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Preliminary conclusions on application of ultrasonic sensors in evaluation of distribution and depth of ruts in forest thinning

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Abstract. The scope of the study is to elaborate equipment for measurement of ruts during log forwarding. The system is supposed to be used in practical forestry to replace manual measurement of length of deep ruts and to provide spatially explicated information on soil bearing capacity, which can be used in planning of forest operations.
A set of 4 pairs of ultrasonic sensors were installed on front and rear bunks to measure distance to the ground at 90° angle (in front and behind the wheels in each side of forwarder) and at certain angle to measure distance to the ground outside strip-road. Measurement data are sent to the logger, where they are stored in .csv files. Wired connection between the sensors and the logger was used in earlier version, but later replaced with wireless connection. Depth of rut is calculated using formula for calculation of length of cathetus of a right-angled triangle. Data processing in spreadsheet includes initial identification of error values and calculation of depth of ruts. Further spatial data analysis is done in GIS software.
According to the study results ultrasonic sensors provides sufficient accuracy to characterize depth of ruts in 1...5 m long segments of strip-roads, including dynamic data on depth and length of ruts after each pass. However, the accuracy is insufficient to compare measurements from sensors mounted on front and rear bunks, as well as on left and right side of machine, therefore it is enough to have 2 pairs on sensors on rear bunks.

Key words: ultrasonic sensors, rut depth, harvesting.

INTRODUCTION

Harvesting in forest can cause soil disturbance through compaction, rut formation and mixing of soil layers (Prindulis et al., 2016). Harmful effect can be also observed on water regime, if forwarding roads interferes with water streams. These impacts affect the soil functions and forest productivity. Soil compaction may result in an increased bulk density and decreased porosity, water permeability and aeration. Deep ruts, particularly in thinnings of coniferous stands, are associated with distribution of root rot, deterioration of moisture regime, and increase of output of methyl-mercury into water bodies (Eklöf et al., 2014). These issues will become more important in the future since harvesting operations on unfrozen soils are getting more common due to the anticipated climate warming and increasing area of forest stands on soils with low bearing capacity requiring thinning.

The ultrasound frequency exceeds 20 kHz (Panda et al., 2016). Nowadays ultrasound is used in many different fields because of its characteristics. Its physical properties in different environments is similar to the normal (audible) sound. Ultrasound can spread in gases, liquids and solids (Maghsoudi et al., 2015). Ultrasound can be divided in two groups, according to field of application:

- active ultrasound – ultrasound of a very high frequency is used to create a physical or chemical reaction. It is used in surface cleaning, welding, drilling etc. (Koval et al., 2016);
- passive ultrasound – low frequency ultrasound is used. It is used to determine a distance, to measure density and detect damages in different materials, detection of gas and liquid flow, as well as in medicine (Koval et al., 2016).

An ultrasonic sensor sends impulses of ultrasound waves towards an object and receives echo signals that are reflected back. The distance between the device and the surface of an object is calculated according to the time period from sending the ultrasound waves and receiving an echo (Gudra et al., 2017). The main advantage of ultrasound emitters is their ability to measure distance, level, contours of an object and position from a distance. Ultrasonic sensors can perform successfully in difficult conditions – measurements are relatively accurate regardless of the impact of light, dust, fog and the material (Koval et al., 2016). It is possible to measure any material that can reflect sound, regardless of its colour and transparency. The growing popularity of ultrasonic sensors demands millimetre range of operation. The main factor that influences measurements is change in the speed of sound, which is influenced by several environmental factors: temperature, relative air humidity, air pressure, CO_2 levels in air and altitude above sea level. However, it was found during latest studies that influence of CO_2 is insignificant. Environmental errors in measurements can be minimized by adjustment procedures (Panda et al., 2016).

Ultrasonic sensors have been used in practice for a relatively long time. In agriculture ultrasonic sensors have been used for more than 40 years to automate and facilitate crop harvesting, to dose pesticides and fertilizers and to detect weeds in crops (Schumann & Zaman, 2005; Escolà et al., 2011; Andújar et al., 2012; Chang et al., 2017).

