Image Referencing for Road Condition Monitoring using Vibration Sensor Technology

The monitoring of road surface conditions is an important task municipalities have to deal with. For them it is always important to use economic methods, that means cheap, simple and still accurate. This is an optimization problem for which improvements are constantly being sought. The results show that it is necessary to extend the vibration monitoring with a visual referencing as the vibration sensor measurements can provide a good picture of the general surface condition on its own, but it is only possible to identify and assign the type, severity and dimension of individual condition features to a limited extent. The results also show that the best way to verify the acceleration measurement data is by video recording even if this is not as accurate as, for example, taking single images. Another important aspect of the investigation was that both video recording and acceleration measurement are possible without any problems up to the German inner-city speed limit of 50 km/h. The referencing results at 30 km/h (85%) are not much more meaningful than at 50 km/h (80%). This is a major advantage for the feasibility of the condition monitoring, as the measuring vehicle does not obstruct other vehicles.

Keywords: referencing, pavement, monitoring, condition, acceleration

Introduction

In German cities the motorized private transport still accounts for the largest share of the modal split which is the distribution of traffic in terms of the number of journeys made by the various modes of transport (Deutscher Bundestag 2017). In order to be able to bear this high traffic load and avoid damaging the vehicles, a good condition of the infrastructure is a requirement which necessitates constant monitoring of the condition of the road surface. At present, however, these condition recordings only take place every three to five years and are very expensive for the municipalities. Therefore, a new cheaper alternative should be established such as using vibration sensor technology to draw conclusions about the quality of the pavement.

The validation systems used in previous studies on the use of vibration sensor technology can generally be grouped into three categories: manual testing by site inspections, sensor-based and image-based systems (Masino et al. 2017). Here in this study, it was concentrated on the use of image-based systems, as sensor-based systems are too expensive and manual inspection is too time-consuming. Douangphachanh et al. (2014), for example, have attached a digital camera to the car used when driving along test tracks for vibration measurements with smartphone sensors. So far, however, only a few studies on the use of vibration sensors for road condition monitoring have focused on the verification of the measurements with video recordings.

With this research the following questions were to be answered:
• Which is the best method to detect damages of the road surface?
• Is this method possible without any problems up to the German inner-city speed limit of 50 km/h?

Searching for an answer to the first question different visual recording methods are compared in the following section “Literature Review” and the emerging possibilities as well as deficiencies of the respective method in connection with acceleration measurements in road condition monitoring are shown. For this purpose, additionally both multi-shot and video recordings were tested by practical studies with car and bicycle, which are described in the section “Materials and Methods”. It is divided in five subsections, concerning used instruments and their set-up for visual recordings, followed by used instruments and their set-up for vibration monitoring. Furthermore the process for data collection and processing is described. Lastly the section details how the measurement data was compared with the videos. The section “Results and Analysis” contains the findings from the comparison of measurements and the videos. It is split into a part about the investigations by car, one by bicycle and a last one about specific deflections in the vibration data related to road damages. The plausibility, quality and error analysis of the results is shown in the section “Discussion”. “Conclusions” closes the paper.

Literature Review

Possibilities for the visual-image-based recording of traffic surfaces can largely be divided into five groups: single image captures, stereo photography, satellite imagery, aerial photos and video recordings.

The recording of condition characteristics by taking individual images is probably the simplest and most accurate, but at the same time the most complex of the methods listed here. Since condition features of the surface are photographed individually and specifically during an inspection, they can usually be easily recognized and assessed during the evaluation. But the positional allocation of the images is important to link them to the acceleration data. Since common digital cameras usually do not have a built-in GPS receiver, the positioning must be done manually by assigning a station, house number or with an external GPS device, which requires a lot of time.

Stereophotography is a process for creating three-dimensional photographs. Two images of the same subject are taken from slightly different angles and merged into one (Herbig 2011). This model can thus be used to assess the dimensions and degree of damage. With this method, however, it is necessary to take the images almost vertically above the asphalt while standing still, which means again that a manual, time-consuming inspection of the investigation area is necessary (Mustaffar et al. 2008).
Satellite images could be a further source of data for recording road damage. However, their acquisition is usually expensive and the required quality is not achieved due to the limited resolution (Fendi et al. 2014).

