Spatial Motion Planning
for
Autonomous Mobile Agents

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Motion planning addresses the problem of finding a sequence of actions that move an agent from its current state to a desired one. Doing so entails finding the optimal set of commands according to a performance criterion, without compromising the dynamics and constraints of the system. Additionally, the spatial bounds resulting from the agent's coexistence with the environment in which it is deployed must also be considered.

Given its generality, the motion planning problem lies at the core of multiple technological advances upon which our society has depended for its evolution and refinement. Its presence across a wide range of scenarios, such as economic-growth associated with industrial and collaborative robots, advanced manufacturing capabilities in CNC machines, flexibility in goods transport by autonomous vehicles, higher health-care standards due to surgical robots or progress in space exploration, exemplifies the impact and relevance of the motion planning problem.

As other fields evolve, so does the complexity of the motion planning problem. On the one hand, advances in hardware increase the agility and robustness of the agents, expanding the reachable state-space and enabling faster and more aggressive motions. On the other hand, the disruption of Artificial Intelligence has led to breakthroughs in computer vision and sensor fusion, yielding unprecedented environment mapping capabilities. The full exploitation of these additional competences requires from richer, yet more complex, motion planners.

For example, until recently, industrial robots operated in isolated and highly monitored work environments, limiting their utility to repetitive tasks. We are already seeing how, due to the aforementioned advances, robots are being released from their cages and allowed to share the workspace with humans and/or other agents, resulting in more varied and flexible workflows, removing the need for additional infrastructure, and thus, democratizing the applicability of robots. This transition would not have been possible without advances in motion planning, which has ultimately provided robots with the ability to account for unexpected changes in the environment.

These achievements are the beginning of an infinite road in which the agent's agility and the environment's dynamicity may constantly be enhanced, making it difficult to define an upper bound on the complexity that the motion planning problem could reach. In the near future we will see this dilemma reflected in one of the most prominent, yet unsolved, challenges of this century: self-driving cars. The motion planner capable of driving through the relatively well-structured roads of the western world will have to be reformulated to account for the the chaotic traffic of some developing countries. If we ever get to this point, seeking to reduce commute time, we may raise the bar by requiring faster driving speeds, forcing us to reiterate, and thus, rendering the motion planning problem endless. This phenomenon applies to any of the aforementioned case-studies and exemplifies how the complexity of the motion planning problem can always be increased.

To account for the difficulty of the problem at hand, state-of-the-art approaches solve the problem in two separate stages. First the *path planning* stage determines a collision-free geometric path according to high level – task related – commands. Second, the predefined path is (exactly) tracked either by *path tracking* or *path following*. The former computes a dynamically feasible timing law for traversing along the predetermined path – *when* to be *where* –, while the latter introduces the timing law and the (bounded) distance to the path as control freedoms. Therefore, only if *both* stages are optimal will the resultant planned motion be optimal, implying that the decoupled nature of these methods jeopardizes the optimality of the resultant motions.

To overcome this shortcoming, my PhD research focuses on finding novel methods capable of *directly* computing optimal motions exclusively by relying on the environment's geometric properties. Shifting the focus from motion planning *around a path* to the *entire free space* is an appealing paradigm shift, since it allows to exploit not only the actuation of the system, but also the entire available free space.

For this purpose, the proposed algorithms aim to be developed based on the following four distinctive features: Firstly, given a desired performance criterion, the planned motions aim to be *optimal* by exploiting the agent's dynamic capabilities within the obstacle-free space without being biased by a higher level geometric reference. Secondly, the presented methods ought to be *universal* in such a way that they are applicable to any dynamic system or constrained environment. Thirdly, the computed trajectories must be *safe* by guaranteeing the integrity of the system's constraints and spatial bounds. Last but not least, the developed algorithms prioritize *efficiency* by attempting to be deployable in real-time.