Several studies describe the operation of ultrasonic sensors. Escolà in his research encountered accuracy problems during measuring distance to apple trees. When measuring trees with thinner foliage, the ultrasound impulse can reflect deeper in the canopy, where the surface of reflection is larger. The distance from the sensor and the shape of the tree crown also affects accuracy of measurements (Escolà et al., 2011). Andújar et al. in their research on weed monitoring in growing food crops found possibility to identify weeds acccording on difference in height between the crops and weeds (Andújar et al., 2012).

Due to device's ability to work under difficult conditions, where high accuracy is not crucial, it can be used to detect the level in different storage tanks. Nowadays waste management in cities is becoming more problematic, therefore it is proposed to install specified sensor blocks in garbage bins, which would consist of an ultrasonic sensor, a gas sensor, a humidity sensor and a GSM modem. These sensors would be used for measuring garbage level as a part of organization of waste management system (Lokhande, 2016).

Ultrasonic sensors can be used as individual elements or grouped in arrays. Ultrasonic sensor arrays are widely used to perform different inspections. Sensor arrays provide increased quality and reduce the amount of time required for inspection, however the main advantage over traditional single element transducers is to perform a number of functions simultaneously. It is possible to place sensors so that they can perform continuous scanning, focused scanning and scanning at a specific angle. Using the ultrasonic sensor array it is possible to carry out measurements and obtain immediate images of the research object (Drinkwater & Wilcox, 2006).

When sensors located nearby are working simultaneously, interference has to be taken into account. It is recommended to divide sensors into groups in order to avoid inaccurate readings due to overlapping of reflected waves. However this method is ineffective, as data collection time increases and quality of data declines, and not suitable for data collection, when the sensors are located on a moving object (Escolà et al., 2011).

Nowadays ultrasonic sensors are also used in road maintenance, in order to detect ruts. Rut depth is measured with a specialized arrays of ultrasonic sensors. The amount of individual elements and their position in the array can vary. All the arrays work simultaneously and periodically to avoid overlapping of signals (Serigos, 2012). Sensor arrays with 3 or 5 elements can detect only depth of ruts that have been formed on the road. Along with increasing the number of elements per array, accuracy of measurements of road surface increases.

During logging significant soil disruptions can occur – tearing of topsoil and compaction and mixing of different soil layers (Prindulis et al., 2016). Soil damage can has negatively influence both, on chemical and physical properties, thereby negatively affecting development of the forest stand. The degree of soil damage depends on a number of factors, e.g., soil moisture, topography, logging type, machines used, drive count and whether logging residues have been put in strip roads (Laffan, Jordan, & Duhig, 2001).

Within the scope of this study an automatic ultrasonic rut measurement system was developed and tested. The aim of the study was to create an automatic rut measuring system, which can be used both, in practice and research. In practice it can be used as a control and monitoring tool to minimize the impact of logging on the remaining trees and soil. In research it can be used to automate soil impact measurement and to obtain more detailed data on distribution and depth of ruts. In this article preliminary results of field trials are presented.

METHODS

Description of the device. Rut measurement system consists of the central block, which reads and stores data, and several attachable blocks – global navigation system antenna, which guarantees accuracy of measurements up to 1 meter, sensors of cabin microclimate and vibrations of operator seat, sensors of engine speed and fuel consumption, as well as 2 distance measuring blocks, which are equipped with ultrasonic distance sensors (HRXL MaxSonar WRMT). Obtained data are stored in the SD card in the central block and the storage period is up to half of a year. The central block collects measurements of each component every second, when it is provided with power supply.

Each distance measuring block consists of two ultrasonic sensors, where one sensor (turned at a 90° angle towards ground) measures distance to the ground behind tractor whereas the other one – at a 67° or 66° angle outside the strip road.

The software developed within the scope of the project includes an option to connect to the central block in real-time, establishing a connection through *Bluetooth* wireless module. Telemetric data and data on measurable parameters from all the attached blocks can be observed online, whereas stored data can be converted to CSV (comma separated value) format for further processing and analysis in external tools.

Methods applied in field tests. Testing of the rut measuring system was carried out in forest thinning. The system was mounted on John Deere 810E forwarder. Forwarder worked in 'business as usual' conditions, without any special requirements in relation to the ruts' measurement.

