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Camera controlled mechanical intra-row weed regulation

A tractor mounted implement for mechanical weed control in the intra-row area of row crops was developed and tested at the Institute of Agricultural Engineering at the University of Bonn. The aim was to hoe the area between the crop plants in the row (intra-row) without damaging them. The main task was the detection of the row crops. For this a camera-based image processing was developed. The machine should be assembled from standardized industrial components off the shelf. Therefore, electrical servo motors were selected to actuate the hoeing tools. An EtherCAT bus system allows a real-time closed-loop control by a real-time controller. This design enables a mechanical weed control with a forward speed up to 7.2 km/h.

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Abstract
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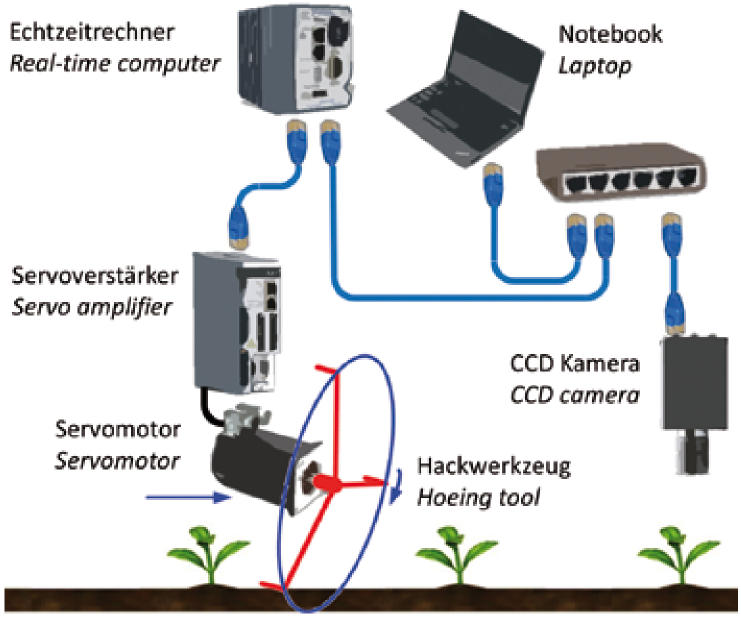
By the politically formulated aim of reducing herbicides and increasing organic farming the mechanical weed control in row crops, such as sugar beets, becomes more and more important. Commercially available hoeing machines for the area between the crop rows (inter-row) process up to 80 % of the area [1]. In order to achieve maximum quality and yield, the weeds within the crop row must be removed too. Hoeing between the rows is possible without complexity. To allow a guidance of the tools in the row and to harm the crop plants as little as possible, more complicated sensor equipment is needed. There are already a number of approaches [2; 3; 4; 5]. Another approach is the rotary hoe [1], on which this work is based. The aim of this work was to transfer the entire system, which was tested in the laboratory, in a field-compatible device and to test it with a driving speed, which is practice-usual in agriculture. The focus was on the development of a real-time image recognition algorithm for plant identification.

Experimental design

The schematic structure of the test vehicle is shown in **Figure 1**. A CCD camera takes an image of the plant row. From the image data, the positions of the crop plants can be calculated. The plant spacing and the position of the tractor are input parameters of the real-time processor. Together they form the reference input of the motor control loop. Using the reference input and the current motor position, the processor calculates trajectory setpoints in a closed-loop control and transmits them to the servomotor. The servomotor disposes of a digital encoder that reports the actual motor position to the controller and thus to the control loop. The components communicate through a real-time EtherCAT bus system, which has low cycle times (≤ 100 µs) and low jitter. This allows a synchronization of the servomotor and the encoder wheel without instabilities. The hoeing tools are rigidly fixed to the motor axis, so that the position of the single tools can be calculated based on the angular position of the motor axis. In case of successful crop plant recognition, the trajectories of the hoeing tools are calculated so that the hoeing tools penetrate the soil in a defined distance to the row crops and leave a safety area around them unprocessed.

