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Gathered riding dynamics data for semi-automated risk assessment of roads

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Abstract

The scope of the project viaMotorrad, funded by the VSF Austrian Road Safety Fund and by the Austrian government, aims for a semi-automated risk assessment of roads, performed by a newly developed probe vehicle. In a joint effort, two Austrian academic institutions, leading in motorcycle dynamics and single-track vehicle research, have developed and instrumented a highly developed motorcycle for testing and measurement tasks related to traffic accident research and analysis. This motorcycle probe vehicle (MoProVe) is based on a high-end street bike, which represents the state-of-the-art in recent motorcycle technology. The vehicle was instrumented with two independent high-performance measurement systems. Covering different areas of measurements, these two systems complement each other, but serve as backup systems and verification tools as well. MoProVe is one of a kind and suitable for an extensive number of studies and investigations in traffic accident research and analysis.

Keywords: motorcycle probe vehicle; MoProVe; traffic accident research; accident investigation and analysis; black spot research; traffic safety, Austrian Road Safety Fund

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Nomenclature

CAN-bus	A Controller Area Network is a vehicle bus standard devised to connect independent electronic control units with each other, facilitating communication and other functions.
CEP	Circular Error Probable refers to the radius of a circle, centered at the true position, containing 50% of the estimated positions.
Doppler shift	Refers to a change in frequency or wavelength of a wave for an observer who is moving relative to the wave source.

1. Introduction

In Europe, one out of six road transport fatalities is a motorcycle rider or pillion passenger on a motorcycle. In Austria, the statistics are even worse: within the last 20 years, approximately 1850 motorcycle fatalities and 66.500 injuries occurred. The percentage of killed motorcycle riders and passengers compared with the total number of traffic accident victims is also disconcerting. In 1992, this percentage was only 5.7%, while in 2016 a record high value of 17.4% was reached (Statistik Austria 2017).

Two factors contribute to this evidence. Firstly, while significant efforts have been made to increase the safety of vehicles and the traffic environment, motorcycle safety has not been a priority. Secondly, the number of registered and used motorcycles has been steadily increasing. Consequently, the positive trend of a declining number of accidents and fatalities for other vehicle categories cannot be observed for motorcycle accidents, at least in Austria. Absolute numbers are more or less constant, with ups and downs over the last years (Statistik Austria 2017). Since the causes for motorcycle accidents are manifold and the measures to avoid them have been proved insufficient, more research with a focus on motorcycle accidents is needed.

This paper presents scope and first findings of the traffic safety project “viaMotorrad”. This initiative aims to improve the safety of motorcycle drivers by collecting riding dynamics data. In the last years, the number of fatal injured motorcyclists has remained constant, and therefore new approaches are needed. Based on analyses of historical accident data together with data of potentially critical locations as identified by motorcyclists and relying on frequently driven motorcyclists’ routes in Austria, road sections were clustered and selected for a unique investigation performed with the newly introduced probe vehicle MoProVe. The goal of the project was to identify high accident-risk spots within the road network, utilizing data collected by MoProVe. The output of this project will make it possible to locate critical areas within the road network, thus contributing to the avoidance of accidents and injuries.

Figure 1 KTM 1290 Super Adventure equipped and instrumented as a Motorcycle Probe Vehicle (MoProVe)

The gained knowledge of critical road sections for motorcyclists, will lead to the development of a hazard map of selected roads, showing the potential safety impact for motorcyclists. Such a hazard map should be prepared for the entire Austrian road network in the future, thus defining a priority ranking of road sections which need attention, to increase road safety for bikers.

2. Probe vehicle

The probe vehicle is a motorcycle sponsored by KTM Sportmotorcycle GmbH (KTM) and was upgraded with additional hardware by the Technical University of Vienna (TUW) and the Austrian Institute of Technology (AIT). This is a one-of-a-kind motorcycle that has the ability to collect all relevant driving dynamics data needed for enhanced road safety investigations, and which also has road approval.