Images from platforms, such as unmanned aerial vehicles (UAVs), can provide higher image quality at lower cost compared to satellite or traditional aerial images (Fendi et al. 2014). UAVs are able to fly over areas to be investigated with an attached digital camera on pre-programmed routes and take images from relatively low altitudes. Using photogrammetric methods, a digital terrain model (DTM) of the road surface can be created from the images, which can be used to detect and assess damage, as tests on rural roads in the USA have shown (Zhang 2008). However, the use of this procedure in inner-city areas does not seem to be appropriate. Especially since often large parts of traffic areas are covered by vehicles and therefore cannot be detected.

Videos recorded directly out of the measurement vehicle have a strong reference to the measurement data, as they are recorded at the same time and at the same location. In addition, existing condition characteristics are usually sufficiently well recognizable due to the relatively short distance between camera and pavement. (Mustaffar et al. 2008) As an alternative that saves memory space, individual images can also be taken at regular intervals. In addition to the smaller amount of data created here, multiple images have the advantage over video files that when using a geospatial information system (GIS), the images can be viewed directly in their actual position on the map and the data can be edited there. If necessary, further information can be supplemented. In addition, surface damage can usually be identified more clearly in the single images of multiple recordings than in the video recordings.

Materials and Methods

Visual Recordings

Due to the settings of the camera used, the images can only be taken at intervals of 0.5 s. In development areas, which are usually limited to 30 km/h, this means that an image is taken every approx. 4 m. At travel speeds of 50 km/h only every 7 m. As only about 4 – 5 m of the roadway in front of the vehicle are sufficiently visible on the images in the direction of travel, it is therefore no more possible to record the entire route without gaps at speeds above 30 km/h. This is a decisive disadvantage of this recording method and restricts the use to a speed that is low for passenger cars. For these reasons and because the individual shots cannot be synchronized with the vibration measurements like videos about the recording time, they are not suitable as a referencing method.

The use of video recordings appears to be the best of the method listed here for the purpose of validating vibration data due to the advantages mentioned above. When recording videos out of driving vehicles, however, it
should be checked in advance whether the camera used can provide the necessary image quality at common driving speeds. Due to the limited field of view in videos, a visual assessment of the peripheral areas and ancillary surfaces is only possible to a limited extent (FGSV 2016). Therefore, a 360° camera (GoPro Fusion) was used for the practical studies to check whether damages can be identified up to a speed of 50 km/h. As a designated "Action Camera", it has a built-in stabilizer and GPS receiver. For this reason and because of its compactness and various mounting options, it seems to be well suited for the application tested here. The instrument set-ups can be seen in Figure 1 and 2.

On the bicycle, the GoPro Fusion was attached to the handlebar with its own bracket and one lens was positioned in the direction of travel to a point in front of the front tire. The small display as well as the control button to start and stop the recordings point to the rider for easier operation. The camera is positioned slightly off-center to provide a clear view of the area directly in front of the front tire.

On the car the "GoPro" has been mounted centrally in the front area of the bonnet by using a suction cup, so that the road surface is only about 1.5 m away, clearly visible in front of the vehicle. Also tested, but not pursued further, was the mounting of the camera on the roof of the car. With this type of mounting, however, the camera would be far away from the road surface, making it less visible.

To be able to start the recording while driving, it was connected to a “GoPro SmartRemote” via Bluetooth. For the subsequent rendering and editing of the recordings the programs "Fusion Studio", "Dash Ware" and "OpenShot Video Editor" were used.
Vibration Monitoring

As you can see in Figure 1, two smartphones were used for the simultaneous vibration measurements by bicycle - a "Sony Xperia XA2" (right side of the hand bar) and an "HTC One mini" (bicycle frame), each with an Android operating system. Both were aligned horizontally in order to be able to assign the directions of the acceleration impulses during evaluation, with the y-axis in the direction of travel and the z-axis vertical. For the measurements the apps "Sensor Log" (Sony Xperia XA2) and "phyphox" (HTC One mini) were used, which record accelerations with a frequency of 80-100 Hz. In order to maintain an almost constant speed during the measurements and to be able to control it continuously, there was also fixed a simple speedometer on the handlebars of the bicycle.

Instead of the "Sony Xperia XA2", a USB acceleration sensor from "Code Mercenaries" of the "JoyWarrior 24F14-WP" model was installed in the car as you can see in Figure 3. The acceleration was recorded with a laptop in the interior at 20 Hz. Figure 4 shows that the smartphone for measuring the acceleration with “SensorLog” was fixed in the glove compartment of the car. Here, again, both devices were aligned in the same way, so that the y-axis is in the direction of travel and the z-axis is vertically upwards.

