Hybrid Control of Multi-robot Systems under Complex Temporal Tasks

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Abstract

Autonomous robots like household service robots, self-driving cars and drones are emerging as important parts of our daily lives in the near future. They need to comprehend and fulfill complex tasks specified by the users with minimal human intervention. Also they should be able to handle un-modeled changes and contingent events in the workspace. More importantly, they shall communicate and collaborate with each other in an efficient and correct manner. In this thesis, we address these issues by focusing on the distributed and hybrid control of multi-robot systems under complex individual tasks.

We start from the nominal case where a single dynamical robot is deployed in a static and fully-known workspace. Its local tasks are specified as Linear Temporal Logic (LTL) formulas containing the desired motion. We provide an automated framework as the nominal solution to construct the hybrid controller that drives the robot such that its resulting trajectory satisfies the given task. Then we expand the problem by considering a team of networked dynamical robots, where each robot has a locally-specified individual task also as LTL formulas. In particular, we analyze four different aspects as described below.

When the workspace is only partially known to each robot, the nominal solution might be inadequate. Thus we first propose an algorithm for initial plan synthesis to handle partially infeasible tasks that contain hard and soft constraints. We design an on-line scheme for each robot to verify and improve its local plan during runtime, utilizing its sensory measurements and communications with other robots. It is ensured that the hard constraints for safety are always fulfilled while the soft constraints for performance are improved gradually.

Secondly, we introduce a new approach to construct a full model of both robot motion and actions. Based on this model, we can specify much broader robotic tasks and it is used to model inter-robot collaborative actions, which are essential for many multi-robot applications to improve system capability, efficiency and robustness. Accordingly, we devise a distributed strategy where the robots coordinate their motion and action plans to fulfill the desired collaboration by their local tasks.

Thirdly, continuous relative-motion constraints among the robots, such as collision avoidance and connectivity maintenance, are closely related to the stability, safety and integrity of multi-robot systems. We propose two different hybrid control approaches to guarantee the satisfaction of all local tasks and the relative-motion constraints at all time: the first one is based on potential fields and nonlinear control technique; the second uses Embedded Graph Grammars (EGGs) as the main tool.

At last, we take into account two common cooperative robotic tasks, namely service and formation tasks. These tasks are requested and exchanged among the robots during run time. The proposed hybrid control scheme ensures
that the real-time plan execution incorporates not only local tasks of each robot but also the contingent service and formation tasks it receives.

Some of the theoretical results of the thesis have been implemented and demonstrated on various robotic platforms.

**Keywords**

Automatic Control, Multi-robot system, Linear Temporal Logic