The list of criteria for the selection of the test motorcycle included numerous items. Among them versatileness, state of the art technology, user-friendliness and accessibility (of hardware and software features) were of utmost importance. It was planned to take advantage of the on-board measurement systems of the motorcycle as to reduce the necessary additional measurement components.

The best match with the target specifications was found in a motorcycle KTM 1290 Super Adventure; see Figure 1 (KTM Sportmotorcycle GmbH, 2017). This vehicle has a 1300cc V-twin engine, delivering 160 HP (horse power) and a maximum torque of 108 Nm (Newton meter). Its dry weight is 222 kg. The motorcycle comes with a number of rider assistance systems such as Motorcycle Traction Control (MTC), Motorcycle Stability Control (MSC), Combined-ABS (C-ABS), Motor Slip Regulation (MSR) and a semi-active suspension system (SCU). This full range of assistance systems relies on numerous sensors, such as several brake pressure gauges, wheel speed sensors, a throttle position sensor and many more. The signals are all accessible via the vehicle CAN-bus and may be recorded and analyzed by an additional data recording system. A big advantage of this vehicle is that it has the option to activate or deactivate assistance systems i.e. by selecting different riding modes. Thereby, it is possible to mimic a more basic motorcycle without additional features, which was very handy for certain measurement tasks.

3. Measurement systems

The vehicle is equipped with two independent measurement systems. Each system consists of a data logger, IMUs (Inertial Measurement Unit), additional sensors and interfaces to the vehicle's CAN-bus. Data acquisition by the independent IMUs was redundant with respect to the measured signals. IMU-data were recorded only by the associated Data Acquisition System (DAQ). In the following, both systems are presented.

3.1. System B (Blue)

This system is based on hard- and software by RACELOGIC (VBOX automotive, 2017). The main component is a VBOX 3i dual-antenna data-logger. This VB3iSL and a functional block diagram are depicted in Figure 2.

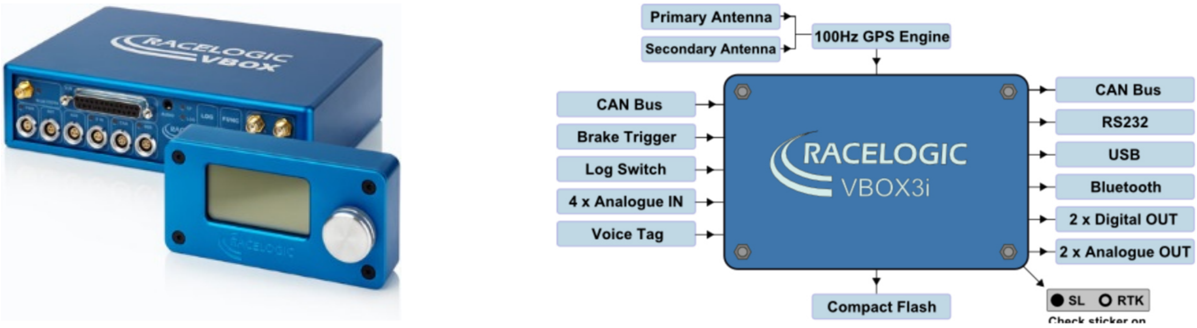

Figure 2 Picture of RACELOGIC data-logger VB3iSL with display unit; (b) Block diagram of Input and Output signals for data-logger VB3iSL (VBOX automotive, 2017).

The VB3iSL features a powerful GPS engine embracing twin antennas capable of providing 100 Hz (Hertz) signal update rate for all GPS / GLONASS parameters (i.e. velocity, heading & position). Velocity and heading are calculated via Doppler Shift in the GPS carrier signal, providing superior data accuracy. In addition to GPS, the VB3iSL tracks the Russian GLONASS range of satellites. The advantage of using both satellite constellations is that there are almost twice as many satellites in view: This helps maintaining a robust satellite lock in areas where

GPS only reception can cause data interruption. Because two GPS / GLONASS antennas are simultaneously in use, measurements of signals such as slip angle, pitch or roll angle, yaw rate, true heading, lateral velocity and longitudinal velocity are possible.

