



Distributed Prescribed-Time Coordination for Multi-Agent Optimization under Time-Varying Inequality Constraints

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DESCRIPTION

Distributed optimization has become increasingly important for systems composed of many interconnected agents that must make coordinated decisions without relying on a central computational unit. In practical applications, the desired solution may change continuously because environmental conditions, demands, operating costs or system states vary with time. At the same time, agents often face inequality constraints that cannot be violated during operation. These characteristics create a demanding optimization setting in which agents must coordinate their decisions, track a moving optimum and complete the required computational process within a prescribed period. A distributed prescribed-time framework provides a promising way to address these requirements by allowing the convergence time to be specified in advance rather than being determined only after the algorithm begins. Consider a network containing multiple agents, where each agent possesses a local objective function and communicates information only with neighboring agents.

The collective objective can be formed by combining the local functions, while inequality constraints describe limitations on resources, safety margins, capacities or operating conditions. Since the objective and constraints may vary with time, the optimal solution is generally not fixed. Instead, the agents must continuously follow a trajectory representing the changing optimum. A successful algorithm must therefore balance local computation, information exchange, constraint satisfaction and synchronization among all participants. The concept of prescribed-time convergence introduces a particularly useful feature. Instead of requiring convergence merely as time approaches infinity or within an unspecified settling interval, the designer selects a desired terminal time beforehand. The algorithm is constructed so that the disagreement among agents and the optimization error approach their required values by that designated instant. This property can be valuable in

applications where decisions must be synchronized with external schedules, communication windows, production cycles or emergency procedures. The predetermined time also provides a clearer performance specification for distributed controllers.

Time-varying optimization adds another layer of difficulty because the target itself is moving. If the optimal solution changes slowly, agents may be able to track it with relatively modest communication and computation. Rapid changes can produce substantial tracking errors, especially when the network is sparse or communication delays are present. A distributed prescribed-time algorithm must therefore respond quickly enough to changes while maintaining numerical and dynamical stability. Properly designed time-dependent gains can increase the correction strength as the prescribed deadline approaches, enabling the agents to reduce synchronization and optimization errors within the available interval. Inequality constraints require special attention because simply converging toward an unconstrained optimum does not guarantee an admissible solution. One approach is to incorporate constraint information directly into local optimization dynamics. Barrier-type functions can discourage agents from approaching prohibited boundaries, while projection mechanisms can return tentative decisions to feasible regions. Other formulations introduce auxiliary variables that represent constraint-related conditions. The choice of mechanism depends on whether feasibility must be preserved continuously or only guaranteed at the final decision point.

Communication topology also strongly influences distributed performance. Agents exchange estimates with their neighbours and the network structure determines how quickly information about local objectives and constraints propagates throughout the system. A connected communication graph is generally necessary for collective coordination. When the topology changes over time, the algorithm must tolerate temporary variations while preserving sufficient information flow. Robust designs can use adaptive interaction weights or consensus mechanisms to reduce

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the impact of changing communication patterns. An important feature of prescribed-time methods is the separation between convergence requirements and the actual complexity of the network. By incorporating the desired terminal time explicitly into the algorithm, the designer can adjust gains according to the required deadline. However, selecting excessively aggressive gains may create large control actions, sensitivity to noise or numerical difficulties. Consequently, prescribed-time convergence should be balanced against communication limitations, computational capacity and robustness requirements. The goal is not simply to make convergence fast, but to achieve predictable convergence without creating undesirable transient behavior.

The framework is particularly relevant to distributed energy management, coordinated robotics, traffic systems, sensor networks and resource allocation. For example, interconnected energy units may need to distribute power according to demand that changes throughout the day while respecting generation and capacity limits. Similarly, autonomous vehicles may need to coordinate decisions within a specified time while satisfying safety-related inequalities. The combination of distributed coordination, prescribed-time convergence, time-varying objectives and inequality constraints creates a flexible foundation for dynamic decision-making.