Contactless Sensor System for Row Navigation and Automatic Depth Control for a Sugar Beet Harvester using a 3D Time of Flight (ToF) Camera

Vadim Tsukor[1,3], Wolfram Strothmann[1,3], Witali Schwamm[2] and Arno Ruckelshausen[1,3]
[1] University of Applied Sciences Osnabrück, 49076 Osnabrück, Germany
[2]Grimme Landmaschinenfabrik GmbH & Co. KG, Hunteburger Str. 32, 49401 Damme, Germany
[3]Competence Center of Applied Agricultural Engineering COALA
(e-mail: V.Tsukor@hs-osnabrueck.de)

ABSTRACT

Steering agricultural machinery during the harvest in fields is a tedious task for drivers. Automated guidance of the machinery will not only reduce driver fatigue but also increase productivity and safety of the harvesting operation. The existing mechanical solutions for row navigation on the sugar beet fields do not provide sufficient accuracy during the harvesting process. The next important factor in optimizing equipment performance and marketable yield is depth control or distance control. Gauge wheels or rollers are common mechanical devices used to reach the correct depth or distance. These systems have limited versatility requiring the operator to make frequent on-the-go adjustments. The objectives of the research presented in this paper were to develop and optimize a contactless sensor system for row navigation and automatic depth control for a sugar beet harvester.

Keywords: Row navigation, depth control, 3D Time of Flight (ToF) camera, image processing, sugar beet harvester

1. INTRODUCTION

Agriculture has its main impact of two important areas: the need of satisfy the demand of food of a growing global population and the increasing environmental impact of that population (Robertson et al., 2005). Innovations in electronics, computer science and sensor technologies strongly influence agricultural engineering and have become key competences of it (Wunder et al., 2012, Ruckelshausen et al., 2009). New technologies have improved most agricultural tasks, thus increasing the task's efficiency. Automation of agricultural machinery reduces driver fatigue and improves precision of the performed work and could finally exclude the need of a machine driver. The developed sensor system is applied to a sugar beet harvester Grimme Maxtron 620. This harvester has various adjustments and arrangements for optimizing the harvesting operation on the field. One of them is a mechanical system for row navigation. This system consists of two contact-based mechanical systems which are used for sensing. One system senses the sugar beet leaves before topping/defoliation. The other system senses the head of the sugar beet after topping/defoliation. They are mounted on the front of the harvester machine (Fig.1) and produce the analog signals that are sent to the harvester control unit for automatic steering. The weight of the influence of both mechanical sensing systems on the automatic steering system of the Maxtron 620 can be adjusted. Typically, values of 70-90% influence from the leaf sensing system and 10-30% from the beet sensing system are used. As state-of-art a passive system for depth control based on seven sensing wheelarms carrying the digging unit is applied. Adjustments for depth of digging are set manually from the driver's cab. An active on-the-go depth control system with automatic parameter setting is currently not in use. A new contactless sensor system must be capable of replacing the sugar beet contact-sensing mechanical system, increasing the precision in the automatic row navigation process and to provide the distance-to-ground information, which can be used for active depth control. Increased accuracy by the harvesting using contactless sensors and automatic harvesting parameter setting allows improving quality and quantity of the yield and alleviates the need for a driver. Automated harvest depth setting is expected to reduce the amount of dirt that accumulates on the machine, resulting in a more efficient use of both machine resources and fuel. The employment of a new contactless sensor system in this case could reduce the weight and length of the harvesting machine which will lead to a more gentle soil treatment.

Figure 1: Sugar beet harvester MAXTRON 620 (middle), mechanical solutions for row navigation in zoom – leaves senses system (left), sugar beet head senses system (right)

2. MATERIAL AND METHODS

The use of optical sensor systems under outdoor conditions is a challenging task - changing light conditions, high humidity, dust, vibration, etc. Developing a specific sensor system or using a combination of different sensor technologies (sensors fusion) does not only depend on the assigned technical problem or specific working area conditions, but also on economic considerations. A feasibility study (Wermeling, 2010) discussed the various sensor systems and technologies – laser scanner, RGB camera, ultrasonic sensor, 3D ToF camera – for the purpose of row navigation of sugar beet harvesters. The results showed that a 3D ToF camera is the most suitable system for this task.
Therefore, the contactless sensor system for row navigation and depth control is based on the following hardware component and software solutions:

