viaMotorrad – Can motorcycle safety be measured?

viaMotorrad – Kann Motorradsicherheit gemessen werden?

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Abstract

In a joint effort, two leading Austrian academic institutions, with expertise 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 sponsored by KTM, which represents the state-of-the-art in current motorcycle technology. Within the viaMotorrad project, the vehicle was upgraded with two independent high-performance measurement systems, by the Technical University of Vienna and the AIT Austrian Institute of Technology. Apart from GPS, HD-Video and IMU-data, CAN-bus data can be directly collected from the motorcycle.

The project viaMotorrad, funded by the Austrian Road Safety Fund (VSF), aims for a semi-automated risk assessment of roads, performed by a probe vehicle. In this project, the vehicle is a one-of-a-kind motorcycle that can collect all relevant driving dynamics data needed for comprehensive road safety investigations. Road sections which are considered high-risk for motorcycles should be detected by the data. The goal is to act and plan measures before accidents occur, in order to decrease the number of fatalities in riders. Based on the results of this project, future research should include the development of a motorcycle-specific Hazard Map of the road network. With the collected data, not only traffic safety investigators could improve their activities, but also road operators and bikers themselves.

First results show that data collected with the MoProVe can provide insights into linking riding dynamic data to infrastructure data of the road network. The analysis started with the transformation of the collected time-based data to the needed path-based data. Current work includes the investigation of data thresholds, in order to establish the difference between considered risky and normal road segments. The final goal is to implement preventative measures to reduce motorcycle accidents.
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Introduction

One out of six road transport fatalities is a motorcycle rider or pillion passenger on a motorcycle, in Europe. The statistics are even more worrying in Austria: approximately 1850 motorcycle fatalities and 66,500 injuries occurred, within the last 20 years. The percentage of killed motorcycle riders and passengers compared to the total number of traffic accident victims is also disconcerting. In 1992, this percentage was only 5.7 %, while in 2017 a record high value of 20.0 % was reached in Austria. (Statistik Austria 2018).

There are two factors which contribute to this evidence. Firstly, motorcycle safety has not been a priority; while significant efforts have been made to increase the safety of vehicles and the traffic environment itself. Secondly, there has been a steady increase in the number of registered and used motorcycles. 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 (Statistik Austria 2018). More research with a focus on motorcycle accidents is needed, since the causes for motorcycle accidents are manifold and the measures to avoid them have proved to be insufficient.

The scope as well as first findings of the traffic safety project “viaMotorrad” will be presented in this paper. This initiative aims to improve the safety of motorcycle drivers by collecting riding dynamics data. New approaches are needed since the number of fatal injured motorcyclists has remained constant in the last years. 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 sections for motorcyclists within the road network, thus contributing to the avoidance of accidents and injuries.

**Fig. 1:** KTM 1290 Super Adventure equipped and instrumented as a Motorcycle Probe Vehicle (MoProVe) .
The findings of critical road sections will lead to the development of a hazard map of selected roads. Within the map, we will be able to show the potential safety impact for motorcyclists. This hazard map can be prepared for the entire Austrian road network in the future. With the gained information, a priority ranking of road sections which need attention should be defined, to increase road safety for bikers.

**MoProVe – The Motorcycle 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). The motorcycle has the ability to collect all relevant driving dynamics data needed for enhanced road safety investigations. Furthermore, it also has a road approval and can be driven under normal conditions.

The selection of the right test motorcycle depended on numerous factors. The plan was to take advantage of the on-board measurement systems of the motorcycle, to reduce the necessity of additional measurement components. Therefore, the motorcycle had to be equipped with new state of the art technology and had to be user-friendly. Very important was the accessibility to internal hardware and software features.

The best match with the target specifications was found in a motorcycle KTM 1290 Super Adventure; see Fig. 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.

**Measurement systems**

Two independent measurement systems are integrated in the test motorcycle. Each system consists of a data logger, IMUs (Inertial Measurement Unit), additional sensors and interfaces to the vehicle’s CAN-bus. Some data acquisition was redundant by the independent IMUs and were recorded only by the associated Data Acquisition System (DAQ). Following, both systems are presented separately.
System B (Blue)

The blue 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 Fig. 2.

![Block diagram of Input and Output signals for data-logger VB3iSL](VBOX automotive, 2017).

