New methodology to assess and test the durability of agricultural machinery

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Abstract

During the last decades fatigue life of agricultural machinery is gaining more interest as the transport and working conditions have changed. Transport and working speed have increased since advanced and more powerful tractors are being offered. In order to compensate for longer operation periods on large farms, manufacturers have developed bigger implements with higher capacity which in some cases e.g. for swathers reach up to 15 meters working width. Factors like higher speed and machine weight affect the durability of agricultural machines with high economic loss in the case of a breakdown. In order to assess agricultural machine durability a new analysis approach is needed to combine field and road surface mapping and dynamic strain and load measurements. In the present paper strain data from critical points of a four rotor swather were recorded as well as the accelerations on the main axle. In addition the surface data that produced the aforementioned load were also obtained to describe the dynamic input loads.

1. Introduction

Agricultural machines like many other machines throughout their working life are subjected to loads that vary according to different parameters such as surface and operation types. This cyclic loading produces a localized damage process of a certain component called *Fatigue* [1]. At points with high stress, plastic deformation is developed which can cause permanent damage. In order for fatigue life to be assessed strain data from critical, highly stressed locations must be obtained or estimated [2]. One of the first important researches in fatigue load analysis of agricultural vehicles was performed by Kloth and Stroppel [3]. Koike and Tanaka [4] measured the strains at different locations of a tractor's rear axle housing calculating its structural strength. A more recent study in the field of structural tests on tractors can be found in [5] where strain data have been collected from an 80 kW tractor.

Acquisition of surface data is also crucial as in combination with the parameters of the wheels and the tractor's speed significantly affect the accelerations that are produced on the axle of the implement [6]. These accelerations play important role on the strains and the forces that are developed on the main chassis of the machine. In the case of prototype development when the actual machine is not yet available agriculture vehicle simulation can be also performed using digital road profiles [7].

Aim of the present project is to develop new methods that analyse fatigue conditions from the perspective of commercial design and test engineering. The principles are based on measuring field and road surfaces as well as detecting and determining the load spectra. The main objective is to be able to perform accelerated structural tests on the implements simulating their transport and working life in test facilities, establishing concrete knowledge about the fundamental parameters that really affect fatigue life. For creating generic methods for being able to apply the methods to different machine designs, simulation of dynamic tire behaviour as well as simulating the test stand set up can be used. In order for these concepts to be investigated, a swather with four rotary units was judged appropriate to be used due to its large size and weight. Results of measuring the load spectra and the accelerations under working conditions are presented.

2. Materials and Methods

In Figure 1 the concept of the project is presented. The first stage includes the use of the

