NIS-Based Adaptive Soft Weighting and Crowd-Flow Hidden-Risk Inference for Earlier Warning of Occluded Static Hazards

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Conventional navigation aids for the visually impaired often suffer from estimation errors during non-linear maneuvers and fail to detect hazards obscured by crowds or corners. This study proposes an integrated walking assistance system that enhances tracking stability and anticipates both visible and hidden static risks. The system maps detected objects from RGB-D inputs into a Bird's Eye View (BEV) space. To balance stability and responsiveness, Kalman Filter (KF) and Unscented Kalman Filter (UKF) are executed in parallel. An adaptive soft-weighting mechanism based on Normalized Innovation Squared (NIS) dynamically fuses these filters via covariance intersection, maintaining linear stability while ensuring high-fidelity tracking during sudden turns. Simultaneously, the system infers "hidden risk confidence" by analyzing crowd-flow patterns—such as detours, decelerations, and bifurcations—to predict unseen obstacles behind occlusions. These insights are integrated into a unified, interpretable BEV risk map. In evaluations across diverse scenarios (e.g., evasion, cornering, and crowded environments), the proposed method reduced position estimation error by 12.8% compared to baseline models. It achieved an average early warning lead time of 1.0 second, a hidden risk inference accuracy of 78.4%, and a directional warning accuracy of 85.6%, with a low false alarm rate of 9.7%. By synergizing adaptive dual filtering with behavioral crowd analysis, this research provides a robust framework for real-time, preemptive navigation, significantly enhancing the safety and autonomy of visually impaired pedestrians.

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