An automated detection system for (forest) road conditions

An automated detection system for (forest) road conditions

Michael Starke*, Martin Ziesak, Daniela Rommel, Philipp Hug

Abstract: Forest roads – or more generally speaking gravel roads – underlie permanent wear out. Due to erosion, influence of weather and traffic-based use the status of a road changes quite dynamically. Hence induced damages on the roadway may get quite severe when not being cured by (regular) road maintenance.
Particularly in the forest sector knowledge about the current road condition is required for an effective planning and execution of those road maintenance actions. At the moment damages on forest roads are very often registered only according to subjective assessment criteria. The registration process frequently only happens with much time delay, at huge costs and with low precision.
A novel approach is presented here, where a measuring instrument was constructed that automatically detects road conditions, particularly for gravel roads. The system is a setup of several hardware components, compiled in a lance like unit, which gets attached to a car at the towing hitch or alternatively at a truck. This part is supplemented by wirelessly linked sensor units, attached near the vehicle wheels.
Raw data collection may typically happen during other (routine) vehicle movements on forest roads. The data analysis is usually done after the measurement campaign in a subsequent later step. The data evaluation is integrated into the software package "iFOS", where an identification and categorization due to different road conditions is done. In particular the strong rules engine supports a versatile use of this tool.
Field tests showed the practicability and usability of the device. The measurement principle facilitates an objective evaluation of road conditions. Forest enterprises receive a transparent tool for the allocation of funds on road maintenance. Consultants may want to use it for road registration and valuations.

Keywords: Forest road; maintenance; automatic detection; road quality evaluation

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1. Introduction

Forest roads are an important asset in forest enterprises. This is true for both public and private owners; it is true for small and big forest enterprises as well as for close-to-nature management regimes and plantations. The dominating road type found in any of these categories is a road without a hard cover, such as bitumen, asphalt or concrete. These dominating unsealed roads need regular maintenance. This is necessary as effects from traffic, road usage, but also from erosion and weathering may create unwanted road damages, such as potholes, surface ruts or corrugations. Hence it is evident that the road status has to be understood as a rather dynamically changing attribute.

For digital road management systems a contemporary forest road description is necessary, in particular the setting up of road maintenance regimes and schedules will be built on such information. In order to fulfill these needs a procedure or tool is necessary, telling the status of forest roads in an objective, precise and easily to achieve manner at competitive costs.

As a key component for the description of a road status the characteristics of the roadway have to be considered first place. Here the longitudinal roughness is a first important element, which may be disturbed by potholes, bumps or corrugations. Another one is the deviation from an expected and wanted cross profile shape, like for instance a roof profile. Here disturbances may be the flattening of such a shape or, again, the forming of ruts, shoving or humps.

2. Overview on some existing systems and measurement principles for road status monitoring

In road maintenance of public roads, which to its majority are nowadays tar-roads, but also in the monitoring of rail tracks, there exit several different approaches for the automated collection of describing status attributes. Laser scanning offers a quick and precise *distance measurement* through light-return-time measurements. When integrated into a tool kit this may offer through its extremely dense measurement dots a rather precise 3D road surface model, respectively information on longitudinal or transversal evenness of a road. As a tool of this kind the PPS (pavement profile scanner) as developed by Fraunhofer IPM may be mentioned here (Anonymous 2013). When applied in favorable illumination and contrast conditions the *light-section principle* offers another way to collect (road) surface information. *Accelerometers* may be used as (indirect) sensors for collecting vibrations at wheels or vehicles, as induced though longitudinal road roughness. A sample setup is described in Johansson, Kosonen, Mathisen, McCulloch and Saarenketo T. (2005), a product built around a sensor of this type is Opti-Grade (Brown, Mercier and Provencher, FERIC 2002) and a newer version would use the g-sensor in a smart phone (Moussaoui, 2013, Forslöf and Jones, 2015). Furthermore *thermal cameras* may help to identify temperature differences induced by moisture differences in the road surface. Mantintupa and Saarenketo (2012) describe an application of this technology, a product solution is offered by e.g. FLIR (see Anonymous, 2011). The *ground penetrating radar* (GPR) finally offers the option to collect sub-surface structural information (Saarenketo, Matintupa and Varin, 2012, Saarenketo, 2016).

