High Precision Outdoor and Indoor Navigation for Autonomous Vehicles

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1. Problem statement

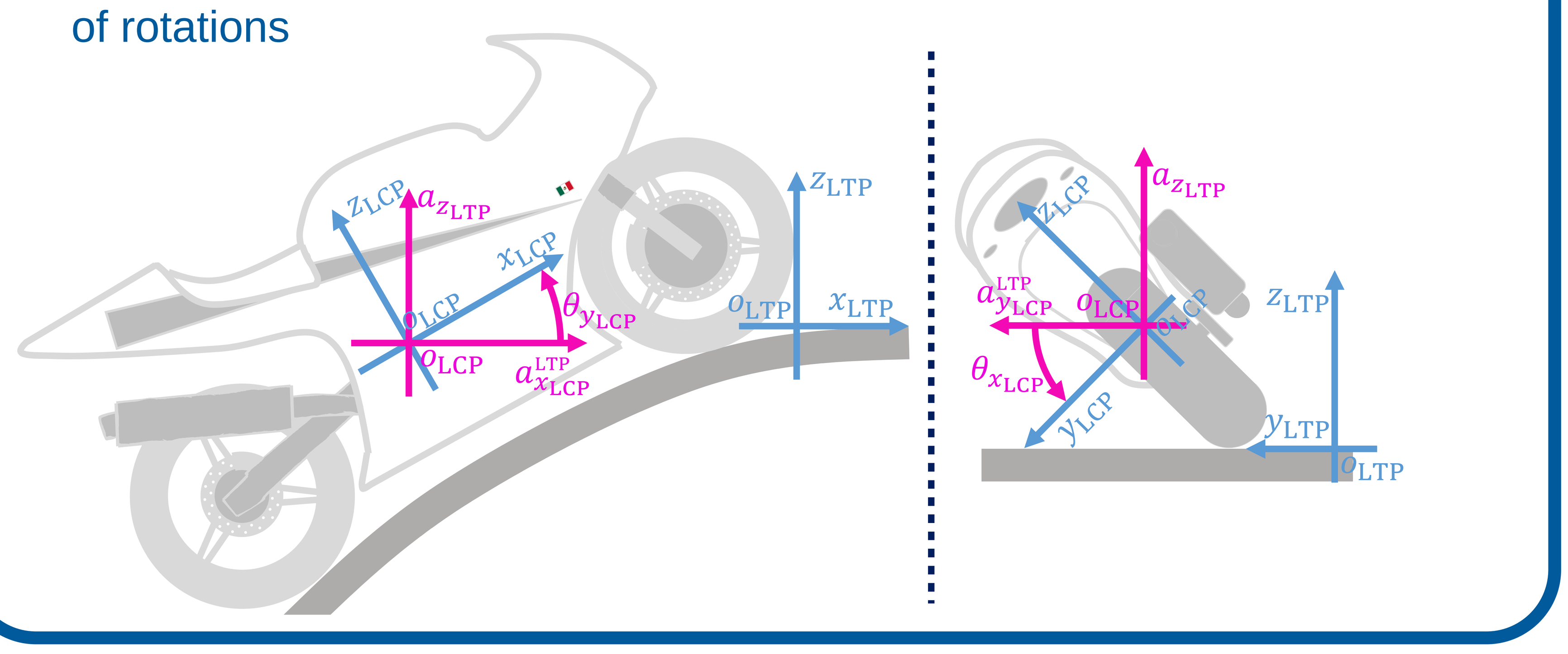
- Satellite navigation systems are widely accepted references, but they are not available at all times
- Temporary interruptions might occur due to tunnels or parking houses, for example
- Some testing setups allow no satellite navigation to be used, such as closed test halls

2. Proposed solution

- To combine three satellite-independent methods for a precise vehicle state estimation:
  1. A machine learning-based standstill classification
  2. A statistical filter for motion prediction
  3. A LiDAR-based Positioning Method (LbPM) for correction data

