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Development of alternative methods for road condition monitoring

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Abstract

The research is focused on the development of an alternative method for road condition monitoring. This report presents the findings from the current development phase. The alternative road condition detection is performed using accelerometer technology by measuring the vertical acceleration of a vehicle while driving. A damage feature is identified from the acceleration data and the extension of the damage is derived. Subsequently, a self-designed measurement system is set up. In order to apply this measurement system to different vehicles, vehicle-specific influencing factors must be minimized. For this purpose, a measurement setup is devised. Finally, a way is presented to test the measurement system for its suitability.

1. Initial situation and motivation

Municipal road condition monitoring relies both on measurement campaigns and visual inspections. This is often unsuitable, as conditions in urban areas change rapidly and recording requires enormous human and financial resources (FGSV 2012). Due to this periodic recording, there is a lack of a continuous overview of the road condition's development. Considering that municipal roads account for about three quarters of the total road network in Germany in terms of distance (BMVI 2020:101), it is therefore mandatory to develop a system focused on municipal issues (FGSV 2012).

The aim of this research is to develop a cost-effective measurement system for continuous monitoring road conditions in urban areas. The use of new data recording methods allows data monitoring and condition assessment to be carried out continuously and with minimum human resources. This innovation supports the road asset management of municipalities and has an impact on economic and political issues. Through such continuous monitoring, damage detection is possible at an early stage, and the condition data updates permanently. The continuous road condition monitoring leads to optimized maintenance strategies instead of expensive early renovation or renewal. The reduction of the employment of human resources needed to record the damages and to take action at an early stage to intervene has cost-saving effects. In addition, the period of use of a road can be extended and traffic safety increases. Overall, this leads to an improvement in sustainability as well as an extension of the road availability. Through this innovation in asset management the mobility requirements of the future can be met.

The new method of road condition monitoring requires GPS, video and acceleration data to be captured while driving. GPS and video data were previously recorded using an action camera. Acceleration data was first logged by smartphones and then by USB accelerometers. During some initial evaluations, it was found that the action camera not only recorded GPS and video data, but also acceleration data. When all three types of data are captured by one device,

synchronization of the data is simplified. For this reason, acceleration measurements were carried out with the GoPro HERO9 Black in one phase of the development and the suitability of this action camera as a measurement system was evaluated.

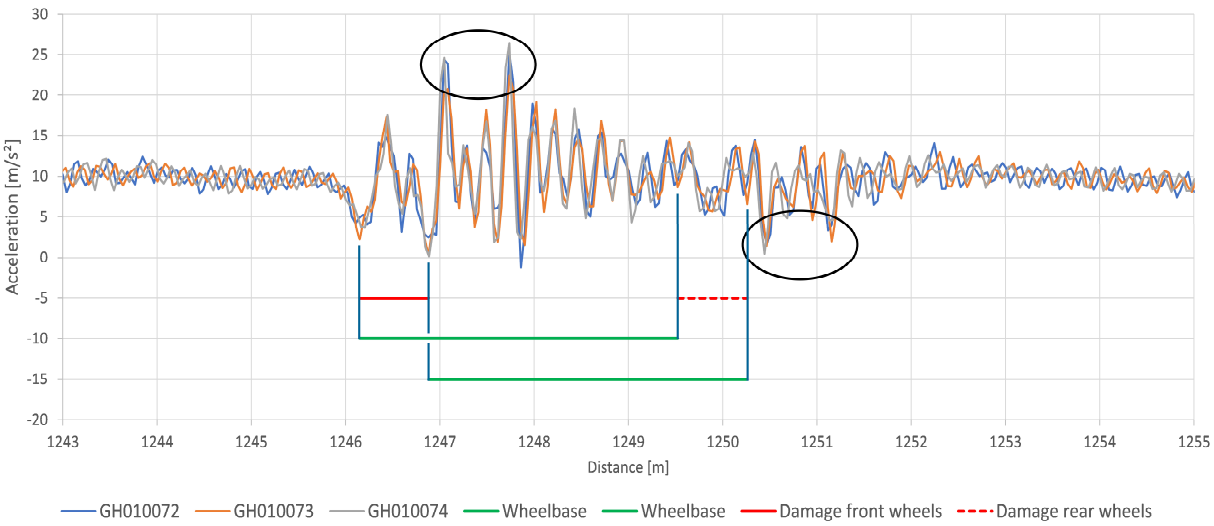
2. Suitability of the GoPro as a measurement system

The GoPro captures accelerations in three directions, the arrangement of the axes is shown in Figure 1.

Figure 1: Arrangement of the axes on the GoPro

The vertical acceleration is the most relevant parameter for measuring road conditions. To test the suitability of the GoPro as a measurement system, three measurement runs were carried out with a VW T5 and the GoPro HERO9 Black. The measurement range with the maximum measurement excursion is shown in the diagram below. Underneath there is a video section of the damage at the location of the maximum deflection (see Figure 2).

Figure 2: Acceleration data in the area of a damage and video section of the damage



The diagram shows the vertical acceleration values on the y-axis and the distance in meters on the x-axis. It shows the acceleration data for all three measurement runs. At the beginning, the acceleration values oscillate around the rest value of 9.81 m/s². Then, the profile is influenced

by the road damage and reaches a low point at the distance 1246.15 m in data series GH010073. The next, similarly significant, low point is located at the distance 1246.88 m. The distance between the two points is 0.73 m. This corresponds approximately to the spread of the damage in the longitudinal direction. The former vibrations were only initiated by the passage of the two front tyres over the damage. Consequently, there are two more extrema. One low point is at the distance 1249.52 m and another at 1250.26 m. The distance between these two points is 0.74 m.