The performance and accuracy of the system is enhanced by two additional features. A DGNSS (Differential Global Navigation Satellite System) Base Station was acquired to further improve the positional accuracy of the VBOX unit by calculating and transmitting differential correction data. By these additional signals from the Base Station, located at a known position, it is possible to accurately monitor the difference between this known position and a position received via GPS/GLONASS. This correction signal is used to significantly improve the accuracy of the absolute position. While the 95% CEP (Circular Error Probable) is 3 meters for standard position measurements, with the DGNSS-station a radius of 80 cm (centimeters) can be reached.

While the relative position accuracy is much better than the absolute position accuracy, it is still enhanced by an Inertial Measurement Unit (IMU). This 6-axes sensor (see Figure 3) is a 3-axes accelerometer with additional 3-axes measurement of the angular rate. By post-processing (numerical integration) these signals, linear velocities and distances as well as roll, pitch- and yaw-angles can be calculated. By processing and combining the IMU-signals with the information obtained from the GPS-antennas, numerical algorithms implemented in the system software can optimize the system output and provide highly accurate position and velocity signals. Moreover, at locations with weak (or no) GPS/ GLONASS satellite signals, e.g. in tunnels, measurements are still possible as the DAQ system can rely on the IMU data.

Figure 3 a) Picture of RACELOGIC Full HD camera system; (b) Inertial Measurement Unit (IMU) to measure 3-axes accelerations and 3-axes angular rates (VBOX automotive, 2017)

The most recent system added to MoProVe is a camera system, see Figure 4. Two separate cameras were mounted in front of the motorcycle. The additional video data obtained by this system is highly relevant for real world observations. In the case of suspicious data caused by the measurement system, the video information may come in handy. Moreover, it is beneficial to observe which path the rider has taken within the traffic lane. This is very important for bikers since they are required to drive as far as possible to the right hand side of the lane.

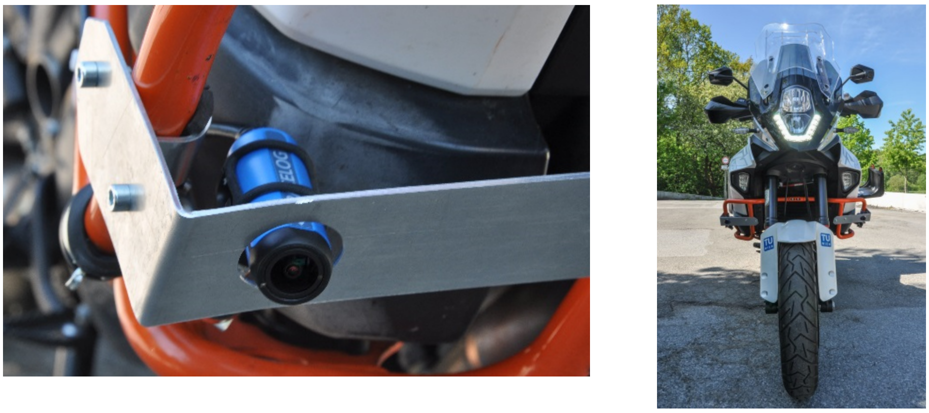

Figure 4 HD-camera system mounted on MoProVe.

3.2. System R (Red)

While System B has been developed primarily for application in automotive engineering, the second data acquisition system implemented on MoProVe is a measurement system especially designed for motorcycle applications. As such, it is frequently used by motorcycle racing teams worldwide. On MoProVe, it works as a supplement to the other system as the focus and features of this system are different from System B.

Since it can be used as a stand-alone system as well, it also consists of a data logger with dashboard display unit, see Figure 5, a single GPS-antenna and two 6-axes IMUs. In terms of the basic components, there is a functional redundancy provided by both systems. However, system R is much more versatile and capable when it comes to the measurement of vehicle parameters. This logger can record up to 200 channels, while the sampling rate may be as high as 3.2 kHz. There are 2x8 analog input channels with 16 bit (high-resolution) ADC (Analog to Digital Converter) available, several dedicated wheel speed input channels and two independent CAN-lines with full CAN routing (2d-datarecording, 2017). Moreover, the logger and components are very small, lightweight and robust, with low power consumption.

