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Automatic Weed Mapping using Digital Image Processing

Digital image processing makes automatic weed detection possible. The system presented employs a mobile camera system which simultaneously photographs two geo-coded images in two different spectral bands and compares them to each other. Pre-processing reduces the images to the outer contours of the plants. For their knowledge-based classification programmed with multi-invariant parameters, sample identification procedures are applied. The classification results stored are used for weed mapping. The average identification rate with a knowledge base, consisting of five weed classes, was around 80 %.

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Keywords

Site-specific weed control, weed mapping, image analysis

Herbicide application adapted to the heterogeneous distribution of weeds within agricultural fields makes it possible to save herbicides and thus to lower production costs and diminish adverse environmental impacts. Site-specific herbicide application is predicated on information about weed species and the number of specimens in every position of the field. The acquisition of such information requires systems that are able to identify weeds fast, automatically and cost-efficiently.

By using digital cameras in combination with image analysis and geo-positioning, information about infestation within a field can be obtained. With the aid of geographical information systems, these data can be used for drawing weed distribution maps [1, 2, 3].

Image acquisition

The different degrees of reflectance of vital plants in the visible and infrared band were used for the image taking [4]. To utilise this effect, a bi-spectral camera system was designed. The main system components were two monochrome camera heads. These were mounted in one camera body in order to obtain two pixel congruent images of any one scene in different spectral bands. A cold mirror was installed in front of the lenses to split the incoming light into the visible and infrared band. The infrared portion of the light is directly projected onto one camera head. By the use of exchangeable filters the waveband for the second image can be defined. An EPROM merged both images into a single image. The difference between the pixel values of both images is used in calculating the combined image, which is sent to a frame grabber (*Fig. 1*). Three such bi-spectral camera systems are mounted on a boom in front of a vehicle. The distance between each camera is 3 m and the ground clearance is 1.5 m. At a geometric camera resolution of 750 • 580 pixel the display window is 55 • 42 cm. The frequency of image acquisition is one set of images (3 images) per second. At a speed of 7 km/h, one image per camera with the corresponding GPS information is stored approximately every 2 m. With an au-

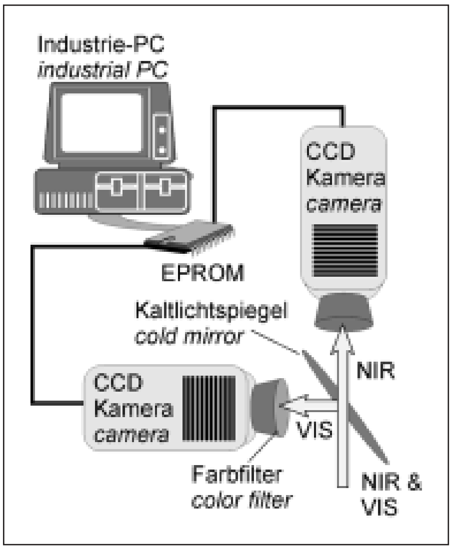

Fig. 1: Principle of bispectral camera system for the pixel congruent acquisition of two images in different spectral bands

tomatic gain and shutter control system that reacts to changes in recording conditions due to clouds and sunshine, it is possible to acquire images with rich contrast and sharp contours. These greyscale images can be stored on the computer's hard disk or analysed by a second computer parallel to image acquisition.

Image processing and image analysis

The process of image analysis is based on knowledge-based pattern recognition. For the purpose of comparing unknown plants, characteristic features of known plants are extracted and stored in a database.