Figure 2 shows the test vehicle, mounted on a tractor. The servomotor for driving the rotary hoe is connected to the frame by a parallelogram and height-guided by rubber-coated feeler wheels. The camera is placed in a housing to avoid external light shading effects. For lighting inside the housing LEDs are used in combination with a LED flash controller, which is activated just like the camera by a trigger signal. The generation and timing of the trigger signal is controlled by the encoder wheel. So an image is captured in each case at a distance of 300 mm. The controller allows the overdriving of the LED modules, so that the number of LEDs can be reduced by 80 % compared to a continuous operation. Thereby the construction space and the energy consumption are reduced at the same time. The real-time controller, the servo amplifier and the notebook are accommodated in a dust- and splash-proof control cabinet. The power supply is provided by a front-mounted generator, which provides up to 8 kW of electrical power. A direct power supply

Fig. 1



Basic setup of the test device. As a link between camera and servomotor, a real-time processor calculates new setpoints for the motor position.

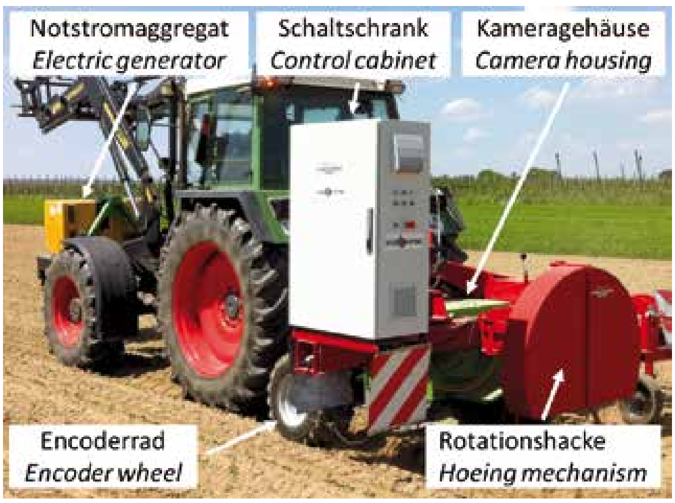
from the 12 V alternator of the tractor is not possible, because the transmitted output for the electronics and the motor (max. 3.7 kW) is not sufficient.

Image processing

As a basis for the plant identification, a CCD camera was used. The camera is mounted orthogonal to the ground and the plant row. Depending on the position of the encoder wheel, in predefined intervals a trigger signal is sent to the camera and the lighting. It signals the camera to capture an image and send it to the controller. The image is provided with a position stamp that records the exact position of the image acquisition in the plant row. The images include a variety of information in the form of color patterns, from which the coordinates of the crop plants can be calculated. For this task, the LabVIEW programming environment is used. In addition, it was deployed for signal processing and motor control. The developed LabVIEW algorithms run on the laptop and on the real-time CompactRIO controller.

In the first step, the captured images (**Figure 3**, a) are compressed by using a wavelet transformation in order to reduce the processing time for the following operations. In the next step, the color image is converted into a binary image with the threshold method (**Figure 3**, b). Here, the HSL color space is

Fig. 2



Test machine on a conventional tractor (Photo: Müter) used, in which each pixel is assigned a color hue value (H), a color saturation value (S) and a relative lightness value (L). To segment the color image into a binary image, minimum and maximum values from 0 to 255 are awarded for the three values. If the three parameters of a pixel are all in a predefined range, the pixel will be declared as part of a plant. If only one value is not in the defined range, the pixel will be represented in the binary image as non-crop. Weed plants, that colors are very different from the crop plants, can already be filtered out, but weed plants with similar color remain in the binary image. In industrial inspection tasks, such as the control of gears, the remaining objects would now be compared with examples from an image database. But in contrast to gears even plants of the same species differ very significantly. The growth and orientation of the leaves are affected by wind, sun, rainfall and the nutrient content of the soil. Instead of one example crop plant a database with thousands of example plants would have to be created in order to allow a useful comparison. The currently available computing power is not sufficient for an online process so that a simpler approach is necessary.