A reliable GPS engine embracing twin antennas capable of providing 100 Hz (Hertz) signal update rate for all GPS / GLONASS parameters is featured by the VB3iSL. Velocity and heading are calculated via Doppler Shift in the GPS carrier signal, providing superior data accuracy. Also, the Russian GLONASS range of satellites is tracked by the VB3iSL. This gives the system the advantage that there are almost twice as many satellites in view and helps maintain a robust satellite lock in areas where GPS-only reception can cause data interruptions. 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 accuracy and performance 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 Fig. 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.

The camera system is the most recent added system to MoProVe, see Fig. 4. Two separate HD-cameras (High-Definition) were mounted in front of the motorcycle. The additional video data obtained by this system is highly relevant for real world observations. When unreliable data are found by the measurement system, it become handy to look at the video information. Moreover, it is beneficial to observe which path the rider has taken within the traffic lane. This is highly relevant for bikers since they are required to drive as far as possible to the right hand side of the lane.

System R (Red)

The second data acquisition system implemented on MoProVe is a measurement system especially designed for motorcycle applications, as System B was developed primarily for application in automotive
System R is the 2D (Debus and Diebold) system and 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.

The Red system also consists of a data logger with dashboard display unit, see Fig. 5, a single GPS-antenna and two 6-axes IMUs, since it can be used as a stand-alone system as well. 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. The logger of the 2D-system 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.

![Fig. 5: a) 2D data logger LM 6; (b) dashboard display (2d-datarecording, 2017).](image)

**System B vs. System R**

System R has a much higher sampling rate than the other System furthermore, it has a large number of channels available. 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 has two lightweight 6-axes IMUs and the sampling rate can be adjusted as high as 3200 Hz. Therefore, in-plane dynamics of the motorcycle, as well as studies on stability and detection of unstable behavior, steering maneuvers, etc. system R has its benefits.

System B on the other hand delivers almost the same data as System R with a bit lower sampling rate. As this Hardware is also a high-performance System, the signal rates are more than high enough for all
evaluations of measurements. Furthermore, the video data gained through System B is highly important, not only for crosschecking the datafiles, but also for data analyses.

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 Fig. 6). At the very end of the luggage bridge, a “sensor bar” made of aluminum was mounted, to hold all 3 GPS-antennas and the IMU of system B. The IMU of system R, was mounted under the seat. The second IMU of system R is integrated in the GPS-antenna mounted on the sensor bar.

![Fig. 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.](image)

**Identification of real-world sections for measurement runs**

As an initial step, an accident analysis was performed to identify significant road sections for the planned investigations and measurement runs. 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 4031 in the year 2017 (Statistik Austria 2018).

Additional to the accident research analyses, subjective assessments from motorcycle riders were collected. On the one 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. On the other hand, data was obtained from a former 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 classified as either safe, neutral or risky route.
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 Fig. 7.

![Fig. 7: a) First Measurement-Route “Höllental” (b) Second Measurement-Route “Kalte Kuchl”.](image)

**Measurements and results**

The riders who performed the measurements were not professional or trained test riders; however, all of them were experienced on motorcycles. The reasoning behind that is that the measurement runs and tasks were challenging and would have been too demanding for a novice rider and therefore risk of injury crashes together with damaging the MoProVe was too high. 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. 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.

The selected road sections were driven by each rider 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.

Next to the variable of rider behavior, traffic was another parameter difficult to isolate and control. The riders experienced a certain variation of their individual riding performance. Another influencing parameter was the time of day, as in the morning everyone was fresh and eager to ride, while in the afternoon, tiredness was noticeable. Environmental conditions such as light conditions, position of the sun, temperature and areas also had an influence on the performance of the riders.
Therefore, individual aspects of rider performance and driving styles need to be accounted for in any subsequent analysis if objective criteria for road safety are to be derived.

Furthermore, Fig. 8 illustrates the difficulty of comparing time-based measurements of the vehicle dynamics obtained during different measuring episodes. Panels (a) and (b) each depict the evolution of vehicle speed during 3 measurements. Panel (a) shows the variability for a single driver at a specific part of the drive (that part being approximately 3000 meters long). The difference in speed is limited to a single digit amount of km/h at most points, although a few domains of higher discrepancy can be identified (i.e. the green curve at the beginning of the measurement). This seems to suggest that these 3 measurements could be readily combined into a measure of overall driver dynamics. However, discrepancies tend to appear in particular at “more demanding” parts of the road (i.e. curves), such as in the beginning of the measurement.

Panel (b) shows the differences of driving dynamics between different motorcycle test riders, on the same 3000-meter part of the drive. While overall the 3 lines are very close, specific domains like the start and later half of the 3000 meters show a number of discrepancies. While they do not appear to be large at any given point, the last fifth of Panel (b) shows how they can eventually counteract one another (blue curve high and green curve low) when combining them into a joint statistic of riding dynamics over time.

