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Smartphone precise positioning in urban environments using internal GNSS and IMU sensors

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Abstract

The last decade has seen the modernization of Global Navigation Satellite Systems (GNSS) and the proliferation of multi-constellation, multi-frequency GNSS chipsets. This progress has boosted the surge of GNSS-enabled handsets and revolutionized receiver industries and Location-Based Services (LBS) for mass-market applications. These applications, including autonomous driving, social networking, health tracking, and personal/property security, increasingly demand higher levels of user positioning accuracy and reliability. In this context, a fundamental push for smartphone positioning came in 2016 after Google released the Android 7.0 platform, allowing users and developers the capability to access GNSS raw measurements, including carrier-phase observations, catalyzing the progress of smartphone precise positioning using Real-Time Kinematic (RTK) and Precise Point Positioning (PPP) technologies. However, challenges such as high received signal noise, limited multipath suppression capabilities, and frequent signal losses are prevalent in smartphone-grade GNSS receivers and antennas. These factors notably degrade the performance of smartphone positioning for precise applications.

In response to these challenges, this dissertation is dedicated to addressing these smartphone positioning limitations and aims to provide accurate, continuous, and resilient Positioning, Navigation, and Timing (PNT) solutions with a developed smartphone processing software. Given that ionospheric refraction at GNSS signals is a significant error source impacting the accuracy of, e.g., PPP solutions, this research commences with an investigation of smartphone PPP performance with external ionospheric constraints. To utilize smartphone observations effectively, a novel PPP algorithm tailored for smartphone navigation is introduced. Further, this algorithm utilizes GPS, Galileo, GLONASS, and BeiDou single- and dual-frequency observations, while also integrating pseudorange-only measurements in scenarios where carrier-phase measurements are missing. Moreover, to overcome limitations in both the PPP and RTK techniques, a novel PPP/RTK hybridization algorithm with smartphone inertial measurement unit (IMU) integration is proposed. Validated through a series of vehicle experiments conducted in realistic driving environments, the enhanced GNSS/IMU smartphone positioning algorithm was evaluated across various urban multipath scenarios, including open-sky

highways, vegetation roads, suburban roads, and underpasses. The results demonstrate a substantial improvement in reducing horizontal root mean square error (rmse), reducing it from approximately 10 m to less than 1.5 m compared to traditional Single Point Positioning (SPP) solutions, showing a noteworthy advancement in smartphone positioning capabilities.

Additionally, this research explores the utilization of the available Galileo HAS corrections for smartphone navigation. To fully leverage all available smartphone measurements and orbit and clock information directly from satellites, this research combines the corrections with broadcast ephemerides for smartphone PPP processing (HASandBRDC PPP). Investigated through vehicle experiments, the results show that the proposed HASandBRDC PPP solutions are highly comparable to PPP solutions utilizing Centre National d'Etudes Spatiales (CNES) ultra-rapid products with four GNSS constellations, achieving approximately 1.5 m of positioning performance. This finding underscores the great potential of real-time smartphone applications in pelagic and mountain areas with limited Internet connectivity.

Keywords: GNSS; Smartphone; PPP; PPP/IMU; Ionospheric constraints; Pseudorange enhancement; PPP/RTK Hybridization; Galileo High Accuracy Service; Urban environments