A standard bicycle and a VW bus model T5 were used as measuring vehicles.

Data Collection

The following criteria were relevant for the selection of routes for the test drives:

- Little traffic for easy, undisturbed execution of the measurements
- Different types of existing condition characteristics
- Route as flat and straight as possible

Figure 3. Sensor Position Car

Figure 4. Smartphone Position Car

Source: Knüpfer 2019.

Source: Knüpfer 2019.
- Few traffic lights or intersections to maintain a steady speed

A road with a speed limit of 30 km/h was chosen as the route to be travelled by bicycle, so that the measurement results obtained can be compared with those of a car at 30 km/h without impeding the flow of traffic. The selected, 350 m long section for test drives is located in the north-east of Nuremberg and highlighted in Figure 5. This section shows a large number of cracks and patches and is therefore ideally suited for the investigations even if the roadway is parked on both sides. When carrying out the measurements, recognizable damages were usually deliberately driven over, even if they were not in the direct lane, which is very narrow in the case of a bicycle.

**Figure 5. Location for Measurements by Bicycle**

![Location for Measurements by Bicycle](image)

*Source: Knüpfert 2019.*

The routes for test drives by car at a speed of 30 km/h are shown in Figures 6 and 7. The first section highlighted in Figure 6 leads over approx. 2.0 km across the area, which has partly already been recorded by bicycle. For analyzing, only the section that was inspected also by bicycle was chosen in the end because there is a multitude of single and crocodile cracks as well as inserted patches. Furthermore, it is possible to compare the results by car and bicycle.
To get more data, it was also analyzed a section of 500 m of “Mommesenstraße” which you can see in Figure 7. The whole test track is almost 3.8 km long and can be divided into two sections with regard to the maximum permitted speed. From “Bismarckstraße” via “Mommsenstraße” to “Nordostbahnhof” the speed is limited to 30 km/h. After a 90° bend at “Nordostbahnhof”, the route runs almost completely straight along “Kieslingstraße” and “Eichendorffstraße” to the east where the maximum speed is limited to 50 km/h.

In order to also be able to make conclusions about the reliability of the results at 50 km/h, main roads were also selected for the measurements by car. Therefore, the section of 1.5 km from “Kieslingstraße” to “Eichendorffstraße” was used for the evaluation which you can see in Figure 7. Due to the straight route, the function as a priority road and only one traffic light, a constant speed of 50 km/h can be maintained on this section of the route and it is ideally suited for further investigations.
Before each test run, the mounting and alignment of the camera and other measuring instruments were checked and corrected if necessary.

The "GoPro Fusion" provides two settings for video recording in terms of resolution and frame rate: 5.2k at 30 fps and 3k at 60 fps. Other settings, such as shutter speed, cannot be adjusted manually. To perform the tests, the higher resolution setting of 5.2k and 30 fps was selected. When using the higher frame rate, a comparison of the two options showed no discernible advantages for the application purpose investigated here. In addition to video recordings, multi-shot recordings, i.e. repeatedly recorded single images at fixed time intervals, were carried out. As time interval between recordings, 0.5 s were selected since this is the shortest interval offered by the GoPro camera. Both smartphone apps used measure in a frequency range of 80-100 Hz, while a lower frequency of 20 Hz and a sensitivity range of 1 G was selected for the USB sensors.

All route sections were driven at least three times in each direction, as this is the number of iterations required according to Shtayat et al. (2019) for meaningful results of the vibration measurements. By driving in both directions, data could be obtained for each lane in order to get an overall impression of the condition of the road section. However, due to the limited space because of parked vehicles on both sides in the area of "Danziger Platz" up to “Graudenzer Straße”, it was decided to drive there only in one direction. In total, about 5.5 km of video and vibration data were collected by bicycle and about 30 km by VW bus.

The tests were carried out in the late morning under a slightly cloudy sky.