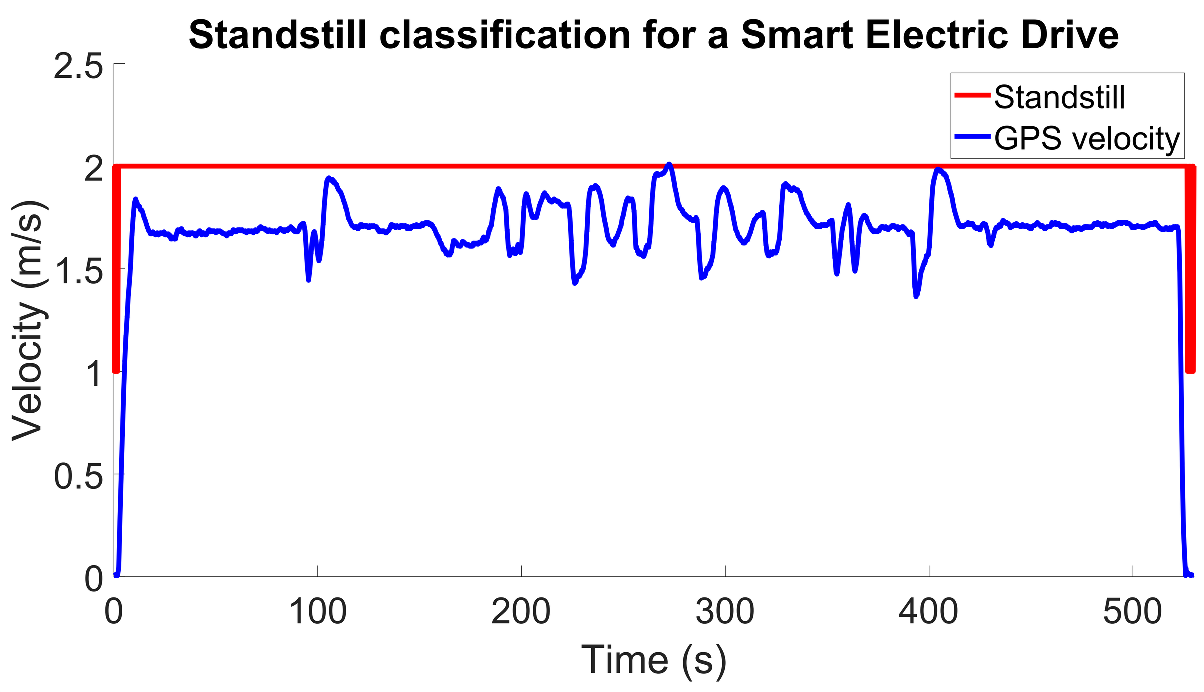
3. Horizontation of IMU measurements

- With an IMU mounted on the vehicle, to horizontate is to project the IMU measurements on a Local Tangent Plane (LTP) as if the (x,y)-plane of the vehicle reference frame was parallel to the (x,y)-plane of the LTP.
- It is done by tracking the axes of the LTP with respect to the Local Car Plane (LCP)
- It is initialized at standstill by using the accelerometers of the IMU
- It is updated when the vehicle is in motion by integrating the composition of rotations