![Fig. 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.](image)

The shape of the diverse curves suggests temporary “offsets” between the different curves, in both panels. These offsets originate in the fact that due to different speeds and driving styles (effectively driven distances), different drivers arrive at the “same” point of the drive after differing amounts of times.

The discussed issue can be reliably avoided, when considering different dynamics data at the (approximately) same point on the road, rather than at the same point in time.
Therefore, any model of road characteristic driving dynamics will require a path-based representation to be derived from a time-based series and this is the course we followed for further analysis.

To illustrate how the obtained dynamics data characterizes road features, we discuss an example within Figure 8 in detail: Close to time 5:00 there is a significant drop in speed in all driving profiles. At this point the road takes a 140 degree turn. Riders arrive at this point with different speeds and at slightly different times, yet, a safe lean angle requires the speed to be within a specific narrow velocity interval. Hence, our proficient drivers all decelerate to almost the same speed at this point. To illustrate, video frames extracted from a companion vehicle driving in front of MoProVe are shown in Fig. 9.

![Fig. 9 Single pictures of a video showing a rider negotiating a sharp turn.](image)

We give a final illustration of the dynamics in this curve in Fig. 10: Profiles of the longitudinal acceleration are shown for the above mentioned (Figure 9) curve. Panel (a) shows differences within the same subject/driver via 3 different measurements, while Panel (b) shows differences over 3 different drivers. Both panels show substantial deviations both within the same driver and between different drivers. The initial drop in acceleration and the subsequent increase certainly are candidates to characterize this difficult turn and would be expected to be useful in detecting other difficult and dangerous turns.
Subsequently, through projections and identification of coordinates, we turned the time-based series into path-based data series. This required a significant effort and had to be done for all six test roads. At the end, the measured data can be related to valid geographical coordinates, which also benefits the association to actual accident data.

We followed a supervised learning approach to extract a characterization of dangerous dynamics from our data: after turning to path-based data, we identified known accident sites from historical data and used these data, together with known “noncritical dynamics” to fit a supervised learning algorithm to multiple drivers and road tracks simultaneously. From this action, we obtained a scalar measure of “danger”, according to the likeness of recorded dynamic data to the dynamics at known accident sites. After having taught our algorithm the nature of the dynamics at known accident sites, we used the very same algorithm to classify/obtain the “danger value” at all points during our test drives. An example result can be seen in Figure 11: We specify a preliminary “warning system” based on the obtained “danger values”, by defining that a given point is marked with a “yellow warning” if its danger function evaluation reaches a value above 90% of the average danger value obtained at known accident sites (see also the purple cross in the figure). We issue a “red warning” if the value reaches above 95% of the average danger value of a known accident site. Note that the maximum danger in this example (green cross in Figure 11) is indicated before the tip of the curve, even though the accident is recorded to have occurred at the tip of the curve.
Fig. 11: Preliminary Risk Profile of driving dynamics in a turn. Yellow circles denote “danger values” which exceed 90% of the average danger value at the critical sites used for the fit. Red circles denote “danger values” which exceed 95% of the average danger value at the critical sites used for the fit. A purple cross signifies the site of an actual accident, while a green cross signifies the maximum danger value in the close vicinity of the known accident site. Note that the measured curve (red circles) deviates somewhat to the left from the satellite map curve.

The example above shows the classification of a single measurement trajectory. Due to using statistical methods, we are able to combine the “danger estimates” of multiple rides and derive a more comprehensive and robust criterion of the accident risk for motorcycle riders and also correct for the above mentioned individual features of drivers and driving circumstances.

We have thus illustrated how a motorcycle accident database can be used together with processed dynamics obtained from measurements, to characterize critical road sections based on the MoProVe data.

**Outlook**

Based on riding dynamics data, this paper presents new ways of a risk assessment method for identifying potential high-risk sites for motorcycles. 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 netwide. With a machine learning approach, a new method will be accomplished, so that motorcycle safety will further increase.
At the end of the project, in-depth knowledge on braking forces, vibrations, slip ratio of the tires, skid resistance of the road surface and other parameters could be utilized to develop an accident prediction model. In the future this could lead to a calculated risk model for Austrian’s road network especially for motorcyclists. Furthermore, a three-stage scale – safe, neutral and risky – could warn motorcyclists to drive more cautiously in high-risk zones. Moreover, road operators could be better advised on investment decisions.

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