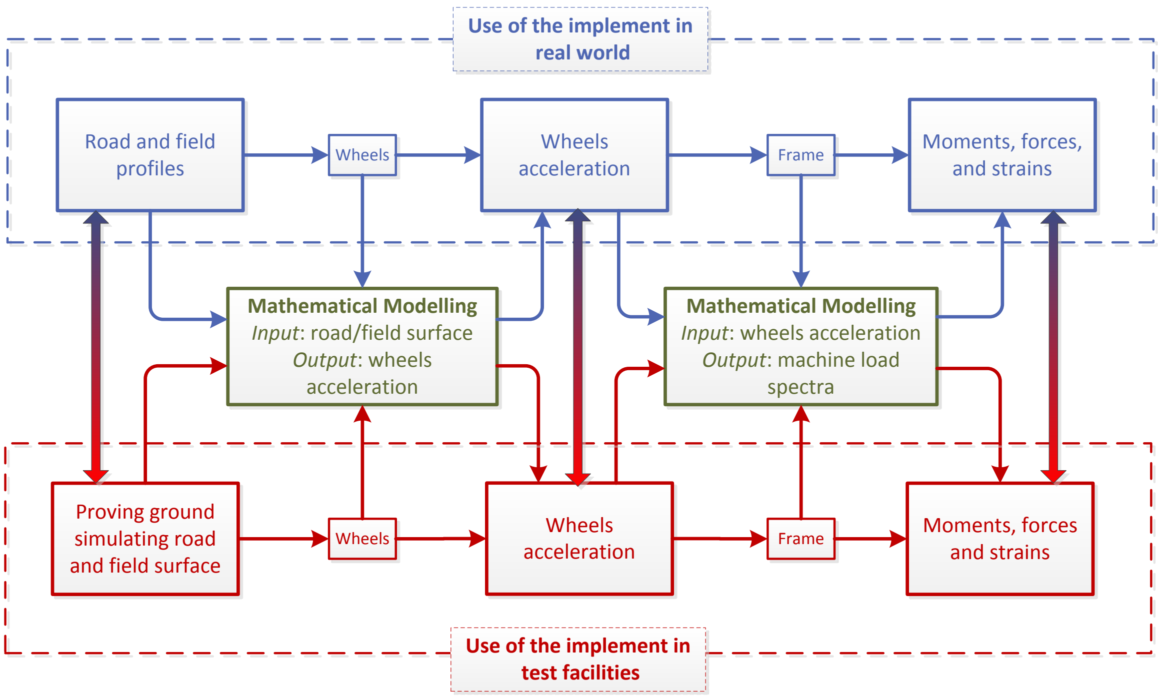

Figure 1: Project concept with interactions between field experiments (real world) and accelerated simulation (test facilities)

implement in the real world under transport and working conditions where road and field surface data, swather wheel axle accelerations and the load spectra in frame profiles are obtained. Subsequently, the implement is used in test facilities where data from the same sensors are acquired. Having surface data in combination with the parameters of the wheels, mathematical modelling can be used in order to output the same wheels accelerations as the measured ones. The same procedure can be followed also to calculate the strains and forces that are applied on the chassis of the implement having as input wheels accelerations. The ultimate goal is to be able to evaluate fatigue life of the implement by using it in test facilities.

For the road and field experiments a four rotor swather (CLAAS Liner 4000) and a 129 kW tractor (CLAAS ARION 650) with GPS-Pilot were used. Data were acquired during transportation with different speeds on asphalt as well as unmade roads. The field experiments were carried out on a grass field of 3.75 ha (N50° 01´ 8.3´´, E8° 59´ 3.2´´).

For measuring the load spectra, sixteen linear 350 Ohm strain gauges (HBM, Darmstadt, Germany) were placed at critical points (see Figure 2) on the chassis of the swather. Twelve of them were attached in a position measuring the uniaxial stress (strains) while the rest four were placed in such a configuration measuring the load from the chassis on the main axle. In addition, two inertial measurement units (IMUs) (VecorNav, Dallas, USA) were utilized one after each wheel of the implement sensing the accelerations on the main axle. An AgGPS 542 RTK-GNSS system (Trimble, Sunnyvale, USA) attached on the swather provided georeference of the acquired data.