Data Processing

For the evaluation of the data, a starting point for the measured route in the recorded acceleration data was defined in a spreadsheet program and it was synchronized with the starting point of the video via the time of day, which is continuously recorded by both the camera and the acceleration sensor. In addition, a macroinstruction has been implemented to allow a manual adjustment of the time values of the vibration data to compensate any inaccuracies in the synchronization. For the comparison of the data with the recorded videos only the vertical acceleration along the z-axis is used because according to Astarita et al. (2012) this corresponds directly to existing surface damages. Nevertheless, recording the acceleration of all three axes is important to check whether disturbing vibration peaks of the other axes have influenced the acceleration profile of the z-axis.

Acceleration profiles of USB sensor and smartphone sensor were compared. In general, no significant differences between the two groups of measuring systems can be detected visually. Therefore, the measurement data of the smartphone app "SensorLog" is used for further evaluations of the vibration data recorded by car as this method is easier to establish in practice, as a smartphone is nowadays part of the basic equipment and a separate sensor does not have to be purchased to perform the execution.
The 360° recordings made with the GoPro camera were oriented with the program "Fusion Studio" and converted into standard videos with a resolution of 1080 p. The range of vision is adjusted to about 150° in the direction of travel, so that the lateral edge borders and secondary areas are also visible. Metadata stored in the original format (GPS coordinates, actual speed and time, distance covered in meters, time elapsed in seconds) are transferred to the final video using the "Dash Ware" software. Since MP4-files are required to use this program, the MOV-files output by "Fusion Studio" are first converted into the required format in the video editing software "OpenShot Video Editor".

The GPS data recorded by the camera was additionally converted into a csv file so that it could be inserted into a GIS as a separate layer. In this way, the routes travelled can be visualized on a map and road damage can be assigned locally. The route is indicated by GPS points that are saved every 0.05s. It has been shown that the routes are recorded with sufficient accuracy to clearly distinguish between drives in different directions.

Since a huge amount of data is created during the recording and editing of video files, it is advisable to decide between the required quality and file size. For this purpose, the recordings were exported in different resolutions and bit rates in order to be able to compare the quality of features using some examples. A resolution of 1080 p and a bit rate of 20 kB/s were set for the further process, as there was no clear difference in quality to videos with higher resolution. But the file size is up to three times smaller.

The multi-shot images were also aligned in the program "Fusion Studio" and exported collectively as single JPG files. Since GPS coordinates are stored in each image after export from the rendering program, they can be imported into a GIS in their true position. There the images are displayed at their original location. The images can be displayed directly in the GIS using a viewer.

**Comparison Acceleration Data and Videos**

For the evaluation of the tests, the vibration measurements were compared with the recorded videos. Sections of the test tracks were selected in which a constant speed was driven over a longer period of time. Of these sections, the number and type of condition characteristics recognizable in the video were registered for each test run and evaluated with regard to their recognizability in the recordings. This criterion was determined by how clearly the respective condition characteristic could be recognized as such. The classification was made subjectively into "clear", "sufficient" and "poor" identifiable as Tables 1, 2 and 3 show. Characteristics were classified as "sufficient" or "poor" if they could not be identified clearly or only uncertainly due to low image quality, blur, lighting conditions or very late recognition in the video recordings. However, slight general blurring or pixilation of the image was also tolerated in the category "clear".

In addition, it was noted whether there was a recognizable measurement deflection in the vibration data at the location of the characteristic concerned.
Both the measurements with the car at 30 km/h and 50 km/h and those with the bicycle were analyzed separately. Finally, all acceleration measurements above a value of 2 (m/s)² were counted in the section of interest and it was recorded whether these deflections could be clearly assigned to a characteristic. The threshold value of 2 (m/s)² was set as the evaluation limit after viewing all vibration profiles, as it was only exceeded in certain parts or by individual measured values. Inherent vibrations of the motor and the vibrations caused by general surface roughness were generally below this value.

For the purpose of this study, it was deviated in some points from the guidelines of the "Forschungsgesellschaft für Straßen- und Verkehrswesen e.V." (FGSV) concerning the definition of certain condition characteristics. Both damaged and intact seams and joints were combined into one characteristic (NF), which are usually registered separately. This generalization was made because in many cases it was not clearly recognizable in the recordings whether the seam or joint in question was actually open and thus damaged. As an extension, raised markings and covers of sewer manholes were included and individual cracks were divided into longitudinal and transverse cracks. Edginess, corrugation, rutting and flushing were not considered, as none of these occur in the considered sections of the road or were not visible in the recordings. In the case of inserted patches, only the patch as a whole was evaluated, but not the joint to the surrounding roadway. Under "Other", other events not belonging to any category, such as slide-valve covers, were included. In general, only condition features that were located in the direct lane of the vehicle were listed. It should be noted that the classification of detectability is highly subjective.