Considering the abilities of these measurement principles for their application on forest roads, some approaches have only limited usability: intensive light and shadow patterns must be expected under forest canopies. This will influence road surface temperatures as well as the visibility of light beams. As a consequence thermal cameras will have limited usability; the same is true for procedures relying on light-section. Accelerometers attached in the cabin of a car or truck will not directly measure road roughness, but reflect very strongly dampening elements such as wheels and shock absorbers from these vehicles (Moussaoui, 2013).

The majority of existing tool kits use dedicated measurement vehicles with firmly fitted sensor units or alternatively they are built onto trailers with sensors being mounted there. This results in the need to send out these dedicated vehicles or trailers for the data collection purpose, an integration of the measurement campaign with other transport movements is more or less impossible. This is a detrimental aspect, as the application will increase costs for data collection campaigns. Furthermore in the evaluation of these existing tool sets their investment costs must be considered. Last but not least the suitability to detect forest road typical damage patterns on the road bed may be limited. In particular single-sensor approaches seem to have some limitations (see Moussaoui, 2013; Conrad, 2013).

This resulted in the decision to develop a new measurement device, using a sensor fusion approach. The concept was constructed in a manner to be mountable at cars (or trucks) and meant primarily for unsealed roads, like forest roads.

3. Conceptual design and user interface of the developed road scanner

To ensure a preferably comprehensive road monitoring the three-part measuring system which is still a prototype version consists of different electronic sensors. Sensor data are transmitted (wirelessly) to a headless embedded computer on the measuring lance. Together with this measurement device comes a separate evaluation software “iFOS” (*integrated Forest Operations Software*) which does a road classification and interpretation based on the collected data.

The hardware is a set of several components. The **measuring lance** (Figure 1, A) is designed for measuring and logging the cross-sections of gravel roads. Several different sensors are integrated: five ultrasonic sensors in a certain arrangement on the lance as well as an acceleration sensor, a GPS (1 Hz) and a gyroscope in a separate box (Figure 1, B) on top of the lance. In order to improve the quality of the GPS based determination of position there is currently an option to fix an additional external antenna for instance on top of the roof of the vehicle. All collected data streams are merged by a data processing unit with a simple 2-button user interface for starting and stopping a measuring cycle. This unit coordinates the measuring process and manages the data output.

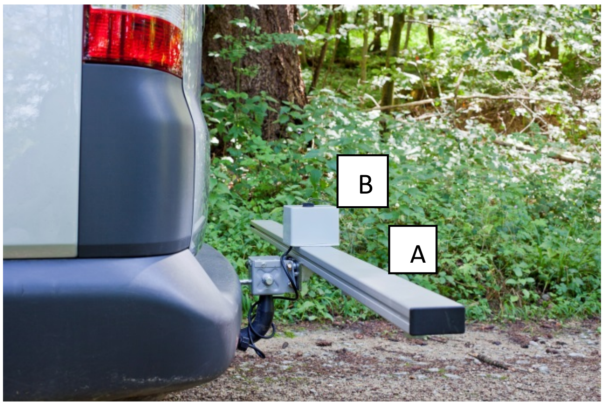

Figure 1: Measuring lance on a vehicle (source: R. Baula).

The measuring system is conducted in a way that it largely operates auto-calibrated. For example, a not exactly horizontal mounting of the measuring lance to the tow coupling is also registered and can be corrected as an unfavorably selected assembly point, such as one-sided inclined road. After calibration and fixation the measuring lance is ready for operation. At this stage the user has also the opportunity to get access to a real time surveillance option of the measurement via Bluetooth, e.g. with an Android smartphone.

To record the longitudinal road unevenness a 3-axis acceleration sensor at a sampling frequency of at the moment 50 Hz is used. Two **wheel sensors** are installed with a U-clip each at the right and left wheel suspension of the vehicle’s rear axle and transmit data wirelessly to the headless embedded computer on the measuring lance. In the course of data interpretation weak spots like potholes in the roadway can be detected.

The hardware system can be kept mounted on the vehicle as long as the batteries of the wheel sensors provide sufficient voltage for a proper data transfer. The readout of the embedded computer can be realized via Bluetooth right after the measurement - also in the field. The parametrization can be done time delayed to the data collection at the office during the analyzing procedure.

The post processing and the categorization of the determined road damages is done by using the specifically developed Windows-based **evaluation software** “iFOS” which includes the option to define own road categories. Depending on the probed parameter (depth of potholes, frequency of appearance of potholes, depth of bumps and lane grooves, etc.) different threshold values and damage ranges (e.g. good, middle and bad road condition) can be set and the results can either be plotted as a color coded map (Figure 2) or be saved as a geo-referenced attribute table for further calculations or documentation.

