Methodical Approach of Highly Realistic Virtual Test Environments for the Evaluation of Monitoring Algorithms in the Agricultural Domain

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ABSTRACT

Agricultural implements for soil preparation, mechanical weeding, sowing, and other field operations are increasingly incorporating advanced intelligence. In pursuit of full autonomization, it is imperative that these implements possess the capability to autonomously detect incipient faults, without reliance on operator or supervisory intervention, and to mitigate them at an early stage. For both current and future generations of agricultural machinery, rapid identification of disturbance inputs or anomalies and the capacity for proactive corrective actions are critical. Moreover, current agricultural systems necessitate that farmers manually parameterize implements based on specific operational requirements and continuously monitor work quality. Future machine generations (as an example, see Fig. 1) will need to prioritize advanced process intelligence, with a focus on autonomous process monitoring and real-time assessment of work quality.

Our current research focuses on disturbance input detection (or anomaly detection) [2, 3] and performance monitoring [4] for agricultural implements. Specifically, we are developing vision-based systems for detecting blockages and tool damage, such as in cultivators, as well as vision-based performance monitoring for implements like cultivators and mechanical weeders. In the context of disturbance variable detection, it is critical to automatically identify both continuous tool wear and unexpected damage during operation. Examples include tool breakage or failure due to collisions with subsurface obstacles. Additionally, excessive accumulation of soil or plant material on the implement presents another significant disturbance variable in soil tillage processes.

Beyond the detection of disturbance variables, there is an urgent demand for a highly automated approach to evaluate the quality of work across various stages of agricultural field cultivation. Currently, this evaluation is performed manually by the operator, who uses the assessment to adjust machine settings. However, in fully autonomous systems, the machine must be capable of responding to sensor-derived data in real-time, adjusting its operational parameters accordingly to maintain optimal performance.

Figure 1: Combined Powers machine [1] – combination of a smart implement with an autonomous towing vehicle (image source: LEMKEN GmbH & Co. KG)

The mentioned system comprises a camera, a control unit, and software incorporating an image processing algorithm capable of detecting cultivator tines within captured images and assessing their wear condition visually. The camera is mounted on the frontmost beam of the cultivator’s steel frame, oriented against the direction of travel with a slight downward tilt to focus on the mounted tines. In the event of tine wear or damage, the operator is notified via the assistance system. In fully autonomous configurations, the monitoring system assumes responsibility for wear detection, thereby eliminating the need for operator intervention.

The development and validation of the image processing algorithm necessitate a substantial volume of image data. This data is predominantly derived from video sequences recorded during field trials of the system at the testing site.

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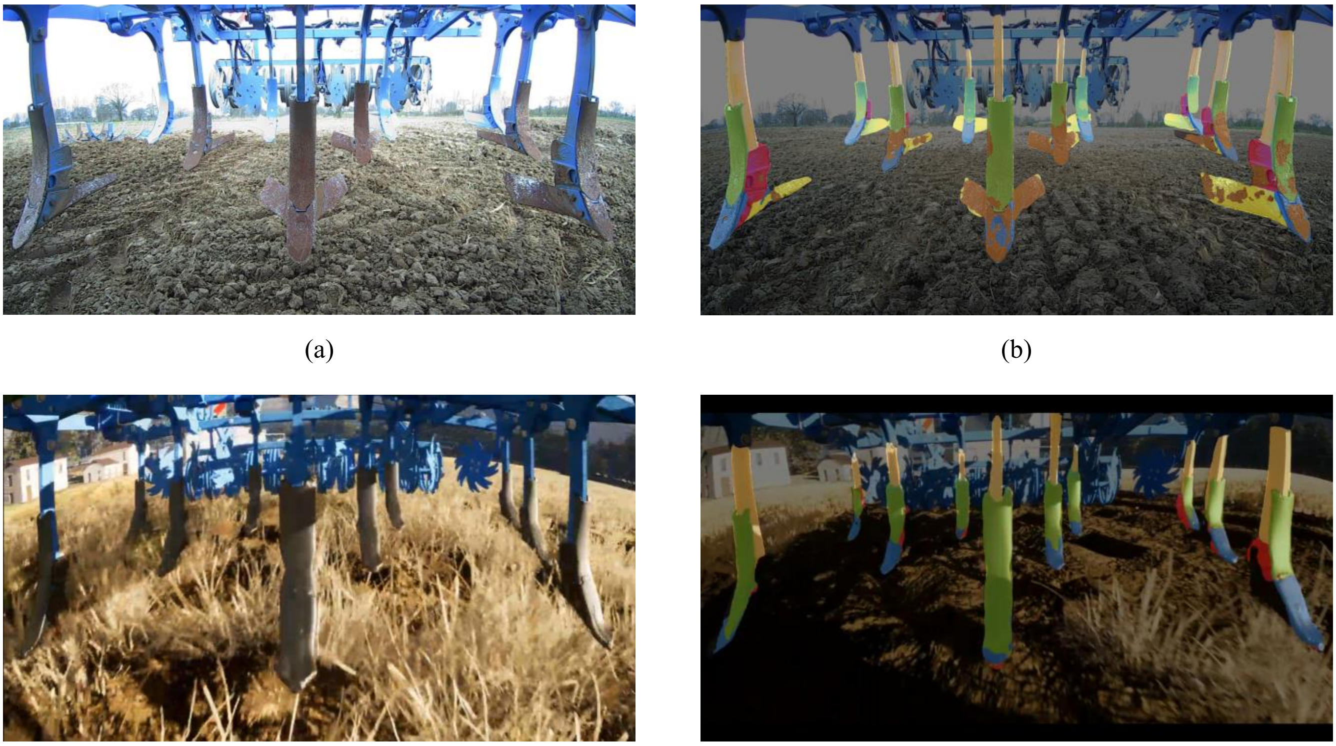
While generating images in real field conditions (see Fig. 2 (a) and Fig. 2 (b)) is a common practice, it has several limitations. One major drawback is the difficulty in ensuring reproducibility of test scenarios, as the environmental conditions during real-world tests – such as weather, lighting, or the path taken – cannot be consistently replicated. In agriculture, this challenge is further compounded by the seasonal variability of vegetation at the test site. Moreover, real-world test drives require extensive preparation, execution, and post-processing, which are both time-consuming and labor-intensive.

These challenges have prompted the exploration of using high-resolution virtual environments as a substitute for real test drives, as in the present case. Simulation environments offer significant advantages, including reduced time and personnel requirements, leading to cost savings and an accelerated development process. However, to effectively use virtually generated images for evaluating software performance, these images must be highly accurate reconstructions of the original recordings captured by the real camera system. This research presents a methodology for generating such image reconstructions in virtual test environments (see Fig. 2 (c) and Fig. 2 (d)) as well as it gives some preliminary results on the performance of the detection algorithms which have been fed with artificial created images.



(a) (b)

(c) (d)

Figure 2: (a) real camera image, (b) annotation based on real camera image, (c) virtual camera image, (d) annotation based on virtual camera image

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