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GNSS/UWB/VIO INTEGRATION FOR PRECISE AND SEAMLESS ROBOTIC LOCALIZATION

Liu Tianxia

Supervisor: Prof. Dr. Wu Chen, The Hong Kong Polytechnic University
Prof. Dr. Bofeng Li, Tongji University

Institutions: The Hong Kong Polytechnic University and Tongji University

ABSTRACT

Autonomous mobile robots are becoming increasingly prominent in modern societies, revolutionizing various industries with their wide-ranging applications. To ensure precise autonomous operations, seamless localization with centimeter to decimeter level accuracy is required. However, the complex urban environments and the equipment of low-cost devices pose significant challenges in achieving reliable and accurate robotic localization. In this thesis, a multi-sensor integrated seamless positioning system combining low-cost GNSS, UWB, MEMS IMU, and stereo cameras is developed to enhance robotic localization in urban environments. The core idea is to first improve absolute ranging accuracy and continuity, thus ensuring globally precise positioning. Then, incorporate relative positioning sensors to enhance performance in highly obscured environments.

To improve UWB ranging performance in large-scale indoor scenarios, two innovative techniques for UWB systematic error mitigation are proposed. Firstly, an antenna phase center offset (PCO) calibration model is established with respect to the tag-to-anchor elevation angles to reduce the remaining PCO effects in UWB TDOA measurements. Secondly, to mitigate the unmodeled environmental errors introduced by time latencies calibrated at a single point, a multipoint time latency determination (MTLD) method is proposed to provide precise time latencies over a large area. The results show that the established PCO calibration model can correct the PCO errors by 70% in TOA measurements. The accuracy of time latency determination is improved by 10% with MTLD, and further by 44% with both MTLD and PCO calibration.

To improve GNSS positioning continuity in urban environments, a cycle slip estimation method with position polynomial fitting (PPF) constraint is proposed. It is dedicated to avoiding the frequent ambiguity re-fixing in RTK positioning through efficient cycle slip repair. As for applications using low-cost GNSS receivers, the conventional measurement polynomial fitting (MPF) and triple differenced residual-based snooping (TRS) methods fail in continuous and multiple cycle slips cases, while the geometry-based (GB) method exhibits low cycle slip repair success rates. Motivated by the principle that a more accurate prior baseline contributes more efficient cycle slip estimation, the new method imposes a precisely formed positional constraint into GB model to enhance cycle slip estimation. The results show that PPF improves the success rates of cycle slip repair and ambiguity resolution by 25.7% and 62.4%, 40.1% and 46.5%, respectively, compared with TRS and MPF.

To further improve GNSS positioning in highly obscured environments, a tightly coupled (TC) GNSS/VIO integration algorithm with VIO-aided cycle slip estimation is proposed. Considering that VIO provides accurate relative pose with less drifts, the new method introduces VIO-predicted baseline constraint into the GB model to further enhance cycle slip estimation. The method is implemented in a TC algorithm of GNSS RTK and VIO integration. The results show that it can repair cycle slips after 10s~60s GNSS data gaps, in which PPF and MPF are unavailable. Compared with the measurement-based MVIO, and the INS-aided MINS and GINS, the positioning accuracy of the proposed algorithm is improved by 26.2%, 65.9%, and 57.4%, respectively.

To enhance seamless urban positioning, a GNSS/UWB/VIO integration system is developed. An EKF-based TC framework includes the main aspects of system initialization, decentralized filter updating, and quality control is designed. A synchronous platform and a ROS package are developed for multi-sensor data collection and processing. Real-world tests show that the developed system achieves 0.411m and 0.077m horizontal positioning in complex outdoor and indoor environments, yielding 71.2% and 18.1% improvements compared with the traditional loosely coupled schemes, which can fulfill the requirements of precise robotic localization in seamless urban environments.