# Path Planning

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## 1 Introduction

While the current part carries the title "path planning" the contributions in this section covers two topics: mapping and planning. In some sense one might argues that intelligent (autonomous) mapping actually requires path planning. While this is correct the contributions actually have a broader scope as is outlined below. A common theme to all of the presentations in this section is the adoption of hybrid representations to facilitate efficient processing in complex environments. Purely geometric models allow for accurate estimation of position and motion generation, but they scale poorly with environmental complexity while qualitative geometric models have a limited accuracy they are well suited for global estimation of trajectories/locations. Through fusion of qualitative and quantitative models it becomes possible to develop systems that have tractable complexity while maintaining geometric accuracy.

## 2 Chapters in the section

The paper by Fox et. al. [1] addresses the problem of simultaneous localisation and mapping (SLAM) from the point of view of place recognition. The approach adopted here is that of place recognition. The ability to perform place recognition is crucial to localisation as at allow not only incremental localisation but also absolute location estimation within a map of the environment. The unknown world is represented as a special class which allow for recognition of "out-of-map" locations that must be added to the map. To allow for such an approach the authors adopt a patch based map representation. In principle a map is represented as a graph of patches that have been explored before. A diraclet probability model is used for each of the patches and the robot position is estimated across a family of distributions. When / if a place is not recognized a new patch is added to the map. The adopted model allows for efficient localisation and map updating, as map complexity is in terms of the number of graph nodes (patches) rather than the full set of map features as is used in a full geometric map. The presented methodology is demonstrated in the case of multi-robot localisation. In addition it is introduced how the the place recognition also can be used to address the loop-closing problem, another of the open problems in SLAM.

The second paper by Kelly and Unnikrishnan [2] addresses the closely related problem of loop closing. A major challenge in localisation and mapping is computational complexity in terms of map size. For the problem of closing loops the entire representation for a loop must be considered to determine when a robot has arrived at an earlier visited location. When a purely geometric map is used the full set of features has been maintained over time which poses a challenge. To avoid this problem the authors have chosen to adopt a hybrid representation in which the global layout of the environment is encoded as a topology graph (a set of regions/places). Within each region a geometric map is maintained. The analysis of the global environmental layout is achieved through use of constraint optimization, a well known branch of optimization. The use of a hybrid representation implies that the complexity of the map updating is reduced to the $O(places)$ which is manageable. The presented approach is evaluated for localisation and mapping using a LADAR system for estimation of the 2D layout of an environment. Through batch analysis of the LADAR data it is possible to achieve loop closing in which both the detailed geometry and the overall topology is updated to ensure map consistency.

Path planning in complex environment is known to computationally demanding. In the contribution by Akinc et. al. [3] the method of sampling based path planning is investigated. Recently two different approaches to sampling based planning have emerged: i) probabilistic roadmaps and ii) rapidly exploring random trees. In this paper the two methods are combined. Through combination of the bottom up generation of trees with top-down sampling of roadmap it becomes possible to address issues that earlier have been intractable. At the same time the methodology allows for easy distribution onto a network of processors for parallel computing of trajectories. Multiple queries can easily be handled with a need for full recomputation. A number of problems that earlier have proven intractable in single CPU systems are reported to demonstrate the utility of the hybrid approach.

An alternative approach to design of efficient motion planning strategies has been use of Voronoi maps. The Voronoi map can in principle be divided into a graph representation (a topological map) for fast search and then subsequenlty refined, once a suitable overall plan has been hypothesised. In the work by Choset & Rizzi [4] a generalized Voronoi map is introduced and the associated algorithm for computation of such a representation is presented. Using the generalised Voronoi topological maps are computed. The new method is presented in the context of path planning and also as an methodology to perform hierarchical localisation and mapping. I.e., the hybrid representation allow for coarse to fine localisation, which results in efficient search.

In path planning there are in principle three options: i) geometric methods, ii) symbolic methods, and iii) a combination of i) and ii). When using option iii) the most common approach is to perform hierarchical planning in which the initial planning is performed using the symbolic representation, and then refined using a subset of the geometric map. In the paper by Gravot et. al. [5] a hybrid approach is also proposed, but the strategy is not purely hierarchical. A strategy is proposed in which it is possible to perform simultaneous localisation is both the geometric and the symbolic maps. The estimation of location in the map is achieved through use of constraint satisfaction techniques. The constraints considered are both in terms of task and geometry which allows for incremental search and efficient trajectory planning in the context of 3D motion planning. The developed methodology is exemplified for multi-robot motion planning is highly cluttered environments, which normally poses significant problems due to the need for scheduling and conflict resolution of shared "narrow corridors".

## 3 Summary

The papers in the present section illustrates in an interesting manner how significant progress can be achieved on problems that traditionally have been considered hard, through combination of multiple techniques to build hybrid algorithms, hybrid representations or multi-abstraction systems. The study of such hybrids requires both a solid understanding of the component problems/fields, and the ability to synthesize these methods into systems for optimized use.

## References

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