**Results and Analysis**

*Measurements by Car*

During these measurements, the vehicle was driven at both 30 and 50 km/h. For both speeds, all visible condition characteristics are recorded in the respective evaluation section of the test track and checked for correlations with the vibration profile. For the evaluation at 50 km/h the 1.5 km long section of the “Kieslingstraße” and “Eichendorffstraße” is considered in both directions. For the measurements at 30 km/h, about 500 m of “Mommsenstraße” were investigated in both directions and another 350 m of “Danziger Platz”, but there only in one direction. In total, data of about 9 km at 50 km/h and about 4 km at 30 km/h were evaluated. The quantitative results of the evaluation of the runs at 50 km/h are summarized in Table 1, and at 30 km/h in Table 2.
Table 1. Identification of Damages in the Video / Vibration Profile by Car

(50 km/h)

<table>
<thead>
<tr>
<th>condition characteristics</th>
<th>quantity</th>
<th>identification in video</th>
<th>deflection in vibration data</th>
<th>clear</th>
<th>sufficient</th>
<th>poor</th>
<th>existing</th>
<th>not existing</th>
</tr>
</thead>
<tbody>
<tr>
<td>inserted patch</td>
<td>EFLI</td>
<td>131 100 %</td>
<td></td>
<td>83</td>
<td>63 %</td>
<td>38</td>
<td>29 %</td>
<td>10 8 %</td>
</tr>
<tr>
<td>applied patch</td>
<td>AFLI</td>
<td>18 100 %</td>
<td></td>
<td>14</td>
<td>78 %</td>
<td>4</td>
<td>22 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>transverse crack</td>
<td>RIS-Q</td>
<td>126 100 %</td>
<td></td>
<td>37</td>
<td>29 %</td>
<td>74</td>
<td>59 %</td>
<td>15 12 %</td>
</tr>
<tr>
<td>longitudinal crack</td>
<td>RIS-L</td>
<td>82 100 %</td>
<td></td>
<td>48</td>
<td>59 %</td>
<td>29</td>
<td>35 %</td>
<td>5 6 %</td>
</tr>
<tr>
<td>crocodile cracks</td>
<td>NRI</td>
<td>31 100 %</td>
<td></td>
<td>11</td>
<td>35 %</td>
<td>16</td>
<td>52 %</td>
<td>4 13 %</td>
</tr>
<tr>
<td>seam / joint</td>
<td>NF</td>
<td>87 100 %</td>
<td></td>
<td>47</td>
<td>66 %</td>
<td>30</td>
<td>29 %</td>
<td>10 7 %</td>
</tr>
<tr>
<td>pothole</td>
<td>AUS</td>
<td>0 -</td>
<td></td>
<td>0 -</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>particle loss</td>
<td>AMA</td>
<td>0 -</td>
<td></td>
<td>0 -</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>manhole cover</td>
<td>SCHACHT</td>
<td>39 100 %</td>
<td></td>
<td>39</td>
<td>100 %</td>
<td>0</td>
<td>0 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>road marking</td>
<td>MARK</td>
<td>12 100 %</td>
<td></td>
<td>7</td>
<td>58 %</td>
<td>5</td>
<td>42 %</td>
<td>0 0 %</td>
</tr>
<tr>
<td>others</td>
<td>SONST</td>
<td>13 100 %</td>
<td></td>
<td>13</td>
<td>100 %</td>
<td>0</td>
<td>0 %</td>
<td>0 0 %</td>
</tr>
</tbody>
</table>

Source: Modified from Knüpfer 2019.

As can be seen in Table 1, patches, especially applied ones, longitudinal cracks, seams and road markings are usually clearly visible. The manhole covers and the sliders listed under "others" could be clearly identified in the video in each case. Transverse cracks running at right angles to the direction of travel and crocodile cracks are more difficult to detect. Due to their local limitations and often narrow crack widths, these are only vaguely visible in many cases. Longitudinal cracks, in contrast, have a greater extension in the direction of travel, i.e., they are visible for a longer period of time and can therefore be seen more clearly in the video material.