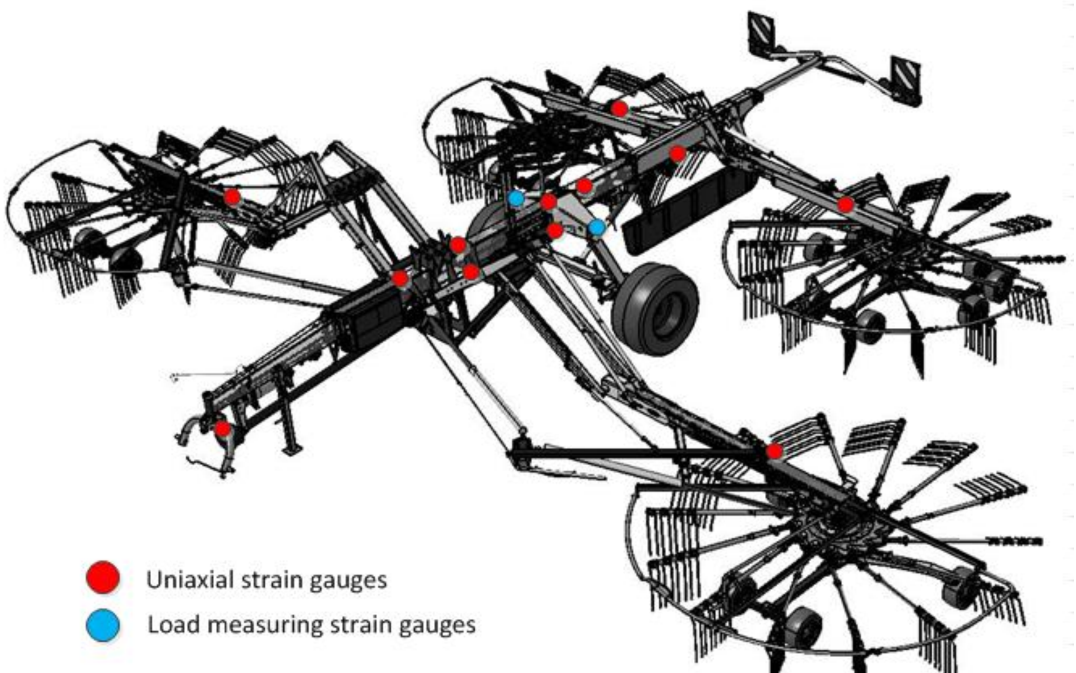

Figure 2: Positions of the attached strain gauges on the swather (Photo CLAAS Saulgau)

Data acquisition on different channels was performed using a DEWE-50-USB2-16 system utilizing sixteen BRIDGE-A modules (DEWETRON GmbH, Grambach, Austria) in a quarter bridge configuration for every channel. In order to configure the aforementioned hardware and store the data, DASYLab 12.0 (National Instruments Ireland Resources Limited) was used. The sampling rate was set to 600 Hz. It was judged appropriate a Bessel-Thompson low pass filter to be applied in order to reduce high frequency noise. The cut-off frequency of this low pass filter was set to 100Hz.

In order to measure road and field surface profiles, a sensing system has been developed that mounts all the needed sensors (see Figure 3). This construction utilized a metal frame which was mounted on the tractor's rear three point hitch and two wheels which followed the path that swather wheels where moving on, to be able to acquire the surface profile of each track. The diameter of these two wheels was 350 mm in order to measure the surface with adequate accuracy. Two DT500 laser pointers (SICK AG, Waldkirch, Germany) with ±3 mm accuracy were measuring the surface elevation provided by the two wheels and an LMS 111 laser scanner (SICK AG, Waldkirch, Germany) was used to scan the entire surface. An AgGPS 542 RTK-GNSS system (Trimble, Sunnyvale, USA) was also used to provide georeference of these surface data while a VN-100 inertial measurement unit (VecorNav, Dallas, USA) was utilized to provide dynamic tilt information.