2.1 Hardware

As part of a contactless sensor system the 3D ToF camera "IFM-O3D201" (Fig.2a) from IFM Electronic with PMD technology with a resolution of 64 x 50 pixels and opening angle of 30° x

40° will be used. A 3D ToF camera calculates the distance to objects by comparing the phase of a reflected light signal to the phase of the light source for each pixel of a built-in CMOS chip (Fig.2b). The IFM-O3D201 illuminates the scene with its internal modulated infrared LED light source. The selected 3D ToF camera generates a real-time 3D image and an additional gray-scale image of the measured reflection without any additional calculations with a speed up to 25 fps.

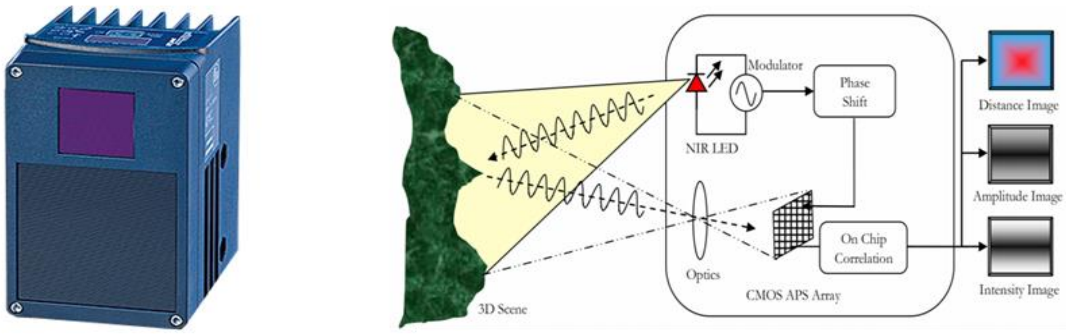

Figure 2: (a) IFM-O3D201 3D ToF camera, (b) ToF phase-measurement principle (Quelle: Sheshu, K., 2011)

The 3D ToF camera hardware, packed in a protective enclosure, is connected via Ethernet interface to a Raspberry Pi single-board computer based on a Broadcom BCM2835 system on a chip (SoC), which includes an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU and 512 MB of RAM. An SD-card is used for booting and persistent storage. Due to its extensive hardware configuration paired with a low price, this computer board is suitable for the targeted image processing tasks of this project.
The Serial Peripheral Interface (SPI) bus was used for communication between the Raspberry Pi board and D/A converter. The use of the D/A converter in this case was due to the task at hand. That is, the developed contactless sensor system was to replace an existing mechanical solution. Therefore, it should not imply any changes in the output signal processing. The converted digital signal with information of a sugar beet position and distance to the ground will be sent to the harvester control unit. It subsequently sends necessary guidance for steering and working depth regarding. The technical layout of the contactless sensor system is shown in Figure 3.

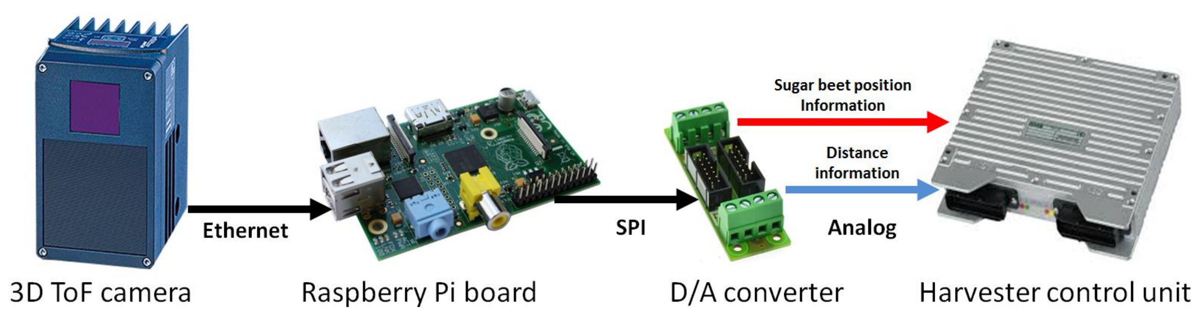

Figure 3: Technical components of the sensor system

The equipment to be installed on the sugar beet harvester should allow identification of the sugar beet position in the row and harvesting depth, as well as to enable monitoring of the measurements and record the outgoing signals from contactless sensor system during the validation field tests. For this purpose an additional PC system (Laptop) was used.

