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# Integer Ambiguity Resolution for Smartphone based multi-GNSS data

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## Abstract

Smartphones are integrated with consumer-grade GNSS chips and inertial sensors, providing an effective research platform for tapping the potential of miniaturized, low-cost sensors for high-precision positioning. However, for the GNSS observations of smartphones, phase biases generated by the low-cost GNSS chips and severe multipath errors introduced by the embedded antenna, resulting in unresolved carrier phase ambiguity.

To solve these problems, this dissertation conducts an in-depth study on the key technologies of GNSS ambiguity resolution and other high-precision positioning for smartphones. The error characteristics of smartphone GNSS observations were analyzed, the carrier phase bias estimation method and multipath mitigation method were proposed, and the smartphone GNSS centimeter-level ambiguity-fixed solutions were obtained. Based on this, we further explored methods such as synchronous integration of smartphone GNSS with the accelerometer, and obtained higher precision and higher resolution positioning results. As a result, the feasibility of centimeter-level high-precision positioning using consumer-grade GNSS chips, antennas and inertial sensors embedded in smartphones was demonstrated. Meanwhile, these works can provide theoretical methods and technical support for high-precision positioning using miniaturized, low-cost GNSS and inertial sensors.

Chapter 1 provides an introduction to this thesis.

Chapter 2 presents the basic GNSS positioning theory such as functional model, stochastic model, estimator and ambiguity resolution methods.

In Chapter 3, the quality and error characteristics of recent smartphone multi-GNSS observations are systematically analyzed. Some error characteristics that distinguish survey receivers, such as low signal strength, uneven gain, a weak correlation between signal strength and elevation, frequent cycle slips, and high observation noise, have been found. In addition, duty-cycle, anomalous “jagged” distribution phase error, clock misalignment, and inconsistent pseudorange and phase clock issues in smartphone GNSS observations have also been identified. In addition, the theoretical parameters of the noise versus $C/N_0$ model are provided for different smartphones GNSS chipsets.

The next two chapters, Chapters 4 and 5, form two important parts of this thesis. The first one deals with the phase bias problem generated by the smartphone GNSS chip in Chapter 4. The second one deals with the severe multipath error issue introduced by the embedded antenna of the smartphone.

In Chapter 4, a double-difference carrier phase bias

and inter-frequency phase bias (IFB) rate extraction method based on the zero/short baseline is proposed. By using this method, the phase biases and the phase IFB rate inconsistent issues of smartphone GNSS observations are found. To solve this problem, a gain filtering-based online phase biases correction method is proposed, and the dual-frequency and full-constellation GNSS ambiguity resolution for the smartphone is implemented.

Two multipath mitigation methods are proposed in Chapter 5. One method is based on the stochastic model compensation of double-difference code-minus-carrier combined observations, and the other method combines stochastic model compensation and functional model correction. Based on these methods, dual-frequency and multi-system GNSS ambiguity resolution is implemented on the smartphone using its embedded GNSS antenna.

Chapter 6 conducts an application study of high-precision broadband positioning based on consumer-grade GNSS chips and accelerometers using smartphones as the research platform. A method to synchronize and integrate Android GNSS with accelerometer data and a single-receiver GNSS/acceleration tight integrated positioning method based on inter-satellite difference are successively proposed. Experimental results show that smartphones using these methods can capture broadband vibrations at centimeter resolution.

Chapter 7 summarizes the thesis and provides an outlook for future research.