It is also documented in percent how many of the condition characteristics identified in the video could be detected in the vibration data in form of a deflection. In this case, patches, other damages and transverse cracks mostly result in clearly visible measurement deflections. For manhole covers and raised road markings even in any case. Crocodile cracks and joints, on the other hand, can only be clearly assigned to vibration data in slightly more than every second case. No associated measurement deflections could be determined in the area of longitudinal cracks.

Conversely, 80% of the measurement deflections above the selected threshold value of 2 (m/s)² could be clearly assigned to one characteristic. This means that the app used only records a few indefinable deflections and thus provides quite reliable data.

The following statistics in Table 2 summarize the results of the measurements along “Mommsenstraße” and “Danziger Platz” at 30 km/h.
Table 2. Identification of Damages in the Video/Vibration Profile by Car (30 km/h)

<table>
<thead>
<tr>
<th>condition characteristics</th>
<th>quantity</th>
<th>identification in video</th>
<th>deflection in vibration data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>clear</td>
<td>sufficient</td>
</tr>
<tr>
<td>inserted patch</td>
<td>EFLI 104</td>
<td>100 %</td>
<td>75 %</td>
</tr>
<tr>
<td>applied patch</td>
<td>AFLI 12</td>
<td>100 %</td>
<td>10 %</td>
</tr>
<tr>
<td>transverse crack</td>
<td>RIS-Q 132</td>
<td>100 %</td>
<td>65 %</td>
</tr>
<tr>
<td>longitudinal crack</td>
<td>RIS-L 96</td>
<td>100 %</td>
<td>24 %</td>
</tr>
<tr>
<td>crocodile cracks</td>
<td>NRI 156</td>
<td>100 %</td>
<td>91 %</td>
</tr>
<tr>
<td>seam / joint</td>
<td>NF 40</td>
<td>100 %</td>
<td>26 %</td>
</tr>
<tr>
<td>pothole</td>
<td>ALS 8</td>
<td>100 %</td>
<td>6 %</td>
</tr>
<tr>
<td>particle loss</td>
<td>AMA 4</td>
<td>100 %</td>
<td>0 %</td>
</tr>
<tr>
<td>manhole cover</td>
<td>SCHACHT 26</td>
<td>100 %</td>
<td>26 %</td>
</tr>
<tr>
<td>road marking</td>
<td>MARK 0</td>
<td>-</td>
<td>0 %</td>
</tr>
<tr>
<td>others</td>
<td>SONST 0</td>
<td>-</td>
<td>0 %</td>
</tr>
</tbody>
</table>

Source: Modified from Knüpfer 2019.

As Table 2 shows, with the exclusion of longitudinal cracks, the detectability in the video recordings at a speed of 30 km/h is the same or higher than in the tests at 50 km/h. However, the worse identifiability of longitudinal cracks is mainly due to the narrow crack width in the area of “Danziger Platz”. Since, according to the guidelines of the FGSV, sealed cracks are to be treated as open cracks without distinction, they have also been summarized in the evaluation. Especially in the area of “Danziger Platz”, there are a lot of sealed cracks.

The very low percentage of cracks visible in the vibration profile (37 %) is caused in this case because sealed cracks produced less severe or less frequent vibrations in the vehicle than open ones. This could be determined when looking separately at parts with an accumulated occurrence of sealed cracks. Nevertheless, the evaluation of the deflections in vibration data confirms that longitudinal cracks cannot be recorded by an acceleration sensor.

Overall, measurement deflections above the selected threshold value could not be assigned significantly better than in the test drives at 50 km/h (85% compared to 80%).

Measurements by Bicycle

For the evaluation of the measurements by bicycle, all drives along “Danziger Platz” (a total of approx. 1.4 km = 350 m x 4; 2 in each direction) at a speed of 25 km / h were used. On this route a lot of cracks, patches and some other characteristics were recorded. The results are summarized in Table 3.
Table 3. Identification of Damages in the Video / Vibration Profile by Bicycle (25 km/h)

