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Roll Angle Estimation for Motorcycles: Comparing Video and Inertial Sensor Approaches

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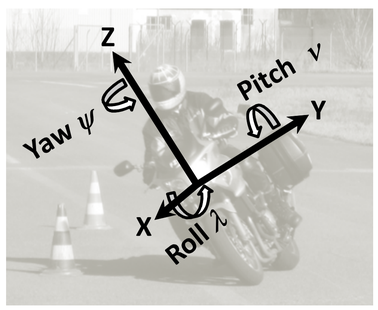
Motivation

- Advanced Rider Assistance Systems improve driving behaviour and safety.
- Further developments will include video-based systems, now deployed in cars.
- Porting ADAS modules to motorcycles requires a known camera pose.

⇒ Roll angle estimation is an important task for various ARAS!



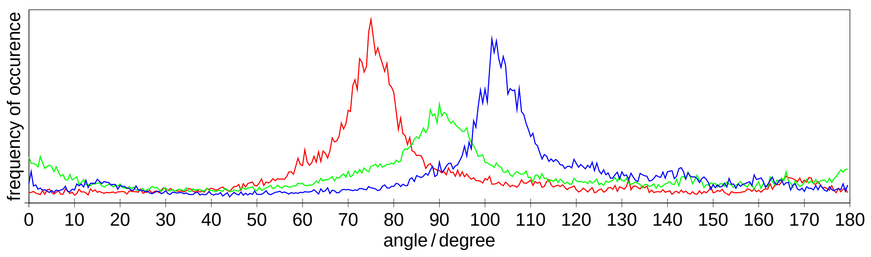
Comparison of independent estimation methods

This study introduces approaches based on inertial measurement units (IMU) as well as video only. We present:

- Evaluation on real video data with ground truth (until now: only results on synthetic data)
- Three valuable improvements to the video-based estimation
- Parameter optimisation using the Covariance Matrix Adaptation Evolution Strategy (CMA-ES)

Video-based roll angle estimation

Typical road scenes feature recurring geometry and compositions of objects. Those result in characteristic orientation distributions of image gradients that code the roll angle of the motorcycle.



Normalised orientation histograms of three closely recorded images.

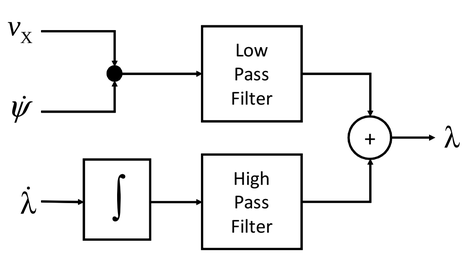
By correlating the statistics of a single image with the learnt distribution, the angle is derived. For details we refer to our earlier publication [1].

This study proposes and evaluates extensions to the original method including optimisation of system parameters using CMA-ES.

- Main gradient orientations can be disturbed by strong local gradients.
  → Increase robustness by introducing a priority search interval around the current estimate.
- Kalman filter parameters (state / observation noise) were originally constant.
  → Adjust dynamically, depending on NCC of each measurement.
- Histogram is discrete and can introduce artefacts.
  → Filter correlation array for angle and rate estimation.

IMU-based roll angle estimation

Two approaches based on inertial measurement units – using vehicle velocity, yaw rate, and roll rate – were applied:

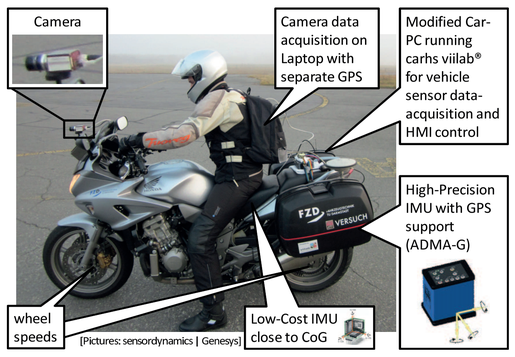


1) Combined Filter Method. A simplified version of the method earlier proposed by Seiniger et al. [2].