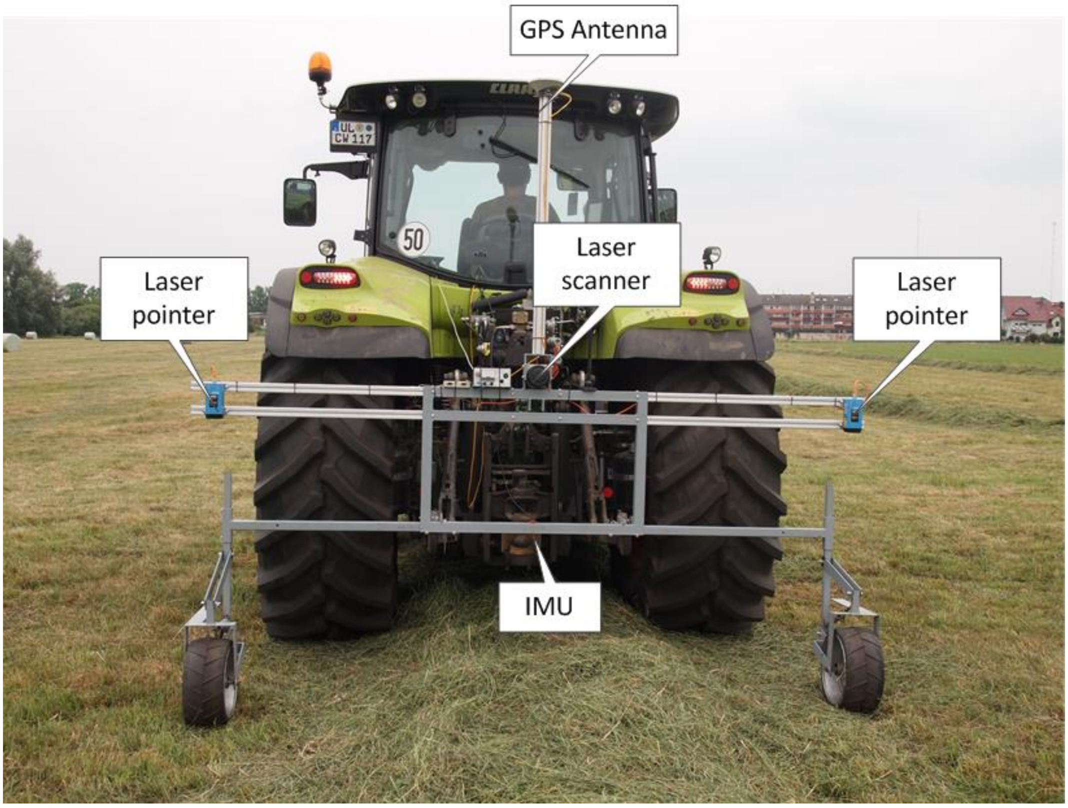

Figure 3: Sensor framework for measuring surface profiles mounted on a tractor

3. Results and Discussion

First road and field experiments were conducted to capture loads under transport and working conditions. Asphalt and unmade roads were measured. The results showed that the measuring set up for surfaces (frame design, sensors and performance) was appropriate and all the desired data were obtained. Because the sampling rate of the laser pointers was only 4 Hz the speed of the tractor while measuring surface profile data was 1 km/h allowing measuring the surface elevation every 70 mm. In order to detect the impact of the surface to the implement this was proved to be enough considering the impact area of swather wheels to be around 0.4 m. During the swathing operation the speeds were varied and complete operation profiles were captured including turning on headlands. For post processing the sensor data were completed with a time and positional stamp to ease data synchronization.

In Figure 4 the vertical acceleration on the main axle of the machine and the corresponding strains at a point on the main chassis are illustrated. It is clear that the strain at the specific point is following the same pattern of vertical acceleration. To evaluate fatigue life further analysis should be done using cycle counting methods, such as rainflow cycle counting [1].

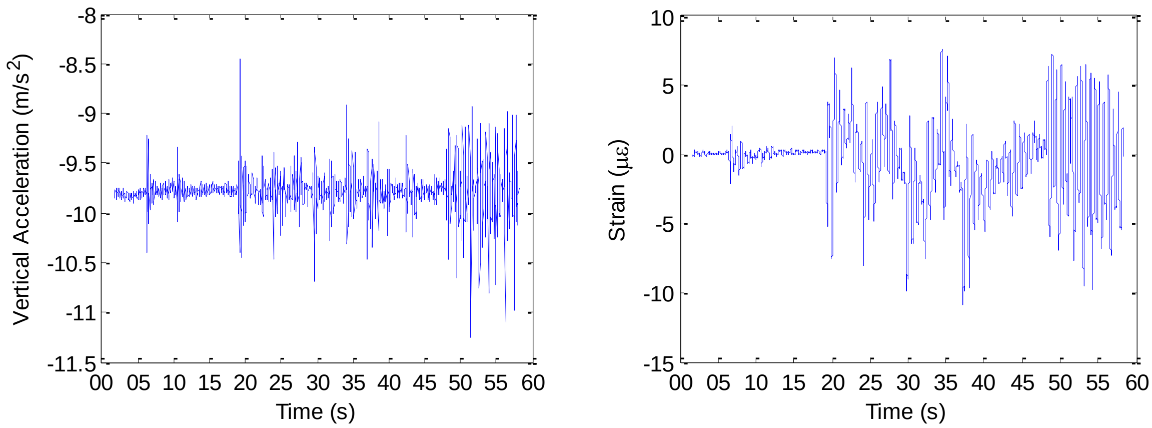

Figure 4: Left: Vertical acceleration on the main axle of the swather. Right: Strains developed on the main chassis

Detailed data analysis will show if critical loads will be able to be identified for what operational condition. Further experiments will take place also in facilities of the DLG Test Centre and CLAAS Saulgau in order to set and complete the basis for being able to test and assess fatigue life as well as setting up a new test program for agricultural machinery.

4. Conclusions

In the present paper sixteen strain gauges were attached on a four rotor swather in order to establish a methodology that can assess fatigue life in agricultural machines. Accelerations on the implement axle were also obtained in combination with an RTK GPS for georeference purposes. A sensor framework for measuring surface profiles has been developed and some first experiments have been conducted. Preliminary data analysis reveals the strong correlation between chassis strains and accelerations on the axle as it was expected. Obtained data must be further investigated in order to have a more clear view on the factors that contribute on fatigue life.

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