ABSTRACT

Modern geospatial data acquisition systems enable high spatial and temporal resolution mapping at a reasonable cost by integrating complementary camera and Light Detection and Ranging (LiDAR) sensors to capture both spectral and geometric information. Based on platform mobility, these systems can be broadly categorized into static mapping systems, such as indoor portable systems, and Mobile Mapping Systems (MMSs), including Uncrewed Aerial Vehicles (UAVs) and backpack-based platforms. The effective use of multi-modal data from these systems depends on positional accuracy. For MMSs operating in outdoor environments, georeferencing is typically provided by onboard Global Navigation Satellite System/Inertial Navigation System (GNSS/INS) units. However, emerging applications might require MMSs to operate in GNSS-challenging environments, such as under-canopy forests. Similarly, static mapping systems often operate indoors with no access to GNSS signal. Beyond georeferencing limitations, positional accuracy is also affected by errors in the system calibration parameters, including sensor Interior Orientation Parameters (IOP) and mounting parameters. The objective of this dissertation is to address these sources of positional error and deliver accurately positioned geospatial data.

This dissertation addresses the misalignment problem in heterogeneous geospatial data by organizing the analysis around three key factors: 1). system calibration status and 2). trajectory quality that induces misalignments, as well as 3). mapping environment that provides features for enhancing the alignment. Different combinations of the three factors lead to distinct scenarios and require different alignment strategies. Four representative scenarios are investigated. The first scenario focuses on UAV system calibration in urban environments, where GNSS/INS trajectories are reliable but the camera–LiDAR system is uncalibrated. For this case, a calibration framework is developed using planar features with adjusted point distributions to account for site characteristics, LiDAR scanning patterns, and flight configurations. The second scenario involves indoor portable system mapping in dome-shaped facilities, where the camera–LiDAR system is pre-calibrated but GNSS is unavailable. In addition, conventional planar and linear primitives are largely absent in dome-shaped facilities. For this case, image information is used for coarse point cloud alignment, followed by refinement based on quadratic surfaces and curves. The third scenario involves multiple platforms, including UAV, backpack, and indoor portable systems, operating across diverse environments such as islands, forests, and barn-shaped facilities. Here,

misalignment is caused by both outdated camera–LiDAR calibration and inaccurate GNSS/INS trajectories. For this general case, a universal image–LiDAR alignment enhancement framework is developed using planar features from different environments. The fourth scenario involves backpack mapping in under-canopy forests, where canopy occlusion induces trajectory errors and camera–LiDAR calibration may become outdated during transportation and handling. This environment also contains cluttered geometry and weakly distinctive features. For this case, a forest-specific image–LiDAR alignment framework is developed using tree trunks and primary branches as semantic features. Together, these studies establish a dissertation framework for addressing geospatial data misalignment under varying georeferencing conditions and for generating accurate mapping products.