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Methods to evaluate steering performance of agricultural tractors

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Abstract

Surveys reveal that farmers are requesting higher speeds for their agricultural tractors in order to reduce the time spent on road between field and farms or between farms. More and more tractors are designed with new transmissions to reach speeds of 50-60km/h, still using hydraulic steering systems. With higher speeds, a higher controllability is needed to not compromise safety. This not only poses a challenge for the design engineers on front axle and steering system design, but also poses a challenge on how to test and evaluate steering performance under high speed roading conditions.

This paper presents how high-speed test tracks in combination with steering robots and the usage of new biometrics can be used to improve the evaluation process of steering performance for agricultural tractors. The steering robot supports repetitive testing and eliminates the variation imposed by test drivers, thereby reducing the number of tests normally needed for a statically founded evaluation of the steering system. To quantify steering effort (which normally is done subjectively by e.g. NASA-TLX), this paper presents how electrodermal activity, electromyography and heart rate measurements can potentially support an objective assessment of steering use and related stress level.

The steering robot and the biometric test have both been applied when developing and testing a new improved hydraulic orbital steering unit. The biometric measurements show an 11-16% reduction of steering effort of the new hydraulic steering unit compared to a standard unit on a 300hp tractor with independent front axle suspension.

The new test method with the steering robot reduces the development time of new steering systems considerably by eliminating uncertainties and variance. The biometric methods will help designers understand and quantify the impact of new technical inventions and improved designs of steering system and axle design.

Introduction

Despite government subsidies being given to farmers in support of land consolidation reducing transport cost, increasing viability of mechanization and precision farming technologies, there is still a demand for tractors to drive on public roads for both farmers and

contractors. Surveys show that farmers see a high value in tractors with higher speed capabilities [1,2] to reduce time spend on road and as a response, speed limit regulations have been increased up to 65km/h in some European countries [3].
Increasing driving speed results in additional mental load of the operator with a higher probability of driving errors [4,5], and due to the fact that farmers are also concerned about better comfort and higher safety on agricultural machines [1,2,6], this not only poses a challenge for the design engineers on front axle and steering system design, but also poses a challenge on how to test and evaluate steering performance under high speed conditions.
Evaluating steering performance has traditionally been conducted by a largely experimental evaluation including several expert drivers to get a consolidated feedback of a design change even without a uniquely quantified performance number. This poses a challenge for design engineers, as each evaluation is time consuming and it is difficult to compare sets of variation with each other. It is therefore desirable to have a metric expressing steering performance (or ease of steering), so an evaluation could be performed one time with one operator only. This paper will discuss methods to evaluate steering performance of agricultural tractors and how these have been utilized in the development of a new hydraulic orbital steering unit technology with zero-deadband called sSteering.

Danfoss Application Development Center EMEA

Fig. 1: Danfoss Application Development Center in Nordborg, Denmark [7].

In order to safely test steering performance at high speed, a restricted test facility is needed. The Application Development Center EMEA is one out three testing facilities owned and operated by Danfoss and includes an oval test track that is 8m wide and 800m long, called Circular track (11), Fig. 1.

Repetitive testing by use of steering robot

A steering system of a tractor includes many components and subsystems including hydraulic pump(s), priority valve, steering orbital unit, hoses, front axle, tires, hoses, front wheel drive and every little detail can have a significant impact on the perception of the steering quality. In order to conduct repetitive tests, Danfoss utilizes a steering robot, Fig. 2. The robot is used for conducting sweep test, emergency steering tests and repeatable tests at the test Application Development Center.

As an example, the robot has been used to demonstrate the impact of reduced deadband by a sine sweep, Fig. 3.

Fig. 2: ABD Steering Robot.

