

**On the Issues of Localization and Mapping in Outdoor  
Unstructured Environments for Mobile Robot Navigation**

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# Summary

The localization information is of paramount importance in several critical tasks such as path and mission planning and control, which are essential to achieve fully autonomous operation of mobile robots. Data association, use of multiple sensors, their fusion and effects of exteroceptive and proprioceptive sensor biases are identified as major issues that affect the performance of robot localization and mapping in outdoor unstructured environments. The importance of addressing these issues is justified using a comprehensive literature review and a discussion.

A generalized sliding window framework utilizing multiple measurement frames is established for the data association in robot navigation applications. It is argued that the feature extraction is a dimensionality reduction and a data compression technique for the data association framework. The issues pertaining to conditional measurement independence are then investigated in the context of the data association problem in Simultaneous Localization and Mapping (SLAM), Map Aided Localization (MAL) and Robotics Mapping (RM). Multi-frame sliding window algorithms for data association are synthesized for SLAM, MAL and RM for the first time using the conditional measurement independence assumption. However, when the vehicle uncertainty is large and the feature density is very high in the context of SLAM and MAL one cannot ignore the effects of strong spatial correlations on the measurements. Under such circumstances conditional measurement independence assumption does not hold. Thus, a new multiple frame temporal consistency criterion (MFTC) algorithm is synthesized for the multi-frame data association in SLAM and MAL relaxing the conditional measurement independence assumption. This method, which is an extension of batch data association methods over multiple temporal frames, incorporates both spatial and temporal correlations inherent to SLAM in the data association process. The search for the correct association is carried out using an interpretation tree search over multiple temporal frames. These multi-frame algorithms are shown to be robust to spurious measurements and clutter present in outdoor and dynamic environments. It has also been demonstrated that the multi-frame data association algorithms are more robust than the existing single frame data association algorithms used for mobile robotics applications in outdoor unstructured environments. Several simulations and experiments were conducted to ascertain the performance of the multi-frame sliding window data association algorithms developed.

The use of multiple sensors in SLAM and approaches in sensor fusion and integration in outdoor environments are investigated. It is established that the group sensor fusion architecture is theoretically sound in multi sensor fusion in SLAM where strong correlations exist. A fully operational system, which is able to perform SLAM using the fusion of range-bearing and bearing only information, is demonstrated. A method of improving multiple sensor performance through information theoretic active sensor control strategy over a finite time window is formulated and verified using simulations.

The effects of exteroceptive and proprioceptive sensor biases, which adversely affect the data association problem, tracking accuracy, map convergence and localization accuracy and hence the performance of SLAM, MAL and RM in outdoor unstructured environments, are investigated. A rigorous theoretical discussion is presented on the estimation theoretic sensor bias correction problem in robot localization and mapping algorithms. The convergence properties of the bias estimates are derived and their lower bounds deduced. The observability properties of SLAM, MAL and RM problems with sensor bias correction are established. Remedies in the form of modified observation models are proposed for the partial observability problem. It was also verified using simulations and experiments that the inertial sensors can be utilized in SLAM and MAL with online bias correction effectively on the basis of the theoretical discussion.

Based on all the facts established it is argued that although the contribution by improving on a single issue affecting robot localization and mapping may not be very significant, the total contribution by improving on all the above issues pertaining to robot localization and mapping performance is substantial.