As long as the battery is on a non-recharge status the hardware keeps mounted on the vehicle which is in use in the forestry district. The user in the office additionally benefits from the fully automatic transmission and the pre-processing of the collected and stored data provided by the embedded PC. After a certain time, data should be readout. The result of data processing can be a road maintenance plan or an action plan for urgent reconstruction needs with consequent activities for the up-coming fiscal years (Figure 3).

4. Results - Road classification and steps of development

In 2014 Schuler evaluated and analyzed the usability of the described sensor setup in a field test. The aim of his thesis was to receive more information about the possibilities and limits in detecting road distresses of aggregate-surfaced roads using the first available road scanner layout. Therefor he describes the occurrence of distresses for 12 road sections, recorded at first in a visual manner, including one whole and two half road segments recorded by a separate laser scanner and compared them with the recorded data of the road scanner. The evaluation is split by ultrasonic and acceleration records. The list of investigated damages is limited by deterioration indicators that are most commonly observed like containing ruts, potholes, corrugations, initial vegetation and roughness (Schuler, 2014).

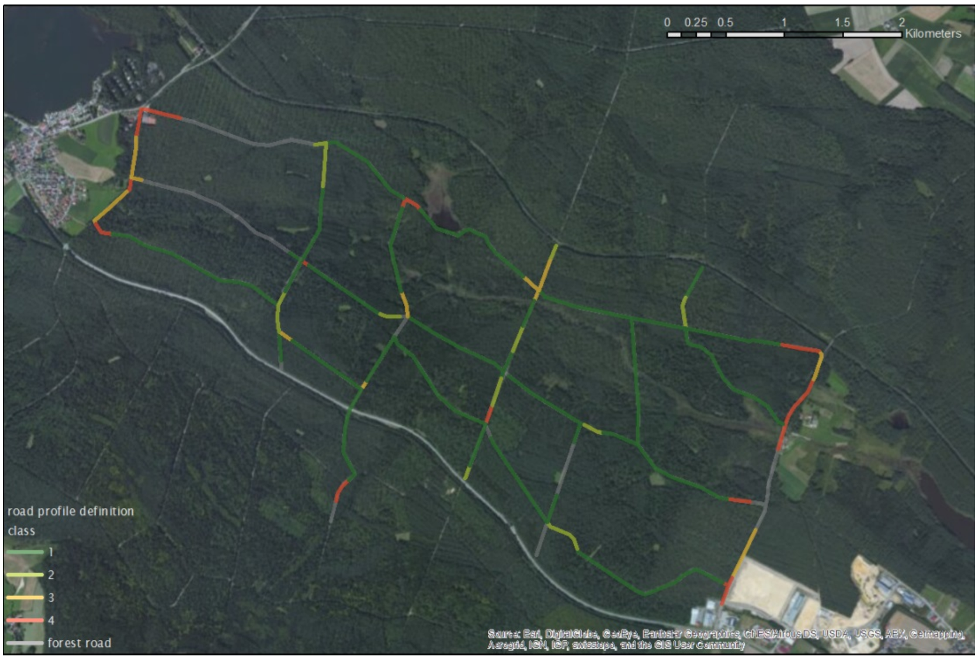

Figure 2: Road segment classification “ThüringenForst” (Starke 2016 based on Roos, 2015); created with ESRI ArcMap.

