**Probabilistic Mapping of Spatial Motion Patterns for Mobile Robots**

av

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## Abstract

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To bring robots closer to real-world autonomy, it is necessary to equip them with tools allowing them to perceive, model and behave adequately to dynamic changes in the environment. The idea of incorporating information about dynamics not only in the robots reactive behaviours but also in global planning process stems from the fact that dynamic changes are typically not completely random and follow spatiotemporal patterns. The overarching idea behind the work presented in this thesis is to investigate methods allowing to represent the variety of the real-world spatial motion patterns in a compact, yet expressive way. The primary focus of the presented work is on building maps capturing the motion patterns of dynamic objects and/or the flow of continuous media.

The contribution of this thesis is twofold. First, I introduce Conditional-Transition Map: a representation for modelling motion patterns of dynamic objects as a multimodal flow of occupancy over a grid map. Furthermore, in this thesis I also propose an extension (Temporal Conditional-Transition Map), which models the speed of said flow. The proposed representations connect the changes of occupancy among adjacent cells. Namely, they build conditional models of the direction to where occupancy is heading given the direction from which the occupancy arrived. Previously, all of the representations modelling dynamics in grid maps assumed cell independence. The representations assuming cell independence are substantially less expressive and store only information about the observed levels of dynamics (i.e. how frequent changes are at a certain location). In contrast, the proposed representations also encode information about the direction of motion. Furthermore, the multimodal and conditional character of the representations allows to distinguish and correctly model intersecting flows. The capabilities of the introduced grid-based representations are demonstrated with experiments performed on real-world data sets.

In the second part of this thesis, I introduce Circular Linear Flow Field map modelling flow of continuous media and discrete objects. This representation, in contrast to the work presented in the first part of this thesis, does not model occupancy changes directly. Instead, it employs a field of Gaussian Mixture Models, whose local elements are probability distributions of (instantaneous) velocities, to describe motion patterns. Since it assumes only velocity measurements, the proposed representation have been used to model a broad spectrum of dynamics including motion patterns of people and airflow. Using a Gaussian Mixture Model allows to capture the multimodal character of real-world dynamics (e.g. intersecting flows) and also to account for flow variability. In addition to the basic learning algorithms, I present solutions (sampling-based and kernel-based approach) for the problem of building a dense Circular Linear Flow Field map using spatially sparse but temporally dense sets of measurements. In the end, I present how to use the Circular Linear Flow Field map in motion planning to achieve flow compliant trajectories. The capabilities of Circular Linear Flow Field maps are presented and evaluated using simulated and real-world datasets.

The spectrum of applications for the representations and approaches presented in this thesis is very broad. Among others, the results of this thesis can be used by service robots providing help for passengers in crowded airports or drones surveying landfills to detect leakages of greenhouse gases. In the case of a service robot interacting with passengers in a populated airport, the information about the flow of passengers allows to build not only the shortest path between points “A” and “B” but also enables the robot to behave seamlessly, unobtrusively and safely. In the case of a drone patrolling a landfill the impact of airflow, is equally significant. In this scenario, information about airflow allows harnessing the energy of airstreams to lower the energy consumption of a drone. Another way to utilise information about the wind flow is to use it to improve localisation of sources of gas leakage.