During the field tests the central block was placed in the operator cabin with continuous access to power source. Both distance measuring blocks and global navigation system antenna were attached in order to test the system during experimental drives. Distance measuring blocks were mounted on the rear bunks of the forwarder in order not to disturb the operator and not to be damaged. Distance measuring block was placed so that the ultrasonic sensor (directed towards ground at an angle of 90°) is positioned in the middle of a rut.

Spatial data processing. When carrying out spatial data analysis, it is possible to observe the motion of the forwarder in the felling site. With spatial data processing it is possible to select strip roads and distribution by segments. Before processing spatial data the initial quality assurance was done to exclude outliers from the analysis.

Data spatial processing was carried out in QGIS software environment. After data input strip road was randomly selected for further processing. Trial was conducted in thinning, where the GPS signal is inaccurate, therefore the selected road was divided in 10 m wide segments. After dividing the road into segments, obtained data were processed using Microsoft Excel to calculate depth of ruts. In future it is planned to do all calculations within the QGIS environment providing powerful tools for spatial and geometry analysis.

Data filtering. Qualitative data selection was carried out by filtering measurements of ultrasonic sensors in Microsoft Excel. In order to filter errors, the maximum (5,000 mm) and the minimum (300 mm) value was set for each sensor. Maximum values in output data indicate that the ultrasound impulse in a 5 m distance has not reached a lock point and the sensor cannot receive the reflected wave from the object locater further away, whereas the minimum value indicates that in a 0.30 m distance from the sensor met an obstacle, e.g., a branch. Values between 300 and 5,000 mm were considered qualitative data.

Calculation of rut depth. In order to calculate rut depth measurements from side sensors were taken into account. Before starting the field tests the distance to soil surface should be measured to calibrate the calculation (Fig. 1). Angle of horizontal position of the machine is considered in the calculation and outlying values are filtered out.

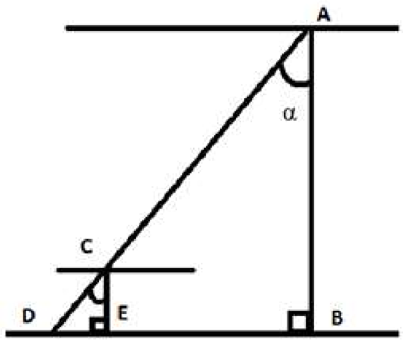

Figure 1. AD – measurement of the sensor pointed sideways; AB – measurement of the sensor pointing downwards; AC – distance between the sensor and ground surface; CE – footprint of a tractor in soil.

Footprints left by the forwarder on the soil can be calculated by subtracting the distance to the ground surface from the measured distance during the drive and carrying out trigonometric adjustments (1).

$$CE = (AD - AC) \times \cos\alpha \qquad (1)$$

RESULTS AND DISCUSSION

Spatial data. The obtained spatial data were of high quality and it was possible to process them. Because of the high accuracy of GPS coordinates it was possible to distinguish strip roads and select them to process data further.

GPS signal in thinnings was less accurate, as it was influenced by remaining trees. The selected strip road was divided into segments, each 10 m long. The length of the selected road was 108 m and it was divided in 11 segments of the same size (Fig 2). Depending from quality of rut depth measurement data the length of segments can be increased or decreased to obtain statistically representative data set for each segment.