Figure 5 (a) 2D data logger LM 6; (b) dashboard display (2d-datarecording, 2017).

3.3. System B vs. System R

Due to the much higher sampling rate and the large number of channels available, system R was found to be more versatile than system B. Moreover, access to the motorcycle’s CAN-bus system is easier with this system and many CAN signals can be recorded. In addition to the high number of sensors and signals already available on the KTM bike, a steering angle sensor was also installed and its signal was sampled. Wheel speed signals, brake fluid pressure, throttle position, engine speed, gear position, brake operation and are example of measurements that can be collected.

With regard to the measurement of acceleration signals and angular rates, system R excels system B since two lightweight 6-axes IMUs are available and the sampling rate can be adjusted as high as 3200 Hz. Therefore, it is evident that in-plane dynamics of the motorcycle, as well as studies on stability and detection of unstable behavior, steering maneuvers, etc. would be better investigated by using system R.

The main components of system R are stored in a side case on the right hand side of the bike, while the side case on the left hand side is reserved for system B (see Figure 6). At the very end of the luggage bridge, a “sensor bar” made from aluminium was mounted, to hold all 3 GPS-antennas and the IMU of system B. The IMU of system R, a tiny little red box, was mounted under the seat. The second IMU of system R is integrated in the GPS-antenna mounted on the sensor bar.

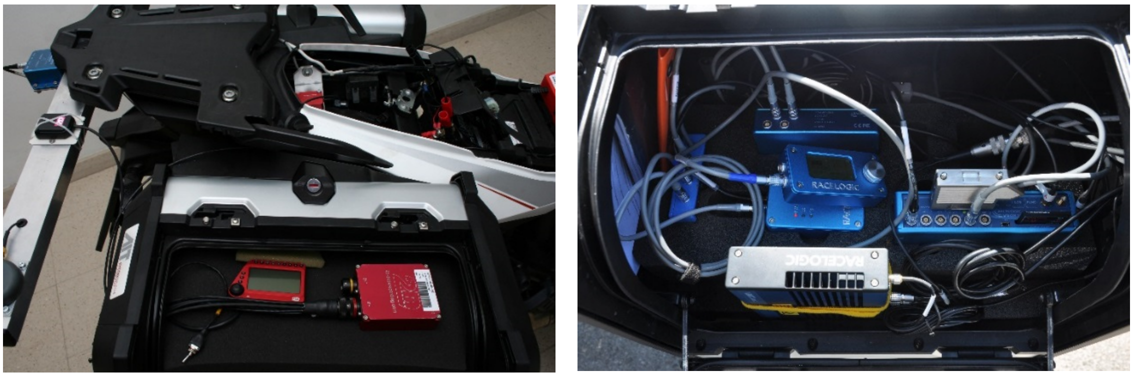

Figure 6 (a) Side case on the right hand side, containing System R, 2D data logger and display; (b) Side case on the left hand side, containing System B, logger VB3iSL, connectors and accessories.

4. Identification of real-world sections for measurement runs

To identify significant road sections for the planned investigations and measurement runs, an accident analysis was performed as an initial step. Since 2010, motorcycle-accident numbers with personal injuries have been increasing in Austria. In the last years, motorcycle accident numbers have increased from 3688 in the year 2012 to 4050 in the year 2015 (Statistik Austria 2017).

Additional to the accident research analyses, subjective assessments from motorcycle riders were collected. On the one hand, data was obtained from a study named “Bikers Project”, an Austrian road safety campaign (Praschl, 2006). In this motorcycle research project, subjective data were collected by questionnaires and interviews with motorcycle riders, after driving on typical road sections. The interviewees had to answer questions regarding any safety issues encountered on the sections, as well as any safety-related events they may have experienced during their ride. All the data collected were analysed and every section included in that project was assessed as either safe, neutral or risky route. On the other hand, a consultation of target groups (via motorcycle riders’ forums) was performed to gain information on typical bikers sections and on Austrian routes which are perceived as dangerous.