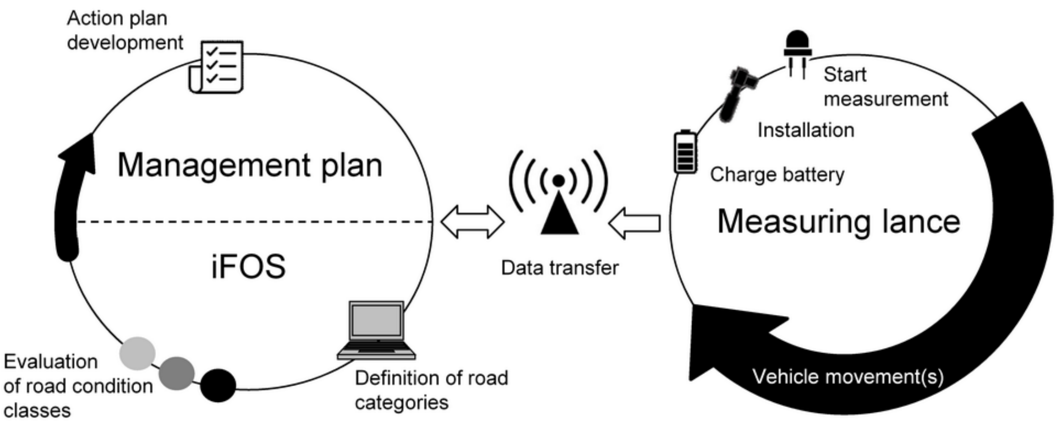

Figure 3: Possible forest enterprise work- flow (Rommel, Ziesak and Starke, 2015).

At this point the sensor layout of the five ultrasonic sensors followed a symmetric mounting design (five sensors in equal distances). A mean value comparison of the cross-section grading patterns between the laser records and the according ultrasonic-recorded profile showed that the ultrasonic recording delivers sufficient results for detecting wide ruts and geometric disturbances in the cross-section grading pattern. However, the detection of potholes as a local road distress, also partially related to the cross-section profile and the intense occurring of vegetation on the road surface, could not be recovered in the mean values of the ultrasonic dataset (ibid.).

The acceleration records, in particular the wheel sensor records, close the missing link for the detection of longitudinal road unevenness, induced by e.g. potholes or bumps. However, it must be clear, that only road bumps which are travelled over will cause signals in the accelerometers. Thus not every single pothole in the driveway may get tracked. Since there is a distinctive relationship between overall road bumpiness and collected accelerometer readings valid results for road unevenness for road segments are still guaranteed. A high variation of different amplitudes can also be related to a potential road roughness (ibid.).

Schuler (2014) mentioned a potential problem in the ultrasonic sensor layout for the rut detection. To make the system more effective towards significant accuracy of road distress discrimination, Starke (2015) designed a fitted concept for ultrasonic sensors with a smaller beam pattern as well as an asymmetric sensor layout, which were implemented in the system to ensure a better detection of slight changes in the cross-section profile and a higher probability of rut classification. The variables for this development were derived from the technical specification of ultrasonic beam patterns (MaxBotix, 2015), as well as from a potential occurrence of ruts, derived by mean track gauges of trucks and cars considering the uncertainty of staying in the track at different driving speeds (Kuonen, 1983).

The implementation in a first classified road validation for practical-use purpose was created by Roos (2015) for regional construction patterns, matching the needs and requirements of Thüringen Forst. He defines four categories of road damages equivalent to those used at Thüringen Forst (ThüringenForst, 2016). They are related to a disturbed water drain in cross-section grading profile, equivalent on Foltz and Elliots theory of the "short water path" to prevent erosion effects, being verified by Heinimann (1997). Hence, the optimal road cross-section profile is determined as a roof shaped grading pattern with a 5% slope (lateral) for the "class 1" characterization (Roos, 2015). For the categorization in "class 2", the road still has to provide a possible lateral water drain, but "class 3" shows the first severe disturbances, ending in "class 4", where a working lateral water drain can be generally excluded (Figure 4**Błąd! Nie można odnaleźć źródła odwołania.**) (Roos, 2015).

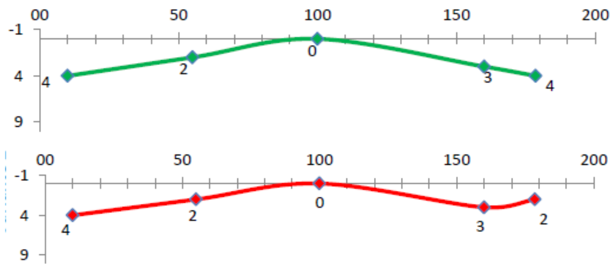

Figure 4: Cross-shaped grading pattern examples, including the measure points of the ultrasonic sensors (Roos, 2015): "ThüringenForst Class 1" (above) and "ThüringenForst Class 4" without working lateral water drain (below).

A field test, done on some 36 kilometers of forest roads, confirmed the matching of a visual classification compared with the designated classes from the road scanner results in sufficient accuracy. This was true when classifying road segments in single track recording and also for repetition accuracy of a 15 times multi track record on three forest road segments. For the single values a high variation of classes was observed for a single record visualization (Figure 5) (Roos, 2015).