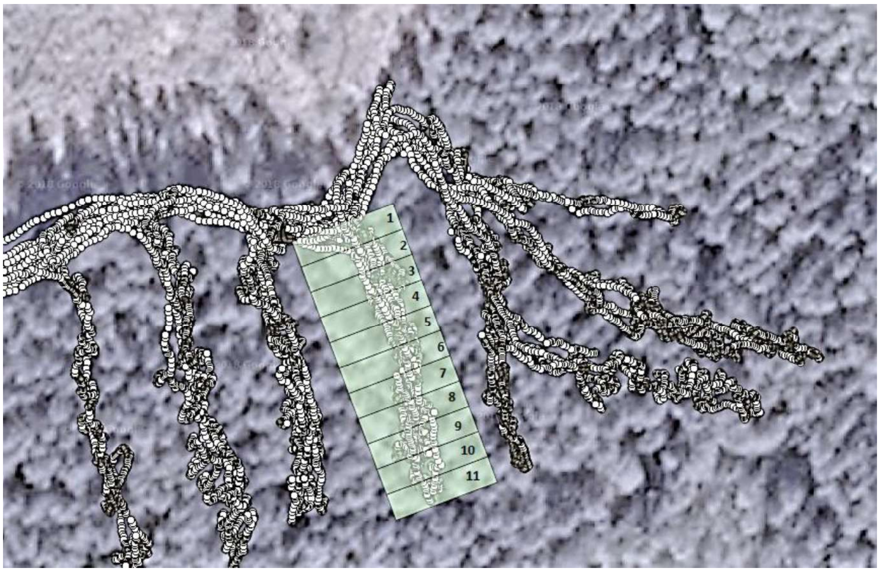

Figure 2. The selected strip road, divided into segments.

The first segment was not used for further data processing in order to avoid measurements that were carried out on the main road. The segments 10 and 11 also were excluded, because it was difficult to precisely distinguish forwarder passes in these segments. It is planned to use average vector direction to identify possible turning points to distinguish the passes.

Geometry analysis. After selection of the strip road and its division in sectors it was possible to distinguish number of passes and time spent in each sector. The total time spent in the selected strip road was 50 min 43 s. In order to haul all logs, 4 passes were required. During the first pass forwarder didn't drive beyond the segment 2, therefore this drive was not taken into account in calculations. During each pass, forwarder crossed each segment 2 times, while driving in and out from the felling site. The rut's measurement data show how the status of the strip road changes after each pass. Taking into account that the forwarder does not always move using the same track, drives cannot be compared completely impartial. It is possible to observe similar tendencies between different drives in the same sectors. It can be assumed that during those drives the forwarder has taken a similar trajectory.

It has to be taken into account that the surface from which the ultrasound wave reflects is very variable. Deviations from the trajectory of the previous drive can significantly impact the measurements. As a result the location, where the ultrasound wave has reflected in the previous drive, and the reflected angle have changed. It would not be correct to compare results from sensors of both sides, as the amount of successful measurement from both sides is small. Therefore data from each sensor was analysed separately (Figs 3 and 4).

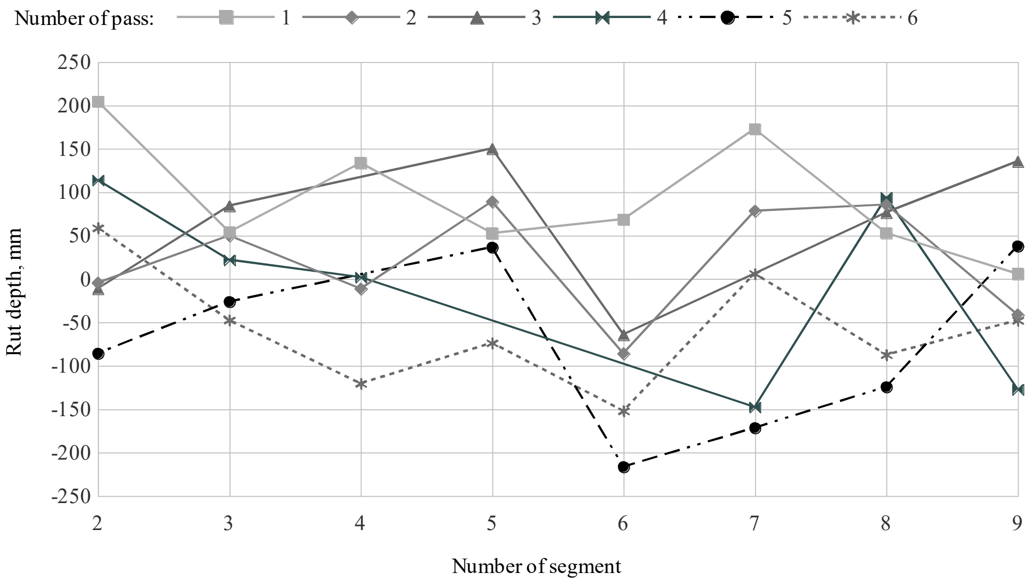

Figure 3. Measurements from the ultrasonic sensor of the left side.