By combining the findings of the actual accident data analyses with the subjective data from motorcycle riders, specific routes for performing the measurement runs were identified. The sections are six different but typical motorcycle tracks in the provinces of Lower Austria and Styria. Two of them are shown in Figure 7.

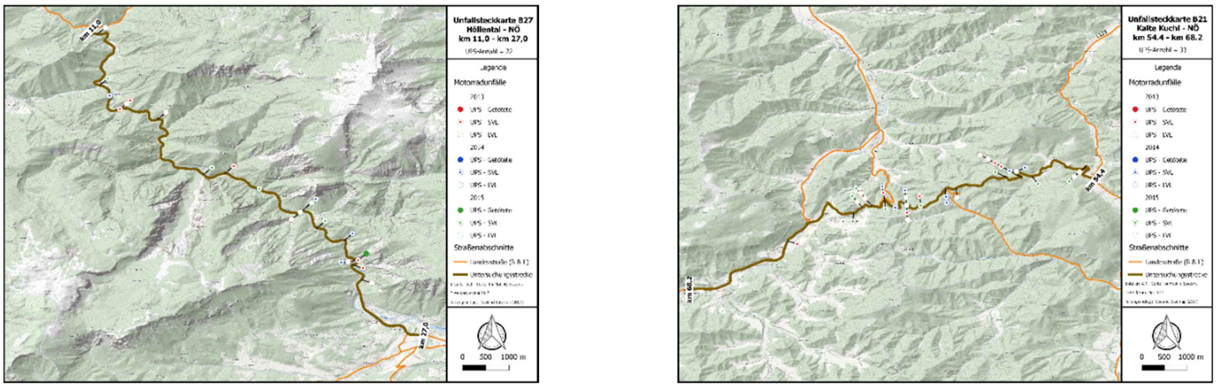

Figure 7 (a) First Measurement-Route “Höllental” (b) Second Measurement-Route “Kalte Kuchl”

Five riders were selected for performing the measurements. While they were not professional or trained test riders, they all had many years of riding experience on motorcycles. The measurement runs and tasks were challenging and would have been too demanding for a novice. The authors are aware of the fact that a larger number of test riders would increase the diversity of the measurements and one would expect to obtain more statistically relevant results. However, the goal of the underlying project was to investigate and test the feasibility of a risk assessment method. Therefore, it was important that the method could be used without needing a huge amount of measurement data from many riders and that it could be applied even on a small statistical base of the sampled data.

Each rider had to drive the selected road sections several times. This was necessary to calculate an “average ride” for each rider and cancel out single events. Also, since the test rides were performed in regular traffic, it was also necessary to have a sufficient number of rides so that the influence of other traffic, such as an overtaking maneuver or a hold-up behind an agricultural vehicle, could be eliminated.

Traffic was not the only test parameter difficult to isolate and control, also rider behavior did vary. The riders experienced a certain variation of their individual riding performance. As the road sections under investigation were already challenging to run, and as there may have been a possible anxiety caused by the subconcious knowledge that fatal accidents had occurred at particular sections, the mental and physical condition of the riders changed, even from one run to the next one. Time of day was another influencing parameter, as in the morning everyone was fresh and eager to ride, while in the afternoon, tiredness was noticeable. Environmental conditions such as temperature, light conditions, position of the sun and location (woody areas) also had an influence on the performance of the riders. For example, the position of the sun can make a turn look significantly different from a rider’s perspective and may cause changes in the riding behavior.