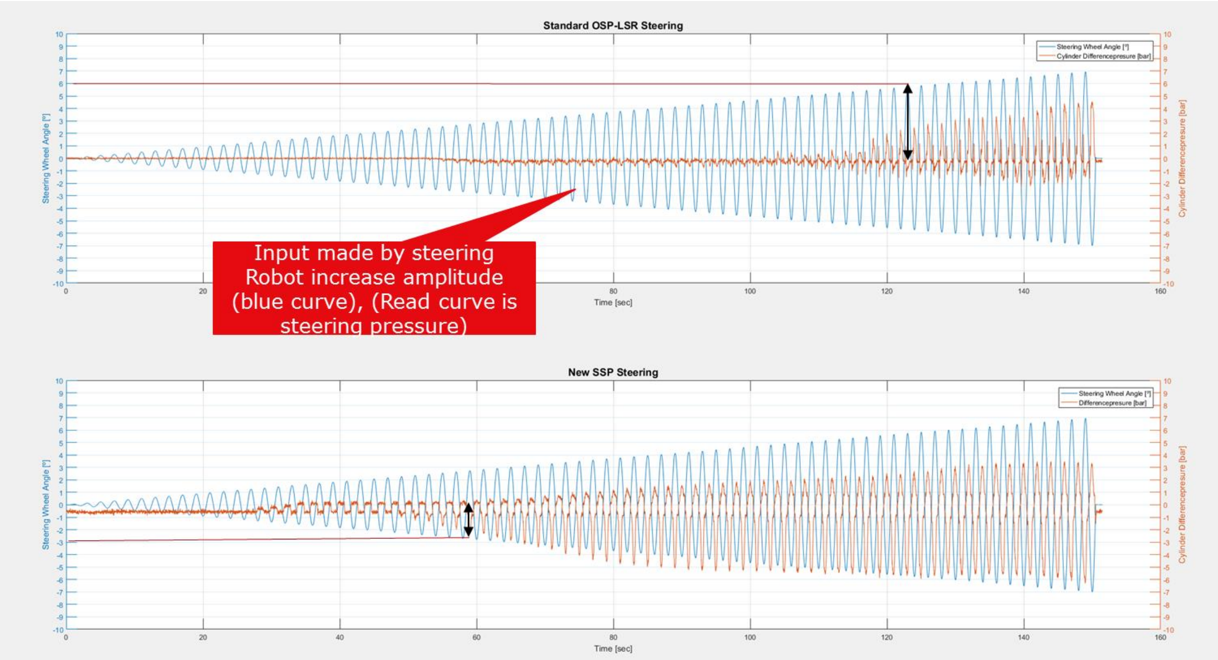

Fig. 3: Test of deadband improvement by steering robot.

Quantifying steering performance

To identify a suitable metric for steering performance evaluation, six different evaluation methods have been applied to 15 experienced tractor operators (Age: 30.7 ± 11.9 years) in a single-blind test at the Application Development Center, Fig. 1. The operators were asked to perform two different tasks with two identical 300hp tractors with 60km/h transmission. One tractor was equipped with a conventional steering unit from Danfoss (c) and the other was equipped with a prototype of the new zero deadband steering unit technology called sSteering (s). Both steering units include self-aligning functionality and the zero deadband steering unit provides (on purpose) more self-alignment than the conventional steering unit.

The test consisted of two tasks. Task 1 (T1) is lane keeping at the oval track, Fig. 1, where the operators were asked to follow the white middle line at 50km/h for approximately 10 minutes corresponding to 10 laps. Task 2 (T2) consist of a double lane change with 30km/h through cones for approximately 10 minutes corresponding to 12 repetitions, Fig. 4.

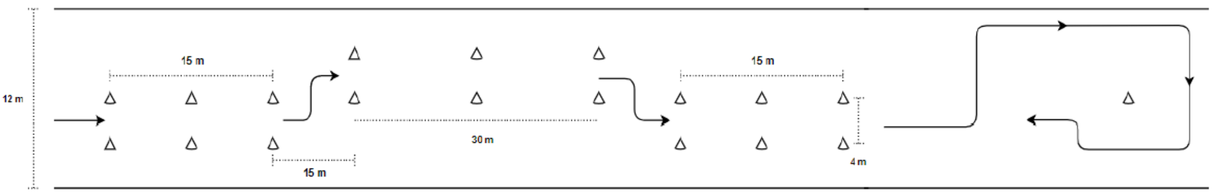

Fig. 4: Task 2 test setup for double lane change.

During the test, six different measures were conducted; 1 subjective and 3 objective measures. The subjective test is a NASA Task Load Index [8]. The 3 objective methods are electrodermal activity (sweat), electromyography (muscle activity), heart rate (HR), steering wheel angle (SWA) and steering wheel speed (SWN).
More details on the experiment, equipment and results can be found in [9].

