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A Method for Lean Angle Estimation of Motorcycle Riders via Factor-Graph-Based Integration of Onboard GNSS/IMU

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Understanding rider posture during cornering is important for analyzing motorcycle dynamics and riding skill. Among posture-related variables, rider lean angle, defined as the relative inclination of the rider with respect to the motorcycle body, is particularly useful for describing how the rider balances the vehicle during turning. Existing approaches to rider posture estimation often rely on cameras or body-mounted sensors, which may reduce practicality in real riding environments. This study investigates a method for estimating rider lean angle using only onboard sensors.

The method is formulated using factor graph optimization with onboard GNSS and IMU measurements. The main idea is not the GNSS/IMU integration itself, but the introduction of rider lean angle as an additional parameter in the factor graph. Because rider lean angle cannot be directly measured by onboard sensors, a pseudo-observation is defined from IMU acceleration under simplified assumptions, including flat road conditions and no sideslip during steady turning. Under these assumptions, the lean angle observation is obtained from the lateral and downward acceleration components in the body frame. This pseudo-observation is incorporated into the graph together with GNSS position and velocity factors and IMU preintegration factors.

Simulation experiments were conducted for a steady-state circular turn after an initial stationary period. The proposed method achieved a mean absolute error of 0.47 deg and an RMSE of 0.61 deg, satisfying the target accuracy of 0.7 deg. These results indicate that the proposed formulation can estimate rider lean angle with sufficient accuracy under the assumed conditions.

The method was also applied to real riding data acquired with a Yamaha MT-25 and a professional rider. Although some differences in estimated lean-angle distributions were observed among instructed riding postures, absolute accuracy could not yet be evaluated because ground-truth posture analysis has not been completed. Therefore, the real-data results are presented as a feasibility study and as a basis for discussing remaining challenges, including model extension for straight and transient riding conditions.Because the proposed method is formulated using factor graph optimization, it has high extensibility for incorporating additional observations and constraints, and its usefulness is expected to become even more evident as the model is extended to a wider range of riding conditions.

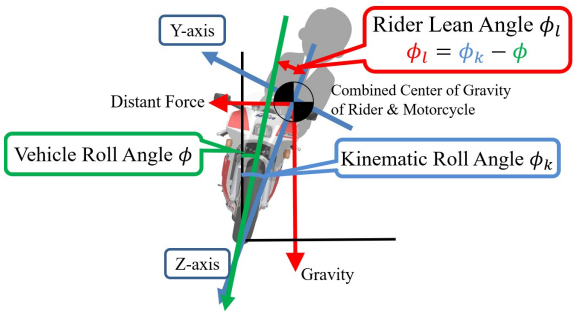

Fig.1 Motorcycle and Rider Posture During Cornering

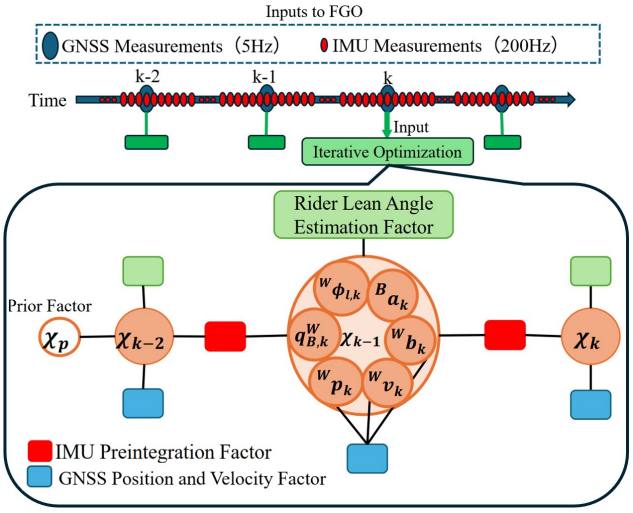

Fig.2 Factor Graph Structure of the Proposed Method

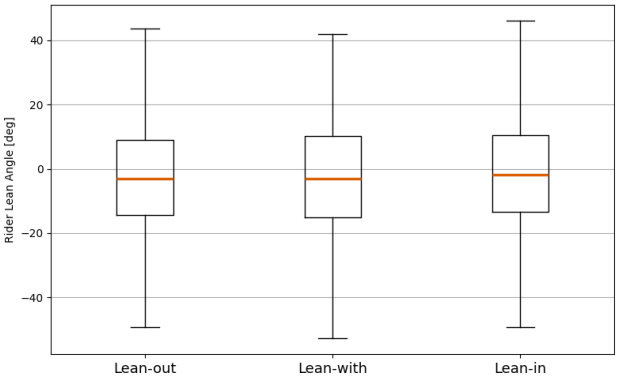

Fig.3 Estimated Rider Lean Angle Over the Entire Course for Each Rider Lean Posture ([deg])