These parameters and their influence had a negative impact on the reproducibility of the measurements. Moreover, interpreting the results must be made in a cautious manner. To give an impression on the various aspects discussed so far, a few measurement examples are shown in Figure 8. Two diagrams show the motorcycle speed over time. In the left diagram (a), three measurements of the same rider at a certain stretch of the test road are shown. As one can see, the variation of speed between the different runs is rather small and does not exceed a few km/h. This indicates a good reproducibility for this set of measurement runs. The variation of speed along the time axis is caused largely by to the road design and lay-out, namely curvature of the road, the road condition, etc. Diagram (b) displays data for the same road section as on the left, but the different curves are produced by different drivers. As one can see, in this example the influence of the individual riding style, quantified by the chosen speed, is larger than the variation within several rides of one specific rider.

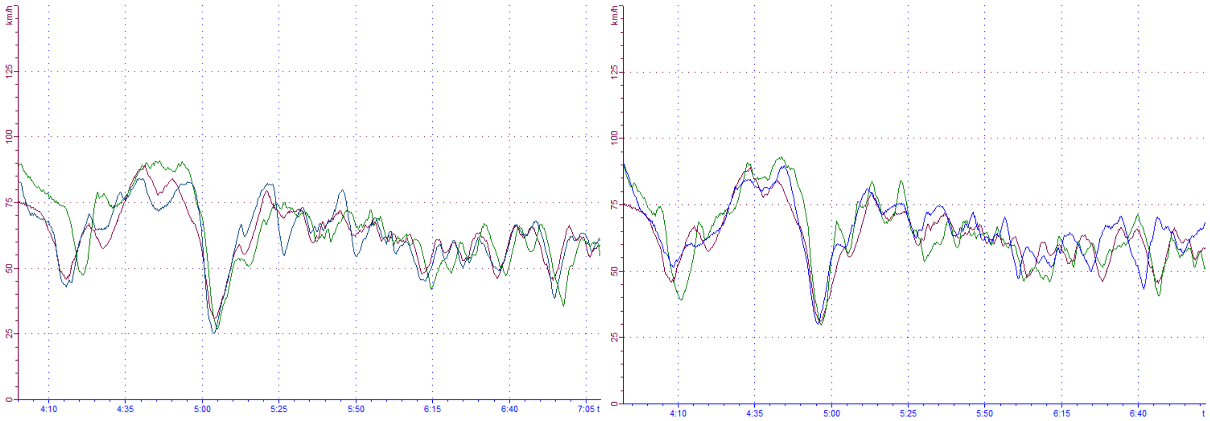

Figure 8 Motorcycle speed as a function of time (minutes) along an approx. 3000m stretch of one of the test roads. (a) result for test rides of the same rider; (b) result for different riders.

When investigating Figure 8 in details, it becomes obvious that the representation as a time-series is somewhat inconvenient, when looking at rather long data samples. Since at higher velocities, more distance is travelled within a certain time interval, speed data at the same points in time will not correspond to the same locations on the road, except for the start of such series after precise synchronization. This is a minor inconvenience for short measurement samples, but a significant problem for long time-series. Since travel time on each of the six different test roads was at least 10 minutes, time series were easily out of sync by ±30 seconds and more, with only ±5% difference in average speed. The solution to this problem is the conversion of the data from a time-based series to a path-based representation. This is not an easy task and will be briefly discussed at the end of this chapter. The following results are based on rather short time series and therefore it was possible to perform the analysis on the original time-based data series.

The dominant decrease of speed, as observed in Figure 8 near time stamp 5:00, was caused by a sharp 140 degree turn. Although the riders did approach that turn at different speeds, going through the turn with a safe lean angle was only convenient within a very narrow velocity range. That is the reason why all measurement curves show almost the same minimum speed. To give an impression of that turn, a few frames from a video, taken from a vehicle driving in front of MoProVe during a test run, are shown in Figure 9.

