as a significant temperature difference is caused by the plant's transpiration. Following this idea, the weed mapping system was completed with an infrared (thermo) camera (Flir ThermaCAM PM 675) with a sensitivity of 0.1°C. At the same time, the algorithm for the infrared images was worked out as well. Here a threshold at 45 is used in the red colour component.

The disadvantage of restricted optical angle, and consequently the limited scanning area may theoretically be compensated e.g. by increasing the optical device's height, or by applying several cameras at the same time. However, the possible mounting height is limited for obvious reasons. Using several cameras might be expensive and even problematic concerning to both its establishment and application under practical circumstances. Difficulties may arise also from the unusual computational background as well.

In our case a special lens with a horizontal view angle of 360 degrees and a vertical view angle from –15 to 20 degrees was applied. This imaging device, called Humanoid Machine Vision System (HMVS) consists of two main parts and an imaging block such as the Panoramic Annular Lens (PAL) that renders omnidirectional panoramic view and a collector lens (Greguss, 2002). The build up of the PAL system is presented in Figure 3.

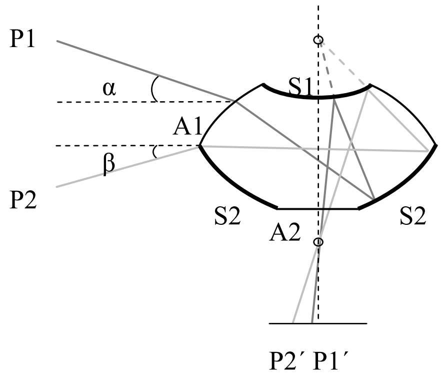

Fig. 3. PAL system

The PAL optic is a piece of glass that consists of a 360-degree circular aperture A1, a rear aperture A2 connecting to the collector lens, a top mirror S1 and a circular mirror S2 (Figure 3). The geometry of the PAL imaging system is somewhat complex, because there are two reflections and two refractions. Fortunately, there can be obtained a rather elegant geometry of a single effective viewpoint under perspective projection given that:

1. The concave circular mirror S2 is ellipsoidal, and the convex top mirror S1 is hyperboloidal.
2. The long axis of the ellipsoidal mirror is aligned with the axis of the hyperboloidal mirror and the optical axis of the camera.
3. A focus point of the hyperboloidal mirror coincides with one focus point of the ellipsoidal mirror, and the other focus point coincides with the nodal point of the real camera.

Because of this, the projection can be simplified to a polar transformation. Once the centre point (x_0,y_0) of the PAL image I(x,y) is calculated, a cylindrical panoramic image I(ρ,θ) can be generated by the following polar transformation:

$$\rho = \sqrt{(x - x_0)^2 + (y - y_0)^2}, \qquad \theta = \tan^{-1}\frac{y - y_0}{x - x_0} \tag{1}$$

Our goal was to try to adopt it and all of its possible advantages into the precision agriculture. Because of its special way of projection, a special picture is resulted (Figure 4). For its interpretation a special tool is also requested. During the experimental application a prototype version of the PAL objective was applied with a medium quality CCD. The effect of these circumstances on the image quality should be taken into account.

The transformation of the PAL image into a cylindrical panoramic image requires four steps:

At first, the centre (x_0,y_0) of the PAL image and the width of the black centre area must be calculated by means of image processing. For this step the physical image centre as the middle of the image is determined. From the physical centre point pixels are analysed in groups in vertical direction, in order to get the upper and the lower edge of the black centre zone (green line). By calculating the average between these two edge points the coordinate y_0 is located. In the same way the image is processed in horizontal direction to get x_0 (red line).

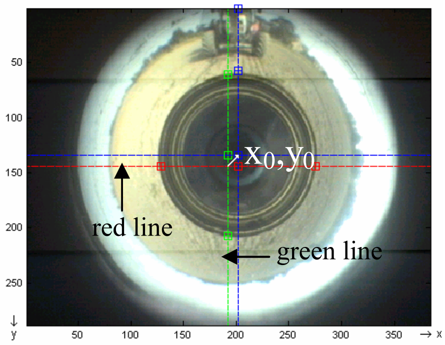

Fig. 4. Centre calculation in a PAL image

In a second step the image is transformed into a cylindrical panoramic image by using polar transformation (1). Figure 5 shows the transformed PAL image without limiting margins and interpolation.

