'Virtual Harvesting' as a Key Element in the Development of a novel LiDAR based Combine Harvester Steering System

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Abstract

This paper describes the development and test of a novel LiDAR based combine harvester steering system using a harvest scenario and sensor point cloud simulation together with an established simulation toolchain for embedded software development. For a realistic sensor behavior simulation, considering the harvesting environment and the sensor mounting position, a phenomenological approach was chosen to build a multilayer LiDAR model at system level in Gazebo and ROS. A software-in-the-loop simulation of the mechatronic steering system was assembled by interfacing the commercial AppBase framework for point cloud processing and feature detection algorithms together with a machine model and control functions implemented in MATLAB/ Simulink. A test of ECUs in a hardware-in-the-loop simulation and as well as HMI elements in a driver-in-the-loop simulation was achieved by using CAN hardware interfaces and a CANoe based restbus simulation.

1. Introduction

In the development of environment-based functions, a broad diversity of possible constellations has to be considered. However, short harvesting periods and rarely ideal conditions for testing function thresholds complicate the refinement of parameters of control systems and software validation. Environmental sensor simulation and scenario based testing are well established methods to enable virtual test drives for the development and test of advanced driver assistance systems (ADAS) in automotive applications [1]. In [2] approaches for the simulation of LiDAR sensor systems in harvest scenarios have been proposed and carried out for the steering control by crop edge detection with a laser scanner attached to the combine header. Together with the new combine harvester machine

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generation CLAAS LEXION 8000 - 5000, a new laser scanner mounted centrally at the driver's cabin roof edge, covering the whole area in front of the machine, was introduced (Fig. 1). The changed sensor setup and wide field of view necessitated a new algorithm design for the "LASER PILOT" function. Hereinafter, the hardware and functional principle of operation as well as the test and optimization of feature detection algorithms and the refinement of parameters of the steering control system using a simulated laser scanner and a virtual harvesting environment are described.

Fig. 1: Laser scanner mounted at the combine header (left) and driver's cabin (right) [3]

2. LiDAR hardware and feature detection

LiDAR is well suited for navigation tasks because it offers a high spatial resolution and high precision together with a large field of view [4]. The "FIELD SCANNER" (Fig. 2) is based on an automotive laser scanner hardware using the time-of-flight measurement principle. An emitted laser pulse is reflected from an object and the backscattered light is detected by the receiver of the sensor. The measured flight time of the light pulse is directly proportional to the distance between sensor and object. The horizontal field of view covers 145° and is scanned using a rotating mirror mechanism. It provides a full scan every 40ms, with an angular resolution of 0.25°. The spinning rotor holds two mirrors with 180° displacement. The mirrors have an angular displacement of 0.3° towards the vertical axis, one looking up and the other one looking down. This results in four scan layers using only three lasers and thus providing a 3.2° vertical field of view. The "FIELD SCANNER" is capable of real time scan processing. Limited by a region of interest, the sensor analyses the surroundings for typical structures. Due to the variety of requirements for different scenarios, several algorithms had to be developed for each use case. Multiple, parallel approaches ensure a high flexibility and robustness. Furthermore it enables the sensor to evaluate its own performance. When detected, the lateral position of a field edge or spray track is communicated to the vehicle.

Fig. 2: CLAAS “FIELD SCANNER” sensor mounted at the cabin roof front edge [3]

3. Steering control

The considered machine has an electrohydraulic steering system in which a hydraulic cylinder controlled by a magnetic valve adjusts the machines rear axis steering angle. Based on the detected edge or spray track in front of the machine a desired course of travel relative to the machines lateral position is calculated. A control system is used to adjust the steering angle for minimizing the deviation between desired and actual machine curvature (Fig. 3).