2.2 Software solutions

The first laboratory camera tests to evaluate the measurements method and algorithms were done with MATLAB R2012b (MathWorks, 2012). The developed software for sensor system is based on a Linux Ubuntu 12.04 operating system. The Raspberry Pi single-board computer has limited resources therefore the operating system was adopted for the sensor system – the packages and the libraries are not used in the software development and end-use was removed. In addition, two software components were installed - open-source computer vision library OpenCV 2.4.6 (Bradski, 2000) version 2.4.6 and Robot Operation System (ROS) Fuerte (Quigley, 2009). ROS is a middleware distributed under the terms of the BSD license and consists of different software frameworks, which allow the development of commercial and non-commercial software applications.

2.3 Algorithm

For the development of the algorithms, the sensor system was installed in the laboratory with a top-down field of view. In order to adjust the complex distance distortion (Fuchs, 2008) of the 3D ToF camera, a calibration was performed before the first measurements. The first dynamic experiments were made on a conveyor belt to simulate the harvester movement while using the sensor system (Fig.4).

Figure 4: Laboratory measurements on a conveyor belt

The sugar beet row detection in the camera field of view (FOV) is achieved by statistical evaluations along the camera image rows in the driving direction. All pixels in one camera row are evaluated together. The first step was to calculate statistical features for each camera row. Based on the mean pixel distance value of each row, an upper percentile - where e. g. 5% (or 10%, 15%) of the row's distance values are smaller - and a lower percentile - where e. g. 70% of row's distance values are smaller – are determined. The upper percentile is called upper (even though the distance values at the 'upper percentile' are smaller than those of the 'lower percentile') because the camera is positioned top-down, i. e. objects that cause upper percentile values are higher than those that cause lower percentile values. A plot of the statistical features of each camera row can be seen in Figure 5.

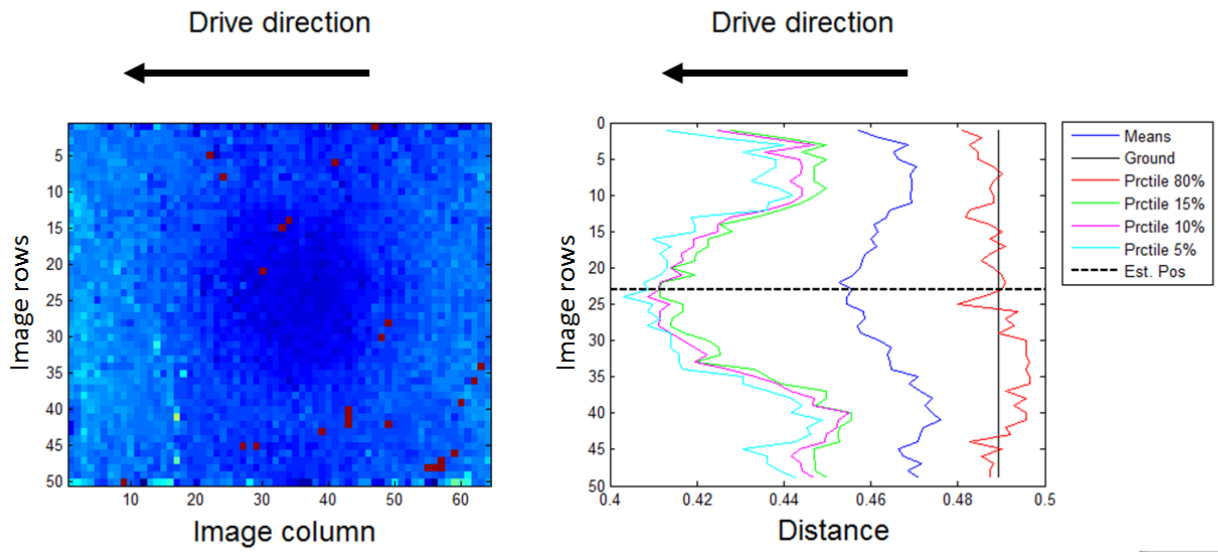

Figure 5: Evaluation of algorithm with MATLAB based on distance information of IFM 3D ToF camera (laboratory mesurements).