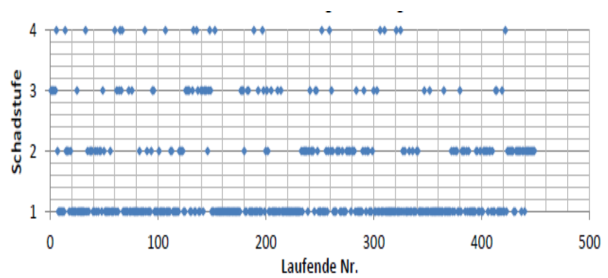

Figure 5: Single value classification of a road segment (Roos, 2015).

In a further thesis Hug (2016) investigated the features for the distance measurements, which are at this time realised by the mentioned ultrasound sensors. The accuracy and characteristics were tested under controlled laboratory conditions. For the measurements, Hug examined the varying side deviation of the ultrasonic sensor center beam and its probability to detect potholes, ruts, different solid objects and vegetation. Without any object placed in the center beam, the repeating accuracy shows no variation at all and thus ensures reliable measurements. The most important cross-profile distress, the rut, will be surely detected. At 2 cm precision level they are recognized at suitable significance of more than 95% (Figure 6).

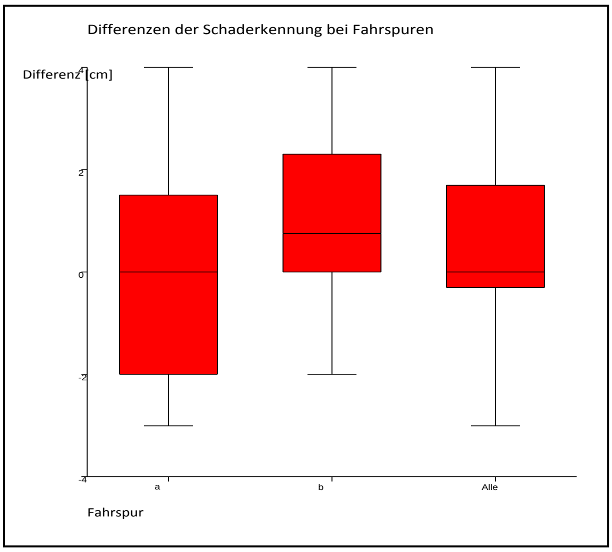

Figure 6: Difference between ultrasonic sensor measurements (a(n=19), b(n=16), all (n=35)) and reference measurements of two manually shaped ruts (Hug, 2016).

As expected, for potholes the detection is not guaranteed, for vegetation even significantly rejected, what confirms Schulers' notice that the ultrasonic sensors are limited in these aspects. Also the occurring of high variation of the single value classification Roos mentioned might be caused by the reflection of angled and rough surfaces and has to be kept in mind in case of implementing further classification variables.

5. Further development and discussion

Considering position data, sometimes the GPS accuracy seems not to be sufficient for a clear data evaluation. Especially in curves or at road junctions the data points could not be assigned to the correct road segment and even get further distorted by clipping algorithms during the post processing. Therefore two different kinds of GPS receivers were compared in Hug's thesis (2016). The "uBlox Neo 6M" that is currently in use and two different antenna setups in combination with a more powerful "uBlox Neo M8N" were compared and tested using an evaluation kit. The best readings can be achieved by the newer "Neo M8N", a receiver for both GPS and GLONASS signals, in combination with the roof top antenna (Figure 7).

The effect of shielding of the GPS signal, caused by an unfavorable low mounting point of the receiver, might cause the problem of a weak accuracy in some situations. For all observed records the positional dilution of precision (PDOP) stayed below the value 2, which can be seen as an indicator for sufficiently good satellite constellation during this measurement campaign. The driving speed has also an effect (between 10 and 30 km/h) on the accuracy of all records (Figure 8), but never led to a total signal loss (Hug, 2016).

At the moment the interpretation options as implemented in "iFOS" are being improved. This includes a classification of road sections based on user defined segment lengths. Furthermore a classification for the accelerometer sensors will be added, which will allow a much finer separation of road damage attributes.