2) Kalman Filter Method. Instead of a combination of high and low pass filters, an Extended Kalman Filter is used for integration.

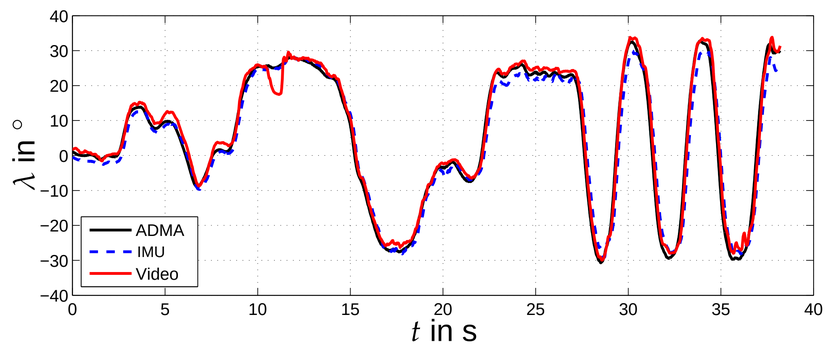
Experimental setup

For evaluation, a test vehicle was equipped with IMU, camera and a highly accurate reference sensor. Test drives were conducted on TU Darmstadt's proving ground, Griesheim Airfield. A set of manoeuvres with roll angles of up to $40°$ was performed, in order to simulate real driving on rural roads. Among others, these are straight driving, constant and variable radius cornering, swerving, and slalom.



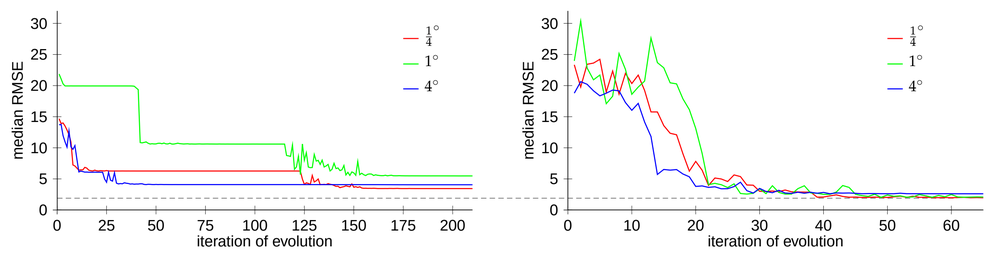
Experimental results

Experiments were conducted on five sequences – two for training and optimisation of the video methods and three for evaluation (I – III).



Reference values (ADMA) and estimates of the roll angle for the IMU-based Kalman filter method (IMU) and the Video-based method (Video)

Among the IMU-based approaches, the Kalman filter method shows superior performance for the analysed test set. The proposed extended image processing approach – including parameter optimisation – reaches a similar performance level and outperforms its original version.



Results of the CMA-ES optimisation with selected histogram resolutions ($0.25° – 4°$) for the original (left) and extended approach (right).

- IMU-based and video-based method perform on par.
- Note: Both produce largest errors in different situations.
- Averaging of the two estimates already increases performance.
- Elaborate fusion is expected to yield further improvements.

method / sequence	I	II	III
Vision – original	3.57	5.48	3.60
Vision – new	2.24	2.78	2.26
IMU – Combined filter	3.75	4.06	3.73
IMU – Kalman filter	2.01	2.23	2.04
Mean Vision / IMU	1.20	1.37	1.68

Results (RMSE) for three dataset given in degree.

⇒ Examining the fusion of the independent approaches in the context of everyday traffic environments is planned for future research.

References

[1] M. Schlipsing, J. Schepanek, and J. Salmen, "Video-based roll angle estimation for two-wheeled vehicles," in *Proceedings of the IEEE Intelligent Vehicles Symposium*, 2011, pp. 876–881.

[2] P. Seiniger, H. Winner, K. Schröter, F. Kolb, A. Eckert, and O. Hoffmann, "Development of a roll angle sensor technology for future brake systems," in *Proceedings of the International Motorcycle Conference*, 2006, pp. 369–388.

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