<table>
<thead>
<tr>
<th>condition characteristics</th>
<th>identification in video</th>
<th>deflection in vibration data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>clear</td>
<td>sufficient</td>
</tr>
<tr>
<td>inserted patch</td>
<td>EFLI</td>
<td>42</td>
</tr>
<tr>
<td>applied patch</td>
<td>AFLI</td>
<td>0</td>
</tr>
<tr>
<td>transverse crack</td>
<td>RIS-Q</td>
<td>93</td>
</tr>
<tr>
<td>longitudinal crack</td>
<td>RIS-L</td>
<td>31</td>
</tr>
<tr>
<td>crocodile cracks</td>
<td>NRI</td>
<td>16</td>
</tr>
<tr>
<td>seam / joint</td>
<td>NF</td>
<td>19</td>
</tr>
<tr>
<td>pothole</td>
<td>AUS</td>
<td>17</td>
</tr>
<tr>
<td>particle loss</td>
<td>AMA</td>
<td>0</td>
</tr>
<tr>
<td>manhole cover</td>
<td>SCHACHT</td>
<td>2</td>
</tr>
<tr>
<td>road marking</td>
<td>MARK</td>
<td>0</td>
</tr>
<tr>
<td>others</td>
<td>SONST</td>
<td>0</td>
</tr>
</tbody>
</table>


Table 3 shows that all examined characteristics, again with the exception of transverse and crocodile cracks, were predominantly clearly visible in the video recordings. This reveals that the poorer detectability of these two damages is definitely due to the type of damage and not primarily to its severity.

Here again, longitudinal cracks could not be recorded by the acceleration sensor. Similarly, crocodile cracks and seams were not recorded consistently reliably. In contrast, patches, transverse cracks and potholes were usually recorded with a high reliability. Manhole covers were clearly identifiable in the recordings as well as in the measurement data.

94% of all measurement deflections above 2 (m/s)² could be clearly assigned to a surface damage in the videos by bicycle. Since only tests were carried out with the bicycle in zones of 30 km/h, the speed of approx. 25 km / h driven there also corresponds roughly to that of a car on these routes. At this speed, even the surface and the condition of the surrounding is clearly visible in the video recordings.

Specific Vibration Profiles

When looking for similarities in the vibration data from different runs in the area of manhole covers, inserted and applied patches, transverse and crocodile cracks and seams, the characteristics could be roughly divided into two groups. Single events are usually due to transverse cracks and seams. All other investigated characteristics usually cause a closely following series of measurement deflections. An exact differentiation of the damages is not possible here, since it is not possible to differentiate clearly whether the number and amount of the deflections are characteristic for the dimension and extent of the damage or for the type of damage. Furthermore, in many cases the transition between individual characteristics is fluid or a combination of several characteristics occurs, which means that a clear assignment of the measurement
deflections is only possible to a limited extent. Figures 8 to 10 show examples for both groups.

**Figure 8. Single Measurement Deflection Sealed Transverse Crack**

![Image](image1.png)

*Source: Knüpfer 2019.*

**Figure 9. Multiple Measurement Deflections Crocodile Cracks and Applied Patch**

![Image](image2.png)

*Source: Knüpfer 2019.*
Figure 10. Multiple Measurement Deflections Inserted Patch

Source: Knüpfer 2019.

Discussion

The test drives with the bicycle provided good empirical values, which were useful when travelling by car, and showed consistently satisfactory results. However, they are not relevant for a further, extensive use of the vibration sensor technology and its validation. Due to the narrow track only a very small part of the roadway can be recorded and the speed, range and uniformity of driving are not sufficient for recording larger areas.

Two speeds were investigated with the VW bus, but not on the same route. In terms of the comparability of recognizability at different speeds in the recordings, driving on the same section would have provided more meaningful results.

The camera used delivers a sufficiently good quality of the video recordings, since a large number of relevant condition characteristics of the road surface can be clearly identified even at speeds of up to 50 km/h. In addition, the wide field of view also allows the condition of the peripheral areas and drainage systems to be visually inspected. Adjacent areas can also be recognized in the video recordings, but are usually too small and distorted for details to be recognized.

The requirement of ZTV ZEB-StB, according to which cracks with crack widths of 1 mm or more must be reliably detected in a visual image-based condition assessment (FGSV 2006), can only be met with the examined camera under good lighting conditions.