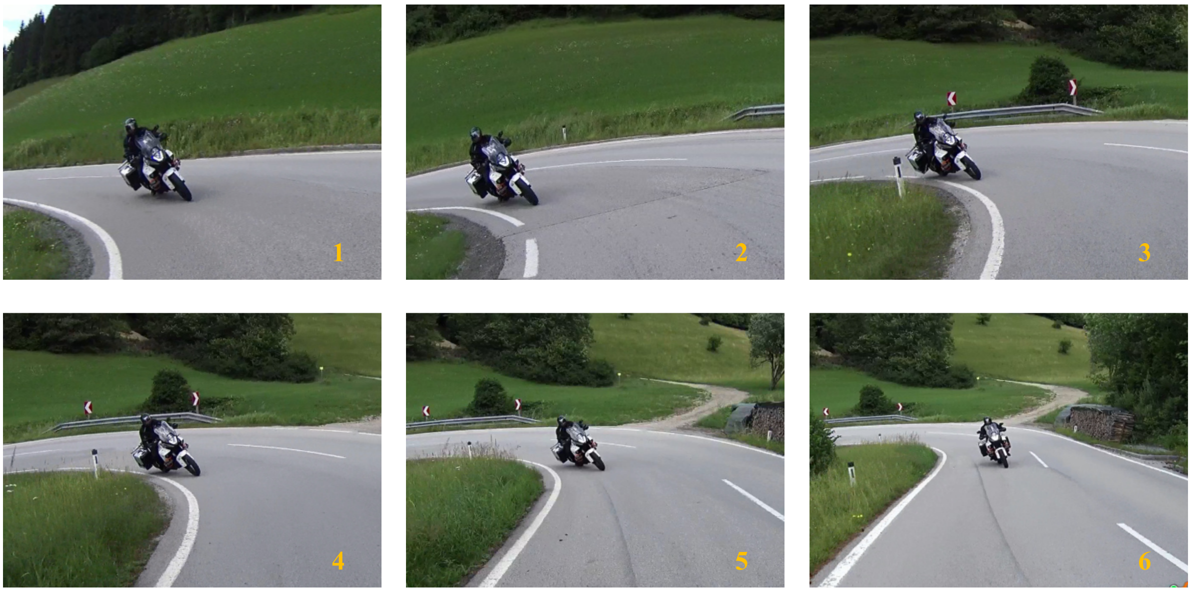

Figure 9 Single pictures of a video showing a rider negotiating a sharp turn

Figure 10 presents diagrams of the longitudinal acceleration, when approaching the turn shown in the figure above, going through that turn and accelerating when the turn has been completed. Again, the left diagram shows three results for the same rider and the right diagram for three different riders. The distance covered during these approx. 19 sec. is about 220 m and the error due to time representation is rather small. In these diagrams, the first negative spike (down) indicates the maximum deceleration when approaching the turn and braking, while the positive part of the signal is caused by the acceleration within the turn and on exiting the turn. The process of performing a turn and going through a bend is a highly complex maneuver on a single-track vehicle and more complicated compared to driving a car. Therefore, it is not surprising that the acceleration signal looks quite different even in the left diagram, which displays data from the same rider. Even more deviations can be noticed for the measurements collected from different riders.

In view of these results and the differences observed between measurements, the question arises, whether such variations are just normal or not. In case of significant deviations beyond normal within different riders, or even more for just one rider, this may be an indication for a turn that is difficult to negotiate.