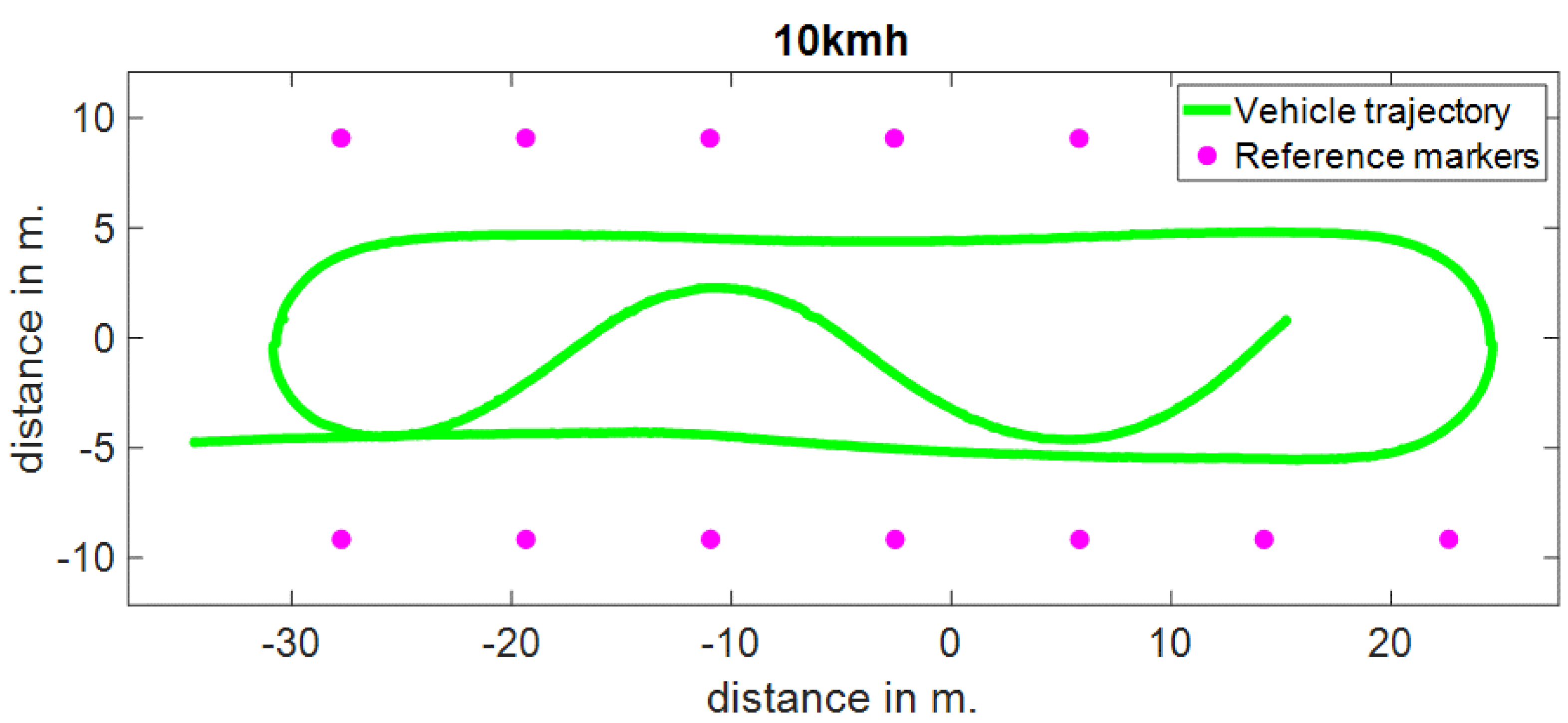
4. Standstill classification

- Achieved by means of a Random Forest (RF)
- With ~10 minutes of training data
- Features in the time and frequency domain are generated
- The classification proves to be robust for all tested vehicles: gasoline, diesel and electric cars, as well as gasoline motorcycles



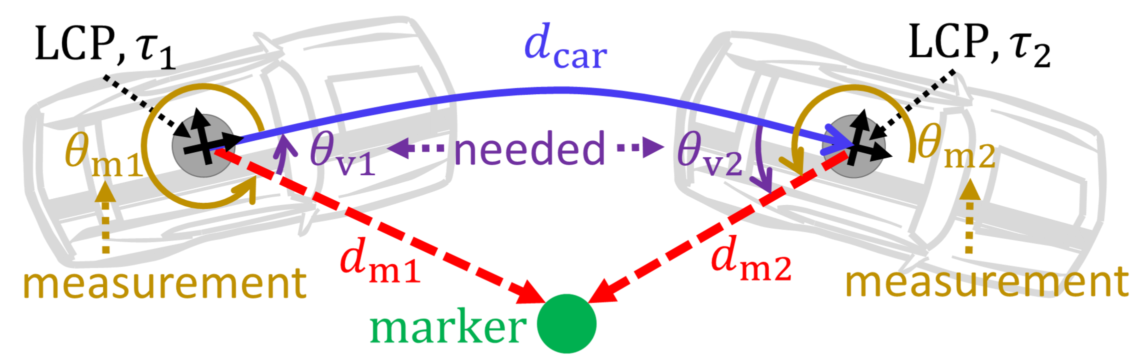
5. Vehicle motion prediction

- Achieved by means of an Extended Kalman Filter (EKF)
- Using the inertial measurements as inputs for the motion model