After the statistical features for each camera row have been calculated, the ground level is estimated. The ground level is estimated based on the lower percentile. If the lower percentile is, e. g. set to 70%, it is thereby assumed that - not depending on whether there are 1, 2 or 3 sugar beets in the camera FOV - any image row may contain at least 30% pixels derived from the ground level. A linear regression is applied to the lower percentile values for deriving the ground line plotted in Figure 4. The linear regression was favored over a mean because in this method makes it possible to cope with possible tilted mounting of the camera.

Using the so defined ground line, the beet position is estimated. For evaluating the beet position the upper percentile is used. If the upper percentile is, e. g. set to 15%, it is thereby assumed that – not depending on whether there are 1, 2 or 3 sugar beets in the camera FOV – for any image row this value is highly influenced by the presence or absence of sugar beets. For image rows without presence of sugar beets this value should be somewhere close to the ground line, for image rows with a presence of sugar beets this value should be significantly different from the ground line. The estimated sugar beet position is then set to the camera image row where the difference between ground line and the upper percentile value reaches its maximum (Fig. 5).
A model than was developed for automatic depth control based on information from two sensor systems, which are mounted on the left and right site from the middle line of the harvester on the front of machine (Fig.7b). The cameras send information regarding distance to ground to the hydraulic system attached to the rear struts of the harvester to keep digging depth constant throughout the field while harvesting (Fig.6). Simultaneously setting of depth parameter from

left and right side of the machine during the harvest improved the adapting of the harvester to the soil profile.

The algorithm for ground level and beet position estimation implemented as described avoids detecting and “hand shaking” each sugar beet, thereby drastically reducing the complexity of the problem. It has very few processing parameters (only the upper and lower percentile values), thereby drastically reducing the need for adaption of parameter values to local field-specific conditions. Further it is fast - running on a Rasperry Pi board in a cycle time of 50 ms.

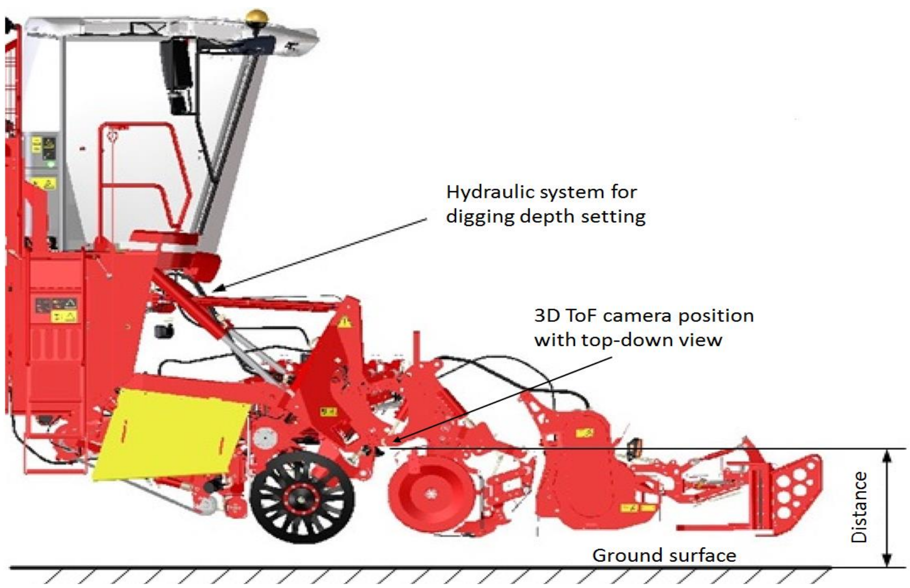

Figure 6: Sugar beet harvester Grimme MAXTRON 620 - side view

3. RESULTS AND CONCLUSIONS

For field measurements, the 3D ToF camera was installed in a funnel to avoid possible damage and dirt with a top-down field of view on the sugar beet harvester machine. The other components of the sensor system were installed in an outdoor case to protect against environmental influences during the field tests. In order to monitor the field measurements and record the outgoing signals, a laptop was connected via Ethernet interface to the contactless sensor system.