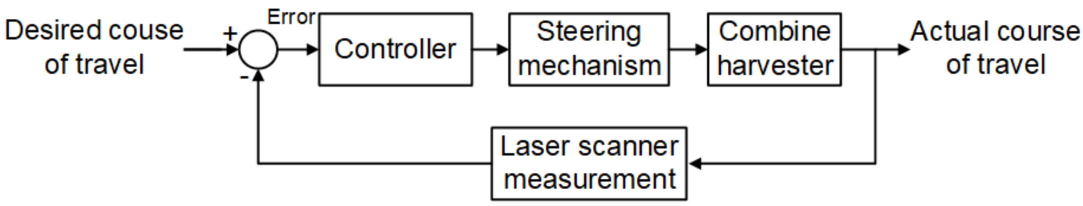

Fig. 3: Block diagram of combine steering control system based on [5]

4. System model

Modeling and simulation of a system process are extensive techniques for investigating, evaluating and improving the process, design and functional parameters of that system [5].
For the test and optimization of feature detection algorithms a point cloud matching the hardware specifications of the “FIELD SCANNER” regarding field of view, step width and scan frequency and sensor mounting position and sensor tilt angle is generated in Gazebo [6] and ROS [7]. For this a virtual harvesting environment with a 3D plant stock and a laser scanner simulation using a phenomenological modelling approach based on ray cast operations as presented in [2] is used. By combining a plurality of individual ray cast operations the effect of beam divergence on the reflected pulse and distance measurement output in plant stock can be reproduced to a high degree [8]. A similar approach based on ray tracing has also been proven to work for the simulation of LiDAR in dense vegetation,

e.g. grass and bushes, for autonomous navigation [9]. Since dust and small particles are quite common in harvesting scenarios and relevant influencing factors for LiDAR measurements, but are not represented in the simulation, the generated signal can be artificially disturbed using different filter techniques. The separate scan layers and hardware specific alternating output of the upper and lower layers of the “FIELD SCANNER” sensor have been realized by combining 4 single layer simulations. The resulting point cloud is then converted matching the sensor scan message definition at system level.

By interfacing the commercial AppBase framework, which was also used for software development, the “LASER PILOT” algorithm implementation can be tested without modifications. The Framework was extended by adding a module with the capability to subscribe to simulated sensor scans and specified configuration messages, as well as publishing data holding the offset to a detected crop edge or spray track.

For the refinement of parameters of the steering control system in a closed loop simulation, a model of the electrohydraulic steering system was implemented in MATLAB/ Simulink [10]. A simplified multibody simulation of the rolling chassis and vehicle body was used to reproduce the dynamic behaviour of the combine harvester considering speed, steering angle and terrain topography. Based on this, the position of the machine model in the virtual harvesting environment is updated during simulation runtime (Fig. 4). Furthermore real hardware components can be included using CAN hardware interfaces and a CANoe [11] based restbus simulation. This was done for the steering controller ECU and original HMI elements like the steering wheel and operator panel for usability tests.

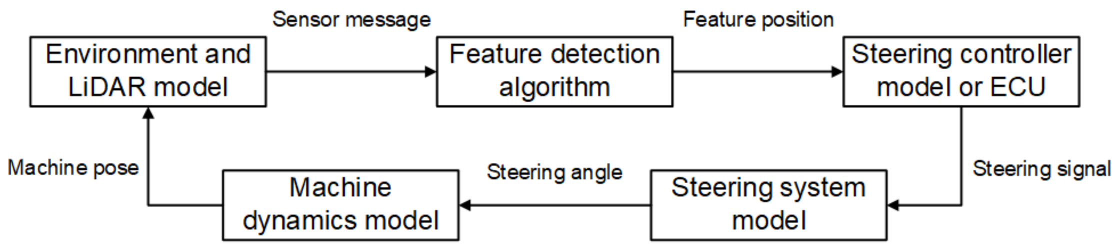

Fig. 4: Block diagram of simulation components and signal flow in a closed loop

5. Results

To ensure the feature detection algorithm capability for different types of contours like right or left handed crop edges and spray tracks and also adapting to zone width settings and different header sizes, different test cases for specific plant stock and terrain constellations have been defined and tested in simulation. By this the algorithm performance has been examined and improved, especially in challenging cases such as uneven terrain, broken edges or low crop density. Fig. 5 shows an image and laser scan of a grain field in front of a combine harvester that was processed with spray track and edge detection algorithms. An extract of the resulting point cloud of a single laser scan is plotted from a bird's eye view. Two lines parallel to the ordinate indicate the lateral positions of a detected spray track (yellow line) and a detected plant stock edge (red line). For the refinement of parameters of the steering control system the feature detection algorithm output was also used for a closed loop simulation using the electrohydraulic steering system model as illustrated in Fig. 4.