In the first pass the histograms of the greyscale images are analysed in order to set a threshold for the segmentation of soil and plants. Object-oriented processes are employed to extract from these calculated binary images the contours of detected plants. The extraction rule ensures the unity of the contours [5]. On the basis of contour length, non-plant objects can be removed. The remaining contours are described by chain coding. The characteristic chain code of the outer contour of a plant consists of a sequence of unit vectors, which describe the course of the contour from pixel to pixel. The sequence and number of chain elements is dependent on the size, the rotation and the position of the plant within the image as well as the starting point of the chain coding. In order to obtain invariant parameters with regard to these factors, the chain code is described as an angle function. The abscissa shows the length of a contour segment, and the ordinate indicates the alternation of the angle in comparison with the starting angle. This approximation results in invariance with regard to rotation and translation of the objects within an image. Invariance with regard to size is achieved by the subsequent standardisation of the angle function's domain to the interval (0.2π). A Fourier series expansion is applied to the standardised angle function; the resulting Fourier descriptors, i.e. the amplitudes of the used trigonometric functions, are specific to the run of the curve and they are independent of the starting point of the chain coding. The compactness of the plants (defined as the ratio of circumference and area) is calculated for further characterisation. The quotient of minimum and maximum Ferrets diameter is also used for plant identification. As a result, numeric data are available which describe the habit of a plant independent of size, rotation and translation. These parameters are stored in a database (knowledge base) for a range of plant species. They are used for the knowledge-based comparison with unknown plants.

Unknown plants are classified on the basis of the knowledge base with the help of the Euclidean metric.

For the analysis of the images all described features can be weighted so that the relevance of the parameters to plant identification can be very diverse.

The classification results of a series of images consist of information about species, number of weeds and the area covered by them as well as the number of cultivated plants and the area covered by them. The results of plant classification are stored in combination with the GPS co-ordinates as a table. This table serves as the pool on which the graphic illustration of the weed distribution in the form of a map can draw.

Weed distribution maps

A mapping software program is used for the calculation of a weed distribution map based on the classification table. The data of the weed classification are imported into the mapping software, and thresholds for the arrangement of weed density classes are defined. The software then automatically calculates the weed maps. Unlike what is described in earlier publications [6, 7], the weed classification data are not interpolated. Because of the high density of image acquisition, the classification result of every single image is taken to represent an area of 3 • 2 m. This area results from the travel speed during image acquisition and the distance between the cameras.

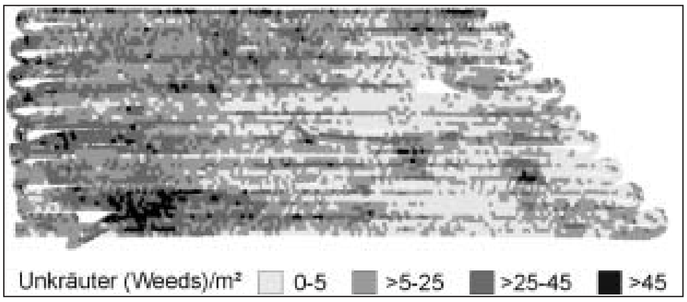

Fig. 2: Automatically generated weed distribution map for one weed class

Results and discussion

By the use of the camera technology explained in this paper, it was possible to obtain images of high quality and free of disturbance. Stones or dead organic material such as straw and root residues are not displayed by the bi-spectral camera system. Thus, only plants were relevant to image analysis. About 1 s was needed for the storing of an image sequence (3 images) on the computer's hard disk as well as the subsequent image analysis. At a speed of 7 km/h an image sequence was taken every 2 m. The above-mentioned distance between the cameras and the area covered by each camera resulted in a detected area of 7.7 % of the total field. As the data collected in areas of this size are sufficient for use in a weed map, it is possible to dispense with interpolation processes (*Fig. 2*). The use of economic weed thresholds and the overlay of weed distribution maps of several weed classes enables automatic weed detection and recognition for site-specific weed control. A fast image analysis or a sufficient distance between image acquisition and actor (nozzle of the sprayer) makes it possible to carry out online weed control on the basis of image analysis technology.

Besides weed recognition time and sample size, reliability and accuracy are essential factors for the operational ability of such a system. For the evaluation of the classification accuracy, images of 25 weed species with only cotyledons were taken in the field. A knowledge base consisting of 40 specimens of each species was built. Another set of 2500 plant images was taken for the determination of the classification results. By an optimal combination and weighting of identification parameters it was possible to achieve an identification rate of 70 % averaged over the 25 species. The span of classification results of a single species was between 44 and 100 %. For site-specific weed control, it is not necessary to discriminate between single weed species, but it is important to differentiate between groups of weeds that are sensitive to the same herbicide or the same dosage of an herbicide. By this practical division of the 25 weed species into five classes, it was possible to achieve an averaged identification rate of 80 %. The range of the classification rate was between 67 and 93 %. In order to verify these results it is necessary to conduct further field tests.

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