The field measurements have been performed with various distances to ground (50, 60 and 70 cm) and with various harvesting speed – 3, 5 and 7 km/h.
Field validation tests for row navigation were made by the two harvesting methods – topped and defoliated sugar beets – under different outdoor conditions. The tests showed that the developed sensor system can detect sugar beet rows with sufficient accuracy of approx. 5 – 10 mm (to the middle line of the row). Thereby, the developed algorithm works with a high reliability. The steering signal weight of the new optical sensor system could be increased from 20-30% (weight of the previous mechanical beet sensing system) to values up to 60-80% without any loss in

harvesting precision. Based on these values, an automated navigation system can guide a sugar beet harvester at usual field operation speeds of 3-7 km/h following both straight and curved rows.

The experiments for determination of working depth have been performed on two different surfaces - asphalt road and agricultural field. For the field tests two contactless sensor systems were mounted on the front of the harvester - on the left and right site. The purpose of the tests on the asphalt road was to determine the time delay of the new camera systems included its algorithms to give changes to the analog output signal in case of changes of the (manually) induced height of the harvesting tool. A time delay of 50 ms has been determined to fulfil the required signal rate of the designed harvester depth control system of 20 Hz.

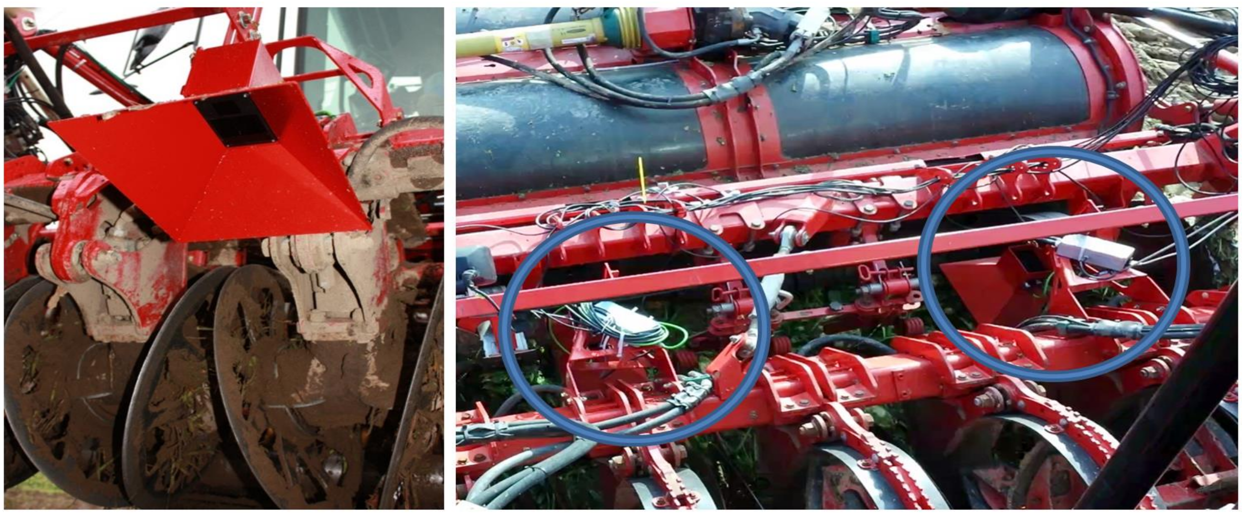

Figure 7: Field measurements (a) 3D ToF camera with a funnel, (b) contactless sensor systems installed on the harvester machine

The analysis of the field measurements data has confirmed that 3D ToF cameras are usable for determining the sugar beet position and working depth in sugar beet rows on the field under outdoor conditions. In the first approach, developed sensor system and sugar beet detection methodology provide accurate overall results. The system can be flexibly integrated in existing agricultural processes and relieves the harvester driver a part of their complex harvesting process. As a next step of this research project, a comparison of the new contactless sensor system to the standard mechanical system as related to changes in the quality of the sugar beets will be done to show the high potential of this innovation.

4. ACKNOWLEGEMENTS

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