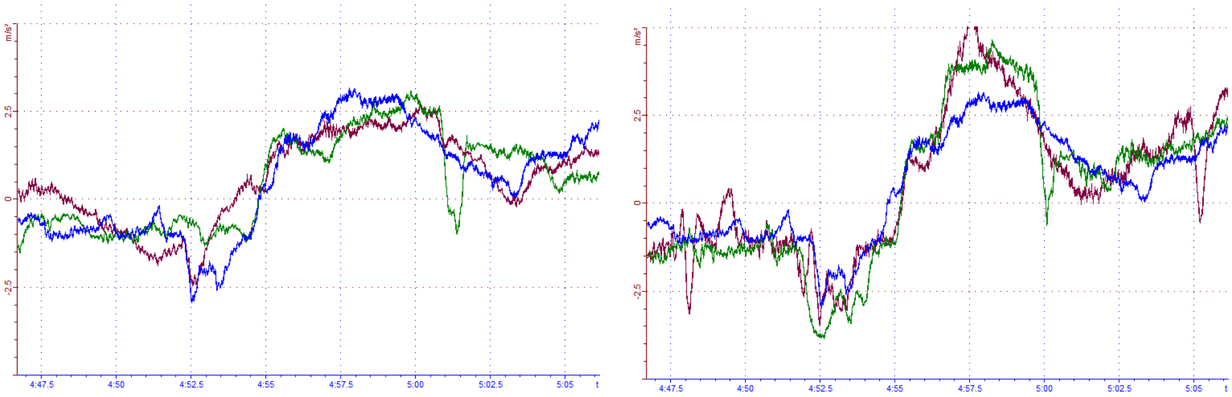

Figure 10 Motorcycle negotiating a turn, longitudinal acceleration as a function of time (minutes). (a) result for test rides of the same rider; (b) result for different riders

To analyze the measurement data for potentially critical / dangerous spots, data needs to be processed in various ways and by using different methods and means. If one is looking for critical turns, a starting point would be the geographical data of the road, from which the curvature can be calculated for every point along the road. Based on a certain trigger level of the curvature, the measured acceleration signals are looked up in the database and analyzed by comparing all the different measurements for this location. In a next step, other significant signals are also taken into account, for example the roll rate. Roll rate and roll angle are the most typical signals for powered two-wheelers (PTWs) and are unique to this type of vehicles. The roll rate in particular is a very sensitive signal. This parameter was measured directly by the on-board IMUs of MoProVe. A “clean ride” in a turn would show a continuous and smooth increase and decrease of the respective roll signal. Multiple sign changes of the signals indicate corrections of the lean angle and may be caused by troubles when negotiating a turn.

Figure 11 complements Figure 10 and presents diagrams of the roll rate, going through the same turn as in the previous figure. As one can see, these signals are even more irregular compared to the longitudinal acceleration in Figure 10. For both signals, an irregularity factor can be computed and evaluated. This procedure could be repeated for other significant signals as well. However, attention must be paid to the relations and dependencies between signals. For example, the brake fluid pressure is related to the deceleration, but may be useful anyway, since ABS operation can be detected from that signal.

Figure 11 Motorcycle negotiating a turn, roll rate as a function of time (minutes). (a) result for test rides of the same rider; (b) result for different riders

By computing such irregularity factors for a number of relevant signals and relating them to the location, one can find high-risk spots from the gathered riding dynamics data. This step will require that all signals needed will have to be transformed from a time-based representation into a path-based description. This transformation is believed to be a simple mathematical task, however only in theory. Since the measured GPS-signals are occasionally invalid due to loss of satellites in woody sections of the road paths, or if the position accuracy is low, it can be rather challenging to compute this transformation. Algorithms for data reconstruction and interpolation will be needed and employed for this step, not yet carried out but planned as a next step in the course of the project. To support this data processing task, a high-performance GPS-satellite-based measurement of the test roads has been carried out. All six test roads have been measured in both driving directions to have precise geographical data for both lanes. Based on this data set, the measured data can be related to valid geographical coordinates, providing the needed link to actual accident data. By joining the accident database with the processed dynamics database obtained from measurements, statistical methods can be applied to find characteristic information about critical road parameters based on measured riding dynamics data.

6. Outlook

This paper presents a risk assessment method for identifying high risk road spots for motorcycles based on riding dynamics data. The gathered parameters will be used to calibrate, evaluate and validate a calculated risk model, in order to use motorcycle dynamic data as an indicator for risk estimation of any road stretch.

At the end of the project, in-depth knowledge on braking forces, vibrations, skid resistance of the road surface, slip ratio of the tires and other parameters could be utilized to develop an accident prediction model. This could lead to a calculated risk model for Austrian's road network for motorcyclists. By trying to set up a three-stage scale – safe, neutral and risky– for scenic and/or frequently used country roads, motorcycle riders could be warned to drive more cautiously in high-risk zones. Moreover, road operators could be better advised on investment decisions.

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