The distance of the first low point of the front wheels to the first low point of the rear wheels is 3.37 m and the distance of the second low point of the front wheels to the second low point of the rear wheels is 3.38 m. This reflects the measuring vehicle's wheelbase of 3.40 m.

It can be critically noted that the effects of the rear wheels are not obvious in the diagram without further knowledge. But it is interesting to note that the accelerations overlap in the later part of the diagram in such a way that more obvious extremes are obtained. These extremes are circled in black in the diagram in Figure 2. The distances between these extrema also represent the extent of the damage in the longitudinal direction and the wheelbase of the measuring vehicle. These superimposed extrema are significantly visible in the diagram and form an initial basis for identifying damage from the acceleration data and determining its extension in the direction of travel.

In the area shown in the diagram, the vehicle was driven at a constant speed for all three measurement series. In the further process of the measurement, speed differences occurred between the measurement series and it could be determined that the longitudinal acceleration of the vehicle has an influence on the vertical acceleration. In vehicle technology, this phenomenon is called pitching (Breuer and Rohrbach-Kerl 2015).

Overall, the GoPro HERO9 Black is suitable as a measurement system and can be used quite well for further investigations. However, it has been shown that it would be useful if there were more information and setting options on the accelerometer. Since the GoPro does not provide any information about the installed components and there is no opportunity to make any settings on the acceleration sensor, a new measurement system with external sensors was set up in the next development phase.

3. Development of an own measurement system

The measurement system is controlled by a single board computer. Currently, a Raspberry Pi 4 B is used for this purpose. The Raspberry Pi addresses two accelerometers and a GNSS module with a Python code. Various settings can be made on the external accelerometer and a complete data sheet about the sensor is provided. But compared to the smartphone and the GoPro, this sensor cannot receive a location signal. According to the support, there is also no prepared interface to pair the sensor with a GNSS module. But if the sensor and the GNSS module are controlled by the same single-board computer, all readings can be stored with the computer's time and synchronized over time.

As soon as sufficient research results are available, further data processing could also be implemented automatically on the Raspberry Pi in the future. The resulting measurement system could then be installed for instance in a municipality's vehicle pool and record road condition data during trips that happen anyway. The data could be transmitted to a cloud, automatically evaluated and made available in a processed form. Currently, the measurement system is being used on a VW T5. In order to be able to use the measurement system on different vehicle models in the future, vehicle-specific influencing factors must be minimized.

4. Minimization of vehicle-specific influences

In order to be able to minimize the vehicle-specific influences in the future, these have to be determined first. In cooperation with the Faculty of Mechanical Engineering, a Matlab/Simulink model has been developed (Schmeller and Schöne 2021), which simulates a quarter vehicle. The simulation by a quarter vehicle includes only a quarter of a whole vehicle. It is a one-dimensional model with two degrees of freedom, which allows to represent the vertical motion of a vehicle (Breuer and Rohrbach-Kerl 2015). When comparing the simulation results with the physical measurement results, it was found that the model can better represent the vertical acceleration at the wheel carrier than the vertical acceleration of the vehicle body. This is due to the fact that, in the case of measurements on the body, the entire vehicle with its vehicle-specific components has an influence on the vertical acceleration.

In addition, several test runs with the measurement vehicle of the Mechanical Engineering Faculty and subsequent Fast Fourier Transforms (FFTs) determined the natural frequency of the wheel carrier to be 2.5 Hz and the natural frequency of the vehicle body to be 13 Hz. During acceleration measurements on the wheel carrier, the natural frequency of the vehicle body does not occur. Overall, it was found that the natural frequencies of the wheel carrier and the vehicle body remain constant even as the speed increases.

In order to find out the vehicle-specific characteristics of the VW T5 from the Faculty of Civil Engineering, a measurement setup was designed. For the measurement runs, an acceleration sensor is to be attached to the wheel carrier (Figure 3, left) and a second sensor in the vehicle entrance (Figure 3, right).

Figure 3: Measurement setup with two accelerometers

The sensors should be installed one above the other as far as possible to prevent the measurement results from being influenced by the position. Different results in the measurements can only be attributed to the height difference of the sensors and mainly to the involved vehicle components.

The comparative measurements between the two attachments showed that a measurement outside the suspension and damping area of the vehicle allows better differentiation of individual damages. This is particularly true in the case of short distances between the damages. It is therefore recommended to carry out future measurements outside the area of influence of the suspension and damping, for example on the wheel carrier.

5. Suitability of acceleration sensor technology for road condition monitoring

Before a new measurement system based on acceleration sensor technology, for example the one using the Raspberry Pi, can be used in road condition monitoring, its suitability must be checked. A differentiation between practical suitability and scientific suitability can be made. The scientific suitability consists of the objectivity, reliability and validity. In order to test the

validity of acceleration sensor technology for road condition monitoring, the data of a current road condition recording and evaluation of a municipality can serve as a reference. Acceleration measurement data as well as reference data of a conventional road condition recording and evaluation are available to carry out the validation of the research results in the further stage of the research.

6. Conclusion and outlook

In order to collect the measurement data and also for referencing, it is beneficial if the data can be mapped on a platform. The aim is to collect all the data in a software environment that can be used to handle the road asset management of a municipality in the future. The current intention is to manage the data through a digital twin.

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