First, a low-pass filtering by using a fast Fourier transformation (FFT) is performed, so that smaller fragments will be filtered out and the contours of the remaining objects are smoothed. The setting of the frequency range must be adapted to the growth stage. Objects, whose surfaces are significantly smaller or larger than that of the crop plant, are removed from the image. In the next step filigree objects such as grasses or weed plants with leaflets, for example chamomile, are removed from the image. In the final step, all remaining plant positions are statistically examined. In this case, the adjusted target distance of the sowing machine and the coordinates of the last detected crop plants are important. Based on these data, the remaining objects on the image are divided in crop plants and weed plants. In **Figure 3** (c) only one plant is still displayed, which has been recognized as a crop plant. The calculated plant center coordinates are indicated by a reticle. The data of the detected crop plants are saved in a database. In addition to the coordinates, other properties such as the leaf size are stored. These additional data are of no interest for the control of the servomotor, but can be used for yield mapping or subsequent statistical analysis.

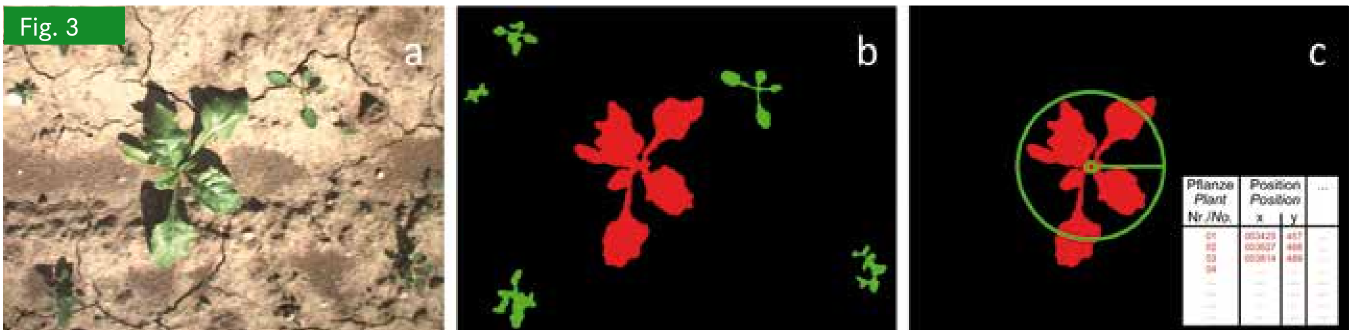
Field tests

The experiments were carried out on a test field of the campus Klein Altendorf. The sowing of sugar beet was done with a standard precision seeder, as usual in sugar beet cultivation. The row to row distance is 450 mm and the set distance between plants in the row 200 mm. The evaluation length of a plant row was limited to 40 m. To test the continuously changing algorithms for image recognition, the sugar beet plants were sown in two week intervals at different test plots. In this way the experiments in the early growth stages could be carried out from April to October, too. The experiments were done in the two-, four-, and six-leaf stage and just before row closure. A treatment with pesticides did not take place. The tests were carried out with different velocities of 0.72 to 7.2 km/h. To evaluate the image recognition, an additional visual assessment was conducted. Thereby the original images were checked for weed and sugar beet plants. These results were compared image by image with the results of the image processing software. Thus, the number of non-detected sugar beet plants and the number of misrecognized sugar beet plants were determined. To analyze the accuracy of the center point calculation, the locations of the single sugar beet plants were measured manually and compared with the software results.

Results and discussion

The first hoeing tests in sugar beet were already performed in the two-leaf growth stage [6]. At this stage, a correct recognition is still very difficult because the weed plants are partly in the same growth stage like the crop plants. In the final experiments in 2012, a distance of about 320 m with 1558 sugar beet plants was tested in the two-leaf stage as a whole. Average 81.6 % of the sugar beet plants were detected there. In the four-leaf stage, the proportion increased to 91.1 % at a distance of about 200 m with 866 sugar beet plants. At the same time, some weed plants were misclassified by the system as sugar beet plants. If the number of real existing sugar beet plants is taken as a basic value, this applied to 15.8 % in the two-leaf stage and 15.6 % in the four-leaf stage. This does not necessarily mean that the hoeing tools damage crop plants because the following statistical algorithms compensate for the image processing errors in most cases.

