Recent advances on coordination approaches for Multi-Robot Systems

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In recent years, the interest towards robotic platforms that can perform complex tasks with a high degree of autonomy is significantly growing, both in industry and in academy. For example, consider the large number of robotic projects that involve large industries such as the Google Self-Driving car[1] or the Amazon Prime Air[2] service.

The increasing presence of robotic platforms naturally shifts the focus of the AI and robotic fields towards Multi-Robot Systems (MRS) where several robotic platforms must interact with one another to achieve their tasks.

Now, a crucial element for the effective control of a complex MRS is the ability for single robots to organize their actions and coordinate their operations. In fact, when multiple robots must execute high level complex tasks they must avoid possible negative influences and take advantage of possible synergies to maximize the performance of the system. For example, consider an environmental monitoring tasks, where a group of UAVs must cooperatively monitor a given area providing a human operator with relevant information, such as video stream of a given area or environmental parameters such as temperature, humidity, wind strength and so forth. In such situation, robots should avoid hindering each other others' movements and at the same time, acquire information that are most important for the system given what is already known to their team mates.

In this presentation, we will describe what we believe are the most relevant scientific issues related to MRS coordination and our recent work in this area. We will then detail what we believe are the most promising directions for future work.

Coordinating a set of robots is a very challenging problem from many point of views. For example, from a purely algorithmic perspective, optimizing the performance of a system composed of several robotic platforms is inherently difficult (typically not-tractable) due to due to exponential grow of the possible join actions for the system. Consequently, there has been a growing interest for coordination techniques that can exploit problem decomposition to provide effective and efficient solutions that can be applied to large scale systems (i.e., many robots, many tasks, large environments.). Such problem decomposition naturally arises from locality of perception, actions and interactions typically present in MRS.

[1] https://plus.google.com/+GoogleSelfDrivingCars/about
[2] http://www.amazon.com/b?node=8037720011

Within this context, in this presentation we will summarize our recent work that proposes a novel perspective for MRS coordination focusing on Distributed Constraint Optimization Problems (DCOPs) [1] and probabilistic graphical models [2].

Specifically, we proposed the use of the max-sum algorithm for coordination [3]. The max-sum algorithm belongs to the Generalized Distributive Law framework which is frequently used for various inference tasks in the probabilistic graphical model community. In more detail, in [3, 4] we show how this algorithm can be used to coordinate the operations of low power devices, such as sensors in a sensor networks, showing that the max-sum algorithm is able to provide better solutions than previous sub-optimal coordination approaches, while maintaining a low coordination and communication overhead and being more robust to message loss.

While in many practical applications, optimal solutions for coordination is not achievable it is often important to characterize solution quality so to avoid pathological behaviours that can not be accepted in critical scenario (such as Search and Rescue). To this end, the max-sum technique has been extended to provide a bound for the optimal value of the solution, by operating on a relaxed tree-structured version of the problem [5]. Along this line, in [6] we also provide important theoretical results on the quality of solutions for fixed points of the max-product (and max-sum) algorithm.

This line of research has been further explored in several following contributions focusing on mobile robots. Specifically, in [7] we apply the max-sum algorithm to a cooperative information gathering task, where robots must provide the most accurate information on a scalar phenomenon that varies in space and time (e.g., temperature, gas concentration etc.). Results show that the approach is able to provide good solutions while enforcing crucial constraints on robots movements (e.g., maintaining a connected network throughout all the simulation). In addition to that, in [8] we provide a methodology to apply the max-sum approach to robotic applications and validate this on a system composed of a set of UAVs that must provide video stream of interest points inserted by a set of users.

Another crucial issue for MRS coordination is the impact of perception noise and non-deterministic action execution, typical of robotic systems, on the overall MRS performance. For example, consider the context of robotic patrolling, where a set of robotic platforms must continuously monitor a set of interest points (or visit locations). In such context, the map of the environment is typically known before-hand and the robotic system can be designed for the specific application, therefore we can assume that the system has a fixed number of robots of known types. Hence a significant strand of work [9] proposes the use of optimal, off-line solutions that pre-compute paths that robots must follow during mission execution. However, such strategies are often suboptimal, or they may even fail, in real situations where the system must cope with (possibly unrecoverable) failures in robot behaviours such as localization and navigation problems, dynamic obstacles and so forth. In contrast, we advocate the use of on-line coordination approaches, where robots coordinate their actions while executing their tasks, so to optimize their choices by considering up-to-date information and hence combat the inevitable effects of uncertainty in perception and action execution. In this context we will describe our recent work proposing the use of on-line, decentralised task assignment techniques for Multi-Robot Patrolling [10].

Finally, we will discuss the most promising future directions for MRS coordination, based on the problems and issues that arise in the described application domains. In particular, one interesting direction for future investigation is the possibility of having coordination approaches for *open* MRS system, where the coordination algorithm should make minimal assumptions on the system composition/configuration (i.e., what is the number of robots, what are their capabilities) and adapt to the current situation as perceived by each robot. Another interesting direction is to investigate solutions that allow a high level interaction between the human operator and the robotic team. Up to now the work in HRI has mainly focused on designing interfaces that facilitate the interaction between the operator and one single robot, while an interesting and challenging direction is to design interfaces and coordination algorithm that would allow an operator to interact with the team as a whole.

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