Results

Figure 5 shows the comparison of the NASA TLX for both tasks and for each of the different steering unit technologies. For Task 1 (T1) the total score was reduced from 39.9 with a conventional steering unit to 25.3 giving a 37% improvement of the operator experience. For Task 2 (T2) the total score was reduced from 36.1 with a conventional steering unit to 22.2 giving a 38% reduction of the effort needed. Hence, the operators evaluated the sSteering to be 37-38% easier to drive. The results from the NASA-TLX index was significant within a 95% confidence interval.

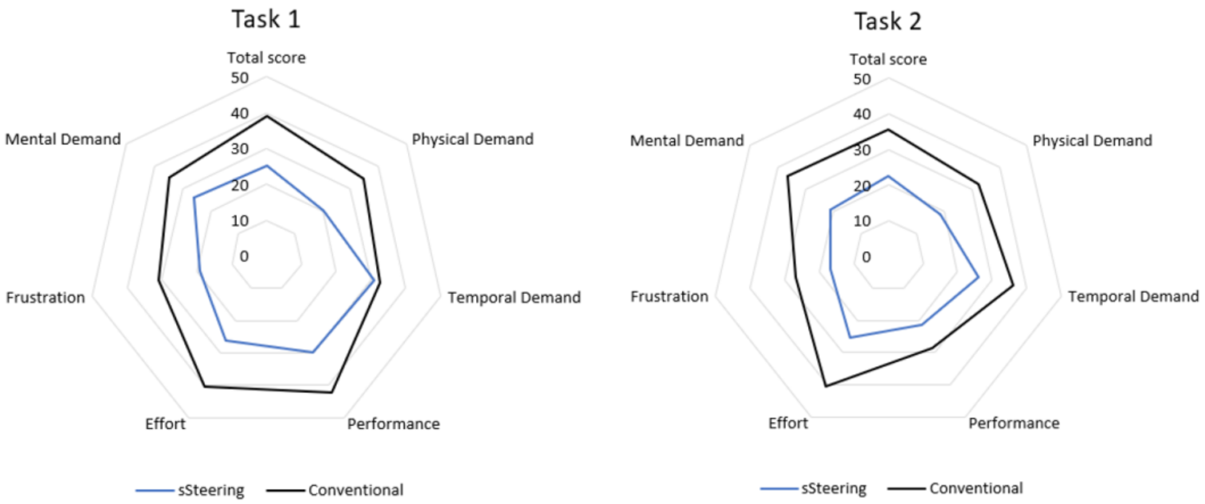

Fig. 5: Results of the NASA TLX evaluation.

The results of the objective methods showed no statistically significant difference. However, for the muscle activity, a trend is seen by 11-16% reduction of electromyographical signal with the sSteering technology, Fig. 6.

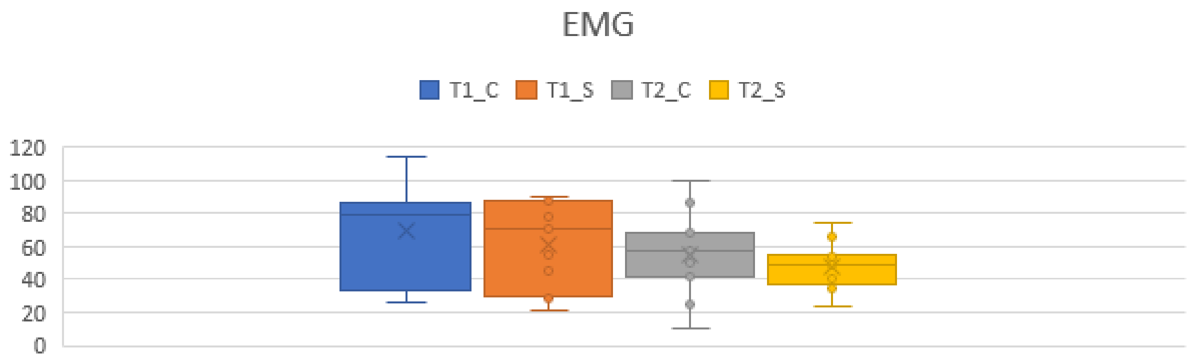

Fig. 6: Comparison of electromyography for Task 1 (T1) and Task 2 (T2) with conventional steering (C) and sSteering (S)

Even though the electrodermal activity did not show a significant difference, between the two steering units, the method appears to work for more extreme differences. In this research, it is observed, that the operators sweat more during Task 2 compared to Task 1, Fig. 7.

