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Theme

A Physics-Informed Neural Network Approach for GNSS-Denied Navigation

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Abstract

Continuous and accurate self-localization is a prerequisite for autonomous ground vehicles, yet the Global Navigation Satellite System (GNSS) on which absolute positioning relies is frequently degraded or unavailable in urban canyons, tunnels, and other obstructed environments. During such outages, a vehicle must fall back on proprioceptive and exteroceptive sensors whose estimates drift without bound or fail under adverse conditions, which makes robust GNSS-denied navigation a central open problem.

This thesis presents a comprehensive review of the state of the art in GNSS-denied vehicle localization, with a focus on physics-informed neural networks (PINNs) as a means of constraining inertial drift. The review first characterizes the GNSS-denied navigation problem and its causes, then surveys the principal families of solutions — inertial dead reckoning, visual odometry and SLAM, LiDAR and radar methods, nonlinear observers, and multi-sensor fusion — analysing their training paradigms, sensor requirements, error behaviour, and reported performance. It then examines the emergence of PINNs in scientific machine learning and their recent application to navigation and control.

The reviewed literature indicates that purely data-driven and purely model-based estimators each face structural limitations, and that embedding physical law into a learned model can suppress long-term drift while retaining the adaptability of data-driven methods. The analysis also shows that modular sensor-fusion architectures built around the Extended Kalman Filter can sustain localization through GNSS outages, but typically bridge those outages with raw visual odometry. Based on the identified gaps, the thesis positions a grey-box PINN — a learned inertial-bias model coupled to a hard-coded kinematic integrator — that dead-reckons position during GNSS outages and substitutes for the GNSS measurement within an EKF fusion update.

Keywords — GNSS-denied navigation, vehicle localization, physics-informed neural networks, PINN, inertial navigation, dead reckoning, visual odometry, high-gain observer, Extended Kalman Filter, sensor fusion.