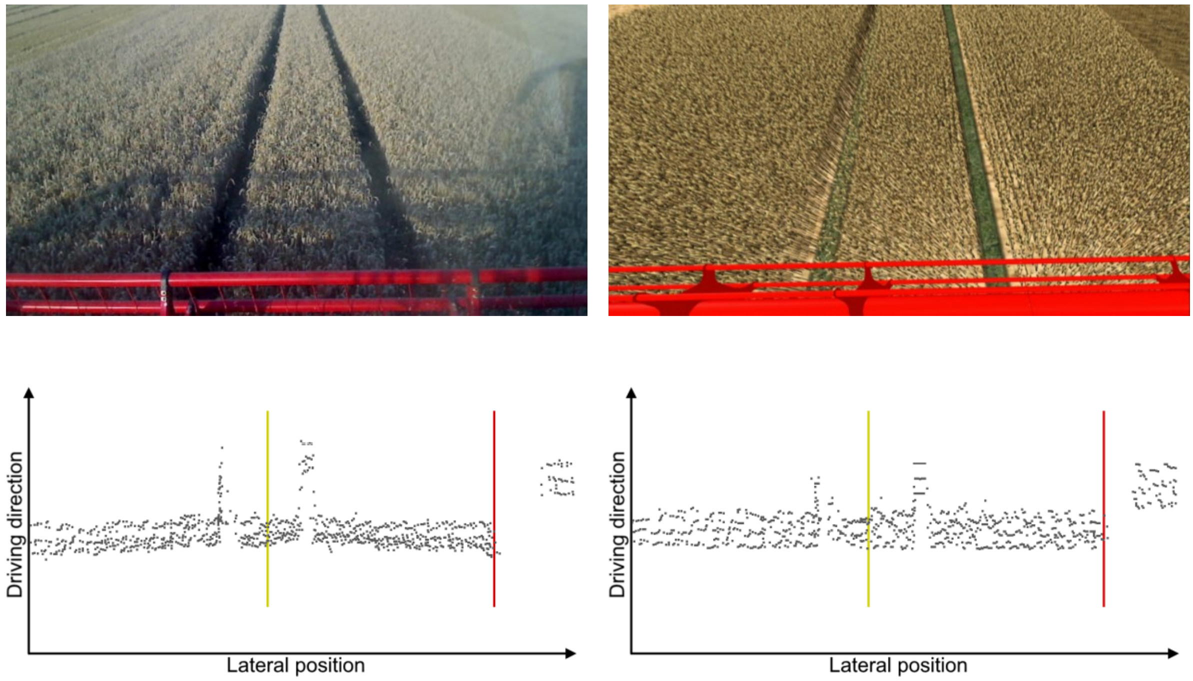

Fig. 5: Image and resulting point cloud of a laser scan, including feature detection algorithm output, based on a field trial (left) and based on 3D simulation (right). The lateral positions of a spray track (yellow line) and a plant stock edge (red line) are indicated.

6. Conclusion

It was shown that 3D scenario and sensor simulation are powerful tools for the development of environment based functions in agricultural scenarios. The presented approach was a key element in facing the challenges in the development of a combine harvester steering system based on the new CLAAS “FIELD SCANNER” sensor. As a supplement to field trials the use of ‘virtual harvesting’ allowed a systematic and reproducible test of algorithms for feature detection in any arrangement of plant stock and terrain conditions. Especially incorrect or unexpected behaviour which was discovered by this means lead to an improved algorithm design in the final product and an overall reduction of time and cost intensive field trials.

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