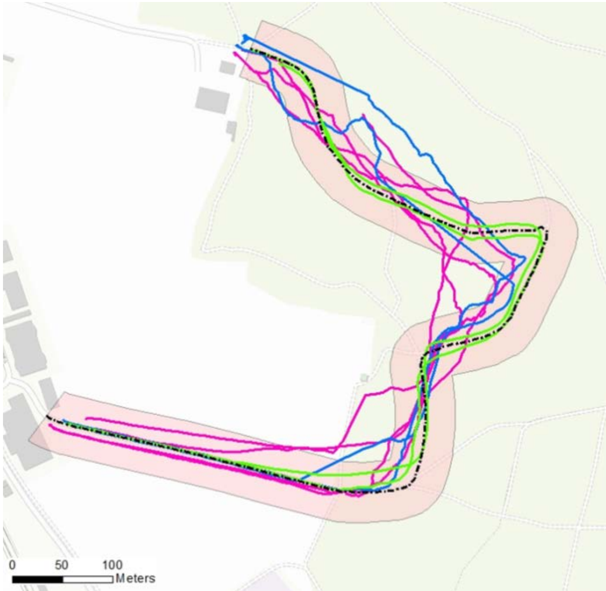

Figure 7: GPS tracks Neo 6M (red) current version, EVK-M8N intern antenna (blue), EVK-M8N extern antenna (green), 60m corridor alongside the road (light red) (Hug, 2016).

The experience of different verification and testing cycles (Schuler 2014, Roos 2015, Hug 2016) could proof that the realized approach for this "road scanner" with a fusion of different sensor types provides a suitable tool, which will detect damages to the road bed in an automated and precise way. Thus this tool can be an important element for digital road management systems. At the moment current work is also underway for implementing this tool in the day-to-day business at Thüringen Forst (Merten, 2016).

6. Acknowledgements

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7. Remarks

This paper has been submitted to the CROJFE - at the moment in the peer review process.

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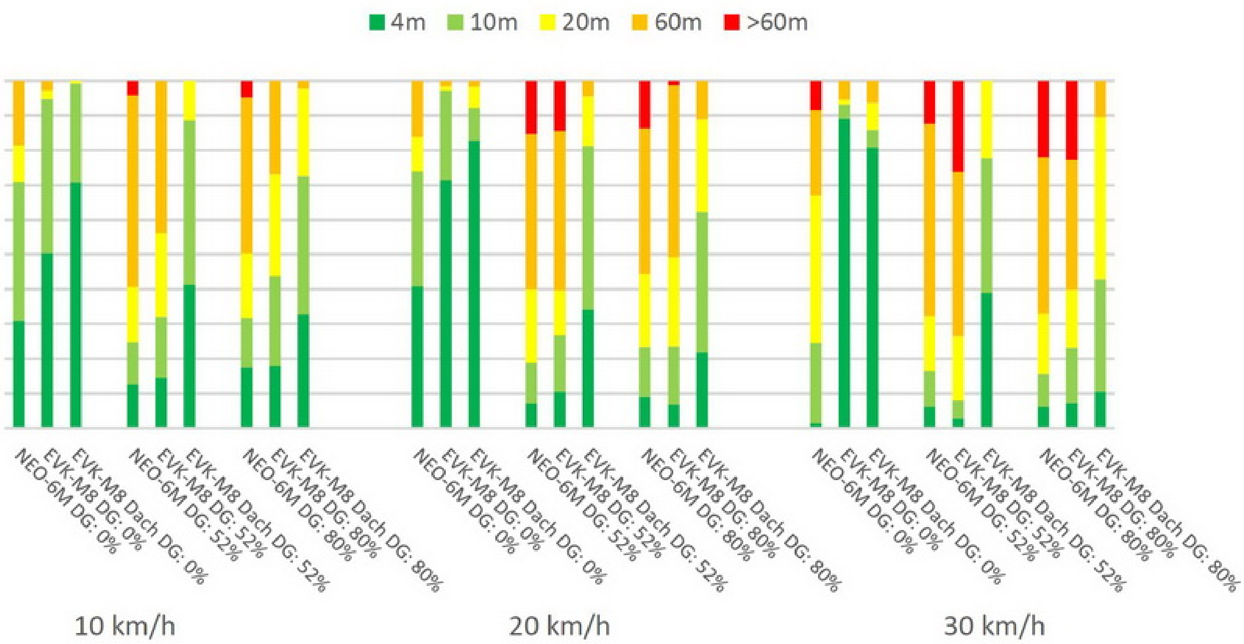

Figure 8: Point deviation in a 4, 10, 20, 60 and > 60 m wide road corridor for different GPS receiver setups including different forest canopy variants (0%, 52%, 80%) (Hug, 2016).

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