# Abstract

Laser scanning is a widely-used surveying technique for measuring and recording the geometry of our environment, which is represented as a three-dimensional point cloud consisting of billions of individual measurement points. By placing the laser scanner on a moving platform, e.g., a car or airplane, large areas can be mapped efficiently. Laser scanning combines laser ranging with a scanning mechanism, which varies deflection and thereby direction of the laser beam and, together with the movement of the carrier platform, allows for 3D sampling of the environment. However, range measurements and beam direction alone only allow determining point coordinates relative to the laser scanner itself. The measurements must be georeferenced, i.e., transformed into an earth-fixed coordinate system, before further use. For this, the position and orientation of the laser scanner with respect to the earth-fixed coordinate system is required. Laser scanning systems therefore comprise auxiliary navigation sensors, most commonly an inertial measurement unit (IMU) consisting of accelerometers and gyroscopes, and a global navigation satellite system (GNSS) receiver and antenna. With inertial navigation and global satellite navigation, the laser scanner's trajectory (position and orientation over time) can be determined and used to georeference the point cloud. In practice, the trajectory estimated via fusion of IMU and GNSS measurement data contains errors that, through georeferencing, consequently cause errors in the point cloud. If an area is scanned multiple times from multiple locations, these errors become apparent as discrepancies between the corresponding point clouds. The standard procedure for georeferencing of laser scanning data thus consists of two steps, first estimating the trajectory from inertial and satellite navigation data, and then subsequently improving this trajectory by minimizing discrepancies in overlapping point clouds or between point cloud and reference data. In this thesis, a holistic approach to trajectory estimation is presented which improves the georeferencing of laser scanning data by unifying these two steps and incorporating both laser scanning data and navigation data together in one non-linear least-squares adjustment.

This is a cumulative thesis consisting of three peer-reviewed journal articles. The first article surveys related literature on trajectory estimation, focusing on integration of satellite and inertial navigation with imaging sensors, and proposes a unified trajectory estimation framework based on maximum a-posteriori estimation. The second article presents a practical implementation thereof, realized as non-linear least-squares estimation, which is demonstrated and evaluated by jointly co-registering simultaneously acquired laser scanning data from crewed aircraft and uncrewed aerial vehicle. The third article improves on this approach by employing an iterative downsampling strategy for the inertial measurements which increases computational efficiency by reducing the number of parameters and measurements in the adjustment, while preserving accuracy and precision even in the presence of high-frequency vibrations. Apart from the journal articles, specific aspects of the proposed approach are evaluated in a number of use-case examples detailed in conference publications, which serve as additional validation. Overall, it is demonstrated that the proposed approach is applicable to a wide range of system set-ups and application scenarios, and delivers precise point clouds with a high degree of automation and reliability.