Fig. 3



Original image (a), binary image after thresholding (b), image with identified plant position (c) (Photo: Müter)

Besides the plant recognition, for precise weed regulation the determination of the plant center is necessary. This is not a problem in the two-leaf stage; however, with increasing leaf size the determination becomes more complex. Due to wind and lighting conditions the blades turn both horizontally and vertically around the plant center. To evaluate the plant recognition with different algorithms, the plant positions were measured manually and compared with the values of the software. In the four-leaf stage, there are deviations of up to 34.4 mm. The median is at 4 mm. In the six-leaf stage, the maximum deviation is 22.5 mm and the median is at 5.4 mm slightly higher than the value from the four-leaf stage. The results in the six-leaf stage are slightly worse because the larger leaves overlap more often and impede a plant center calculation. The results of the plant center calculation show that the deviation of the calculated position from the real position increases with the growing stage and therefore the necessary safety area needs to be larger. As the leaf surface increases with the plant growth, the area around the crop plant is increasingly protected from sunlight and weed pressure decreases in the immediate vicinity. Therefore, the security area around the crop plants, where no weed treatment happens, can be increased. Due to the real-time controller and the real-time bus system, the field tests could be performed with up to 7.2 km/h forward speed. In this range, the speed did not impact on the results of the image processing. Only at higher speeds, it happened that the time for the calculation of the individual images was not sufficient. A predefined maximum speed cannot be specified, because the calculation period depends on the structural complexity of each individual image and therefore is high variable.

Conclusions

With the test vehicle could be shown that the demanding task of weed control is to achieve with industrial components off the shelf. The trend to electric drives in the automotive as well as in the agricultural machinery industry has been taken up here.

In comparison to fluid power drives, the use of electric servomotors allows a better dynamic performance and accuracy for a rotary hoeing tool kinematics. In order to enforce these drives in the series, the conditions for mobile electric power supply must be created. There are already approaches of the tractor manufacturer [7]. One of the key challenges was the image processing, since there were no suitable algorithms for the detection of crop plants. The results of the experiments show that the developed algorithms provide good results up to 7.2 km/h forward speed in field trials. This speed allows a combination with a conventional hoe for the area between the rows so that a comprehensive mechanical weed control without any additional effort is possible.

Nevertheless, the development of suitable algorithms is still in its infancy. For an application in practice they must be more flexible, so that the operator has to set just a few parameters and can use the machine in different crops. A user-friendly solution would query for a maximum of parameters such as plant species and growth stage. Therefore, the work on the system should be continued.

References

[1] Gobor, Z. (2007): Development of a novel mechatronic system for mechanical weed control of the intra-row area in row crops based on detection of single plants and adequate controlling of the hoeing tool in real-time. Dissertation, Rheinische Friedrich-Wilhelms-Universität Bonn

[2] Åstrand, B. (2005): Vision based perception for mechatronic weed control. Dissertation, Chalmers University of Technology, Göteborg, p. 107

[3] Griepentrog, H. W. (2005): Weed Control by Autonomous Vehicle Systems. In: Workshop Proceedings Precision Farming - Sensing and Robotics, 18.10.2005, Hohenheim, pp. 6–9

[4] Bakker, T.; Asselt, C. v.; Bontsema, J.; Müller, J.; Straten, G. v. (2006): Autonomous navigation with a weeding robot. In: Proceedings of the International Conference ATOE, Automation Technology for Off-road equipment, 1–2 September 2006, Bonn, pp. 51–57

[5] Dedousis, A. P.; O'Dogherty, M.J. ; Godwin, R.J. ; Tillett, N. D. ; Brighton, J.L. (2006): A novel approach to precision mechanical weed control with a rotating disc for inter and intrarow weed hoeing. In: Proceedings of the 17th Triennial Conference of the International Soil Tillage Research Organisation, Kiel, pp. 123–129

[6] Heyland, K.-U.; Diepenbrock, W.; Fischbeck, G.; Knauer, N. (1999): Spezieller Pflanzenbau. 3. Auflage, Stuttgart, UTB Verlag, S. 203

[7] Agco (2013): Fendt X Concept. http://www.fendt.com/int/7710.asp, Zugriff am 23.1.2014

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Notes

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