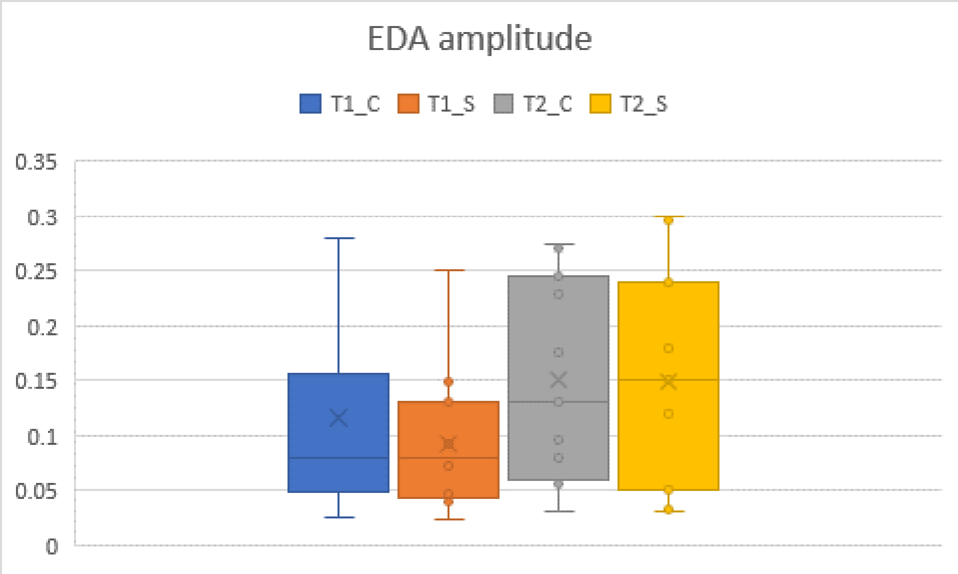

Fig. 7: Comparison of electrodermal activity for Task 1 (T1) and Task 2 (T2).

Evaluating the SWA and SWN, a correlation is found between the NASA-TLX results and the number of zero crossings of the steering wheel speed (SWN), Fig. 8. Counting the number of zero-crossings showed a 11-33% reduction with sSteering compared to the conventional steering unit. The number of zero crossings can also be expressed as the number of directional corrections, the operator performs.

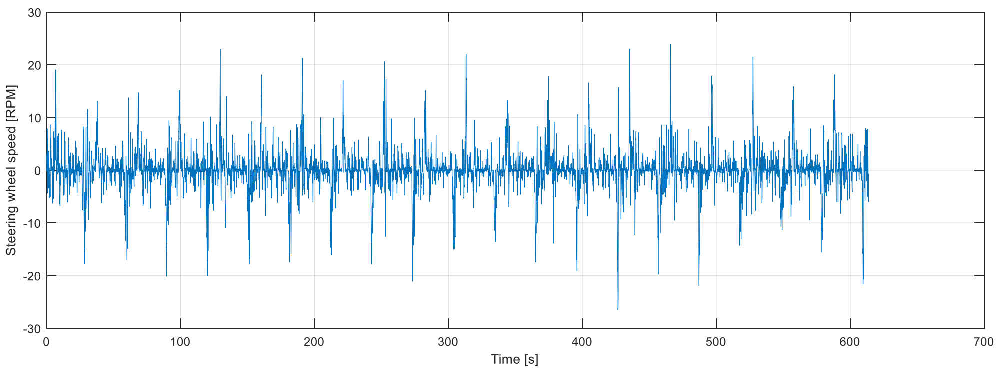

Fig. 7: Sample of time signal of steering wheel speed (SWN) during Task 1.

Conclusion

Evaluating design change impact on steering performance of a tractor requires test facilities, expert operators and advanced equipment. Steering robot technology offers great potential for improved testing especially for detailed evaluation of changes without the need for human assessment. The NASA-TLX has shown to be the most promising method to quantify operators' assessment of steering performance. As it is desirable to have an objective method for faster and more precise evaluation work, in this research a correlation between the subjective evaluation and the number of zero-crossings of the steering wheel speed. The authors will hence recommend moving forward with a closer correlation study between the NASA-TLX method and the zero-crossings of steering wheel speed, as it shows a promising metric to get a quantified feedback from operators.

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