ABSTRACT

Mobile LiDAR mapping systems (MLMS) are rapidly gaining popularity for a multitude of applications due to their ability to provide complete and accurate 3D point clouds for any and every scene of interest. The key sensors constituting an MLMS are LiDAR and GNSS/INS. Obtaining accurate 3D point clouds from a sensor suite onboard any MLMS is contingent upon two major components: (a) accurate system calibration and (b) accurate GNSS/INS trajectory information. This dissertation addresses both these components for any MLMS irrespective of the utilized platform (airborne or terrestrial), LiDAR scanning mechanism (3D spinning multi-beam or 2D profiler), and/or environmental factors causing GNSS/INS trajectory quality deterioration.

The MLMS calibration and GNSS/INS trajectory enhancement strategies proposed in this dissertation rely on optimization frameworks to derive the best solution, which is most frequently addressed using Least Squares Adjustment (LSA) models. Such optimization problems pertaining to the field of geomatics (especially, the research presented in this dissertation) result in scenarios involving a rank-deficient weight matrix that causes complications in finding the solutions based on existing LSA models. So, this dissertation starts by proposing an approach to solve the widely encountered problem of rank-deficient LSA models. The proposed solution is then applied to the optimization problems formulated in this dissertation for MLMS calibration and trajectory enhancement.

Next, this research addresses the approaches for accurate system calibration of MLMS with two different types of onboard LiDAR units – (a) spinning multi-beam LiDAR units and (b) 2D profiler LiDAR units. A fully automated profile-based calibration strategy is proposed and validated for MLMS with spinning multi-beam LiDAR units. The major contribution of the proposed calibration strategy is its ability to calibrate airborne and terrestrial MLMS without any requirement for specially designed targets or features in the surrounding environment. For calibration of MLMS with 2D profiler LiDAR units, configuration preferences in terms of LiDAR mounting orientation, target primitives as well as drive-runs are deduced based on a theoretical bias impact analysis while taking into account the practical challenges and shortcomings of the data acquisition from such systems.

For a well-calibrated MLMS, the accuracy of mapping products is influenced by the GNSS/INS trajectory quality. The quality of GNSS/INS trajectory could deteriorate due to

intermittent or complete GNSS signal loss in forests (canopy cover), transportation corridors (roadside vegetation and overhead bridges), and indoor environments (complete GNSS signal loss). In order to generate highly accurate mapping products from MLMS under such GNSS-challenged and GNSS-denied environments, we propose a strategy to enhance the quality of post-processed GNSS/INS trajectory by leveraging information embedded in the 3D point cloud obtained from onboard LiDAR sensor(s). The approach utilizes readily available entities in the surroundings that can be treated as geometric features during trajectory enhancement. This dissertation mainly focuses on forest environments for this investigation where terrain patches and tree trunks are used as planar and cylindrical features, respectively.

The proposed MLMS calibration and GNSS/INS trajectory enhancement strategies, while relying on LSA models with rank-deficient weight matrix, are proved experimentally to produce highly accurate 3D point clouds irrespective of the mobile mapping platform, LiDAR scanning mechanism, and/or environmental factors impacting the GNSS/INS trajectory quality.