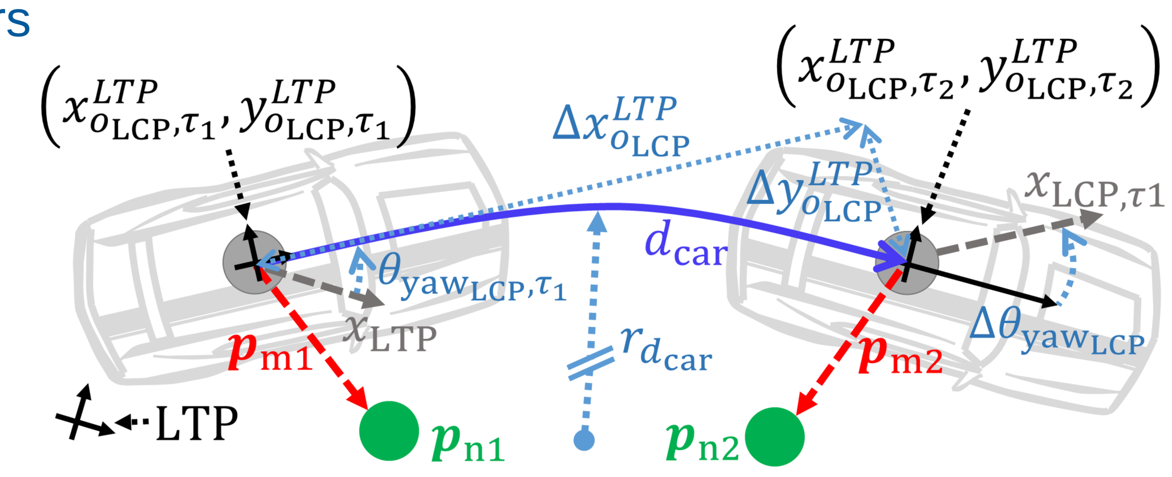


6. LiDAR-based Positioning Method (LbPM)

- For estimating the vehicle state, two LiDAR measurements from two different time instances are required
- The velocity is estimated by generating a cone shape from two measurements pointing to the same marker



- For the pose estimation (position and orientation), the measurements have to point to different markers
- The position is back-calculated from the relative position to the markers



- For evaluating the LbPM, a drive by and a slalom are driven with velocities varying from 5 km/h and up to 40 km/h
- The precision results of the LbPM closely approximate the precission of the reference
- For analyzing real-time implementation possibilities, the runtime of the LbPM is measured with the Matlab Profiler
- Matlab and Mex codes are evaluated

Quantity	Mean error
Position	4.7 cm
Orientation	1 °
Velocity	0.1 m/s

LbPM precision when compared to an INS

Estimation	Code type	Median runtime
Velocity	Matlab	11.32 μs
Velocity	Mex	20.76 μs
Pose	Matlab	42.66 μs
Pose	Mex	20.01 μs

Runtime performance on an Intel i7-6820HQ CPU

7. Method evaluation

- All presented methods are evaluated by using an ADMA G-Pro+ as reference
- The ADMA G-Pro+ is an Inertial Navigation System (INS) that integrates servo-accelerometers, optical gyroscopes, and GPS correction data with Real-Time-Kinematic (RTK)
- The typical precision of this INS is 2 cm in position, 0.01° in orientation and 0.03 km/h in velocity

8. Conclusion

- A LiDAR-based Positioning System is presented
- The LbPM is evaluated using an ADMA G-Pro+ as a reference
- The LbPM shows a high accuracy for estimating the position, orientation and velocity of the test vehicle
- Runtime measurements indicate the possibility of real-time implementation of the LbPM