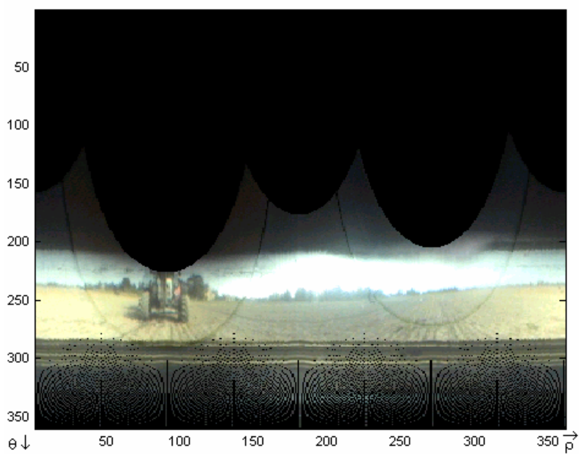

Fig. 5. Transformed PAL image

In a third step, the image height is reduced by knowledge of the black centre width, which was calculated in the first step and was transformed into polar coordinates. The panorama image shows some artefacts at the upper and at the lower margin, which are caused by a degree inaccuracy during transformation.

By using the nearest-neighbour method, all empty pixels are interpolated in a fourth step. The complete transformation process is carried out by means of a self-developed MATLAB application.

3. RESULTS

According to the calibration measurements the introduced weed monitoring system is capable of discriminate the soil and weed parts and gives the value of weed (plant) density in on-line mode. An average error of 13% was found between automatically analysed and manually measured weed density using the CCD. The accuracy improved significantly applying the infrared camera. The average error decreased to 1%.

By means of the transport function, the recorded information can be transformed into several destination formats, and thus can be mapped (Figure 6).

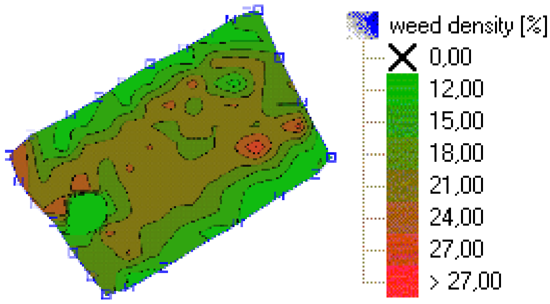

Fig. 6. Weed density map in AgroMap Basic

As the capture frequency is adjustable both time and distance dependently a perfect coverage of the filed can be ensured. The operating speed is limited only by the working speed of the carrying machine and the field conditions and not by the computing time of the software.

The integration of the PAL device into the weed monitoring system was successful. Our first experiences show that its advantages can be taken in the field of precision agriculture as well. The scanned area could have been significantly enlarged – the 1 ha sized experimental field could have been covered with a single image taken at a height of 1.30 meter.

The self-developed MATLAB application is capable of transforming the PAL images into panoramic ones. (Figure 7).

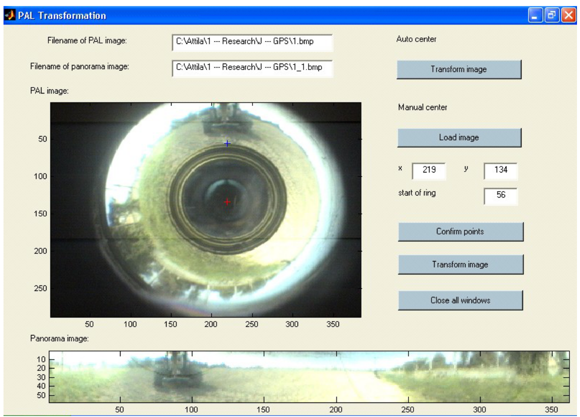

Fig. 7. MATLAB application for transforming a PAL image

The resolution of the PAL images proved however, insufficient. Because of its special way of imaging, approximately the 30% of the pixels are effective, in other words, only each third pixel consist information about the examined 1 ha area. Consequently, the theoretical resolution (comparing the effective pixel number to the size of the scanned area) is about 2.4 m^2 per pixel, i.e. 1 pixel covers 2.4 m^2. The relation between distance (measured from the center of the image) and area covered with a single pixel shows an exponential character. Thus, near to the center a better, far from there a worse resolution comes forward. It can be stated, that this level of resolution is not enough for practical application.

4. EXPERIENCES

Both the satisfactory accuracy and the high operation speed make the developed system suitable for plant monitoring under practical conditions. As plants are not differentiated into weeds and cultivated plants, summarized plant coverage can be mapped. However, with proper application the weed density within the rows can be monitored or a pre-sowing herbicide application can be planned based on a stubble analysis carried out with the system.

The observed lower accuracy of plant identification in case of the CCD is caused mainly by lighting influence in the field, according to our mind. Therefore the application of any constant lighting is under consideration. The different characteristics of plants and soil appear more definitely using infrared camera.

By now, a more sophisticated piece of PAL optic is available together with a 4 megapixel CCD and the first tests are running. According to the first results, the resolution improved with one order of magnitude (to approximately 25.8cm^2). Nonetheless, this detail level is still unsatisfactory, even taking into account the mentioned phenomenon that pixels cover increasing areas moving toward the edge of the PAL image. To be able to detect a 4cm^2 spot in the mentioned 1ha area, a CCD with at least 75 million pixels is required, taking into account the peculiarities of the PAL optic. This resolution is unattainable at the present.

The ideas of reaching similar resolution with the available equipments and positioning of each pixel are under investigation.

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