Differing lighting conditions have been identified as a potential source of problems for both video and still image recordings. In general, surface damage is easier to detect in direct sunlight than in shaded areas, but in sunny weather there is a constant change between light and dark areas due to the surrounding buildings. In the case of shadows that are not fully covered, e.g. tree shadows, or in the case of transitions between these areas, the surface texture can be
difficult to recognize due to the abrupt change of light and shadow. The same
applies to large areas of shadows. The camera needs a short time to adjust
internal settings when switching between light and dark areas. This can cause
the image to be severely under- or overexposed in transition areas. In addition,
in sunny weather it is almost unavoidable that the shadow of the measuring
vehicle moves in front of the vehicle and thus into the recording area of the
camera. This also makes it more difficult to detect damage in this area. To
avoid these problems, it is useful to take measurements with this type of image
recording on overcast days with little direct sunlight or at noon, when the sun is
in a vertical position. In addition to the lighting conditions mentioned before,
other weather influences must also be taken into account. When it rains,
droplets can form on the camera's lens and considerably disturb the recording.
In addition, a wet, reflective or snowy road surface prevents clear images of the
road surface.

In general, it can be said that individual cracks along and across the
direction of travel are sufficiently well visible in the recordings of the camera
used up to the maximum speed of 50 km/h, even if in some cases light
conditions in particular make it difficult to detect transverse cracks clearly.
However, only transverse cracks can be recorded with the acceleration sensors.
In the case of network cracks, the detectability with the examined method
depends strongly on their characteristics. Fine cracks with limited propagation
are only detectable to a limited extent, whereas strongly pronounced cracks are
usually clearly visible. Patching and spalling can be identified with high
reliability in the image recordings and measurement data. The same applies to
seams. However, it cannot be clearly determined whether the seams are open or
intact. But this distinction is important because according to the guidelines of
the FGSV, only open seams or joints are included in the evaluation when
recording road conditions. Measurement deflections due to raised or damaged
markings can usually be reliably verified with the recorded image material. The
same also applies to structures located in the road area such as manhole covers
or slides. With regard to particle loss, binder accumulation and rutting, the
recognizability in the video is strongly dependent on their characteristics, the
texture of the surrounding road surface and the local lighting conditions.
Therefore, no general statement can be made. In addition, binder accumulations
often cannot be clearly distinguished from simple discoloration or wet spots.

For the clear differentiation of different condition characteristics as well as
the classification of the extent of the damage on the basis of the vibration
profile, the measuring method in the interior of the vehicle seems to be too
inaccurate, which could be due to the strong suspension/damping of a
passenger car. It was only possible to distinguish between short (cracks, seams)
and longer (patches, mesh cracks) events.

By comparing the image recordings with the actual state, a better
assessment of the recognizability in the video is possible. This requires
continuous, manual documentation of the existing features of all examined
sections.
The driving speed also has an effect on the size of the measured values, so it should be kept constant. Within the sections considered in the evaluation, an attempt was made to maintain a stable speed, but due to traffic conditions this was not always possible continuously. It is therefore advisable to travel during off-peak hours in order to minimize traffic-related disruptions. It should also be borne in mind that due to vehicles parked at the roadside, the edges of the driven-off roads cannot or can only partially be recorded.

When looking through the finished video files, it can also be seen that in some cases the video quality fluctuates during the recording. This could not be corrected by repeating the rendering process and using higher resolutions.

Another difficulty in the evaluation was the exact time synchronization of the image and vibration data. The times recorded by the camera and the accelerometer showed deviations in the range of up to three seconds. This was determined by temporal synchronization of prominent points that could be clearly identified in the vibration profile and the video recordings, such as the moment of stopping at a traffic light. Despite manual corrections, in some cases this led to uncertainties regarding the clear assignment of measurement deflections.

All in all, the two central problems so far are to keep a constant speed in flowing traffic and to estimate and at best minimize the influences of vehicle suspension or damping.

Conclusions

As regulations specified by FGSV count among the acknowledged rules of technology for road condition monitoring in Germany, road damages should be classified and evaluated according to all characteristics for damages listed in the directives. But with the current measurement set-up it is difficult to meet the requirements.

On the one hand the longitudinal evenness can be recorded using vibration sensor technology but not the transverse evenness. On the other hand, even the substance characteristics of the surface cannot be recorded completely. Individual cracks in the direction of travel as well as binder accumulations are not registered. It is also not possible to differentiate between open and closed seams or joints as a deflection in the vibration profile can be seen in both cases but only open seams and joints represent a damage. Therefore, in any case a supplement must be made by visual recordings for which video recording is the best solution. This is no problem up to a speed of 50 km/h but still it is not possible to record the full amount of damages at the moment.
References