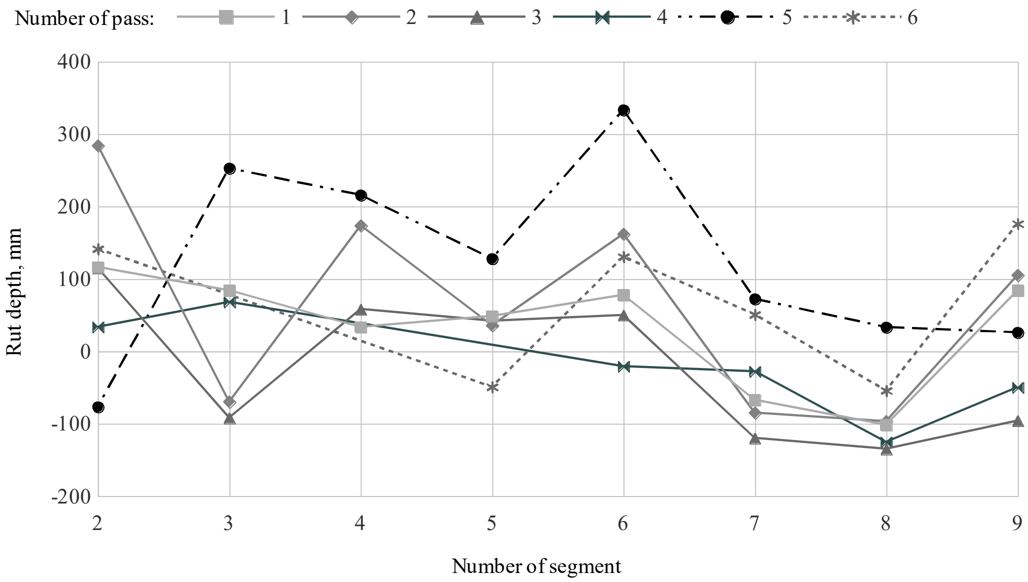

Figure 4. Measurements from the ultrasonic sensor of the right side.

A 10 m long segment provides sufficient quantitative information on soil impact and rut formation during forwarding; however, it is too long to provide information on rut formation demanded for the formal quality assurance. Additional benefit of the elaborated system is detailed representation of number of passes, driving speed, productivity, soil bearing capacity, fuel consumption and other technical information, which can be utilized to improve the forwarding performance, as well as to plan further forest management activities in a particular stand. The amount of valid data has to be increased in future to reduce length of the segments and to improve accuracy of the measurements.

Comparing the tendencies during following passes the rut depth in the forest can be characterized. Results from the sensor of the right side show that significant footprints in soil could have occurred in segments 7 and 8 (Fig. 4). None of the footprints exceeded the depth of 20 cm, therefore they cannot be considered as ruts according to formal quality requirements.

In field test harvesting residues were placed on strip roads. In result, forwarder was driving above actual ground level, which explains positive values. If the results from both side ultrasonic sensors are either positive or negative it possible to say if there is or is not any ruts. Taking into account, that results shows average values from segments, it is hard to say if in these segments are obstacles which impair movement of forwarder. To see obstacles on strip roads closer investigation in all segments needs to be done.

It can be observed that the amplitude between the measurements from the sensors of the left side is larger and it is more complicate to observe certain patterns. The tilt of the forwarder was not taken into account, when taking measurements, therefore it is difficult to assess, if changes in results are due to tilting of the forwarder or due to the chosen driving trajectory. The tilting is associated with use of harvesting residues in strip-roads to improve forwarding conditions, therefore forwarder is driving over a kind of embankment until it is completely compacted and mixed with topsoil.

Comparing results from sensors of both sides, an opposite change in results is observed. It can be assumed that changes are proportional to the tilt of the forwarder. However the tilt of the forwarder was not taken into account in calculations, therefore in this case clear connections cannot be drawn. Tilt of the forwarder should be taken into account when carrying out further research on rut formation, using ultrasonic sensors. Additional forwarder tilt sensor can be added to system to determine forwarder horizontal and vertical tilt. It is also important to consider that forwarder can use different tracks during different passes to avoid ruts' formation, therefore for the quality assurance purpose the deepest ruts in a particular segment should be used Instead of ruts depth during the last pass.

Future trials should be carried out in final felling sites, where harvesting residues are not placed in strip roads, in order to investigate dynamics of ruts formation more precisely and to avoid impact of logging residues. In order to evaluate the system more effectively, felling sites with flat terrain should be selected.

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