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New advances in complex motion control for single robot systems and multi-agent systems

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Motion control is a classic problem, which has constantly attracted attentions from the control and the robotics communities. The problem used to be tackled in idealistic settings or using simplified models to complete complex tasks. Now the wish to control robots in realistic environments has driven the researchers to consider more and more complex systems and scenarios. This brings new challenges to the motion control problems.

One that may complicate the motion control problem is the observability of the environment. In a fully observable environment, the observation of the robot can reveals the current state of the environment, which can then be used to design control laws [1–3]. In a partially observable environment, the robot may produce different observations for one state of the environment, because of incomplete information, also called imperfect information. The situation of imperfect information is often seen in multi-agent systems, where agent's communications are limited and interactions are complicated [4–8]. Imperfect information complicates the control design problem and may degrade the performance of the overall system. Cooperation with human was adopted to improve the performance of a multi-agent system in complex environments [9–10].

To develop practical robot applications, it is necessary to take the environment into consideration, and the more complex the environment is, the more difficult it will be when designing the control law. Complex environments lead to complicated mechanisms, which makes the design problem complex. Recent studies focused on the controller design problem in complex environments for holonomic and nonholonomic robot systems, where different approaches to deal with the complexity were also proposed. Ref. [1] considered how to design a unified theoretical framework for both holonomic and nonholonomic robot systems in stair-climbing. A novel control law called active tension control combined with the computed torque method was presented for holonomic or nonholonomic robotic systems. There is also a corresponding work on realistic environment, such as rough terrains, where most of the existing bio-inspired legged robots do not possess walking abilities [2]. Generation of adaptive multiple gaits in rough terrains was considered and a central pattern generator (CPG)-based locomotion control method was proposed, integrated with a contact force feedback function. Another recently proposed method to solve the complex motion control problem for a single robot is to improve robot's structure combined with new controller design [3]. For example, ref. [3] introduced a ±50° yawing head joint that functions as the neck for improving turning ability, which enables the robotic fish to carry out complex motions. Correspondingly, an improved central pattern generator (CPG) model was also proposed.

In multi-agent systems, communications and cooperations are unavoidable. This complicates the motion control problem. Usually, a simplified model leads to a simplified control system structure. Recent study considered the influence of model uncertainty and external disturbance in complex environment with obstacles [4]. The null-space-based (NSB) sketch, one of behavioral based approaches, was extended to the application for more complex dynamics. Thus, the control problem was decomposed into elementary missions (behaviors) implemented by each individual system. Additionally, combination with a sliding model control guarantees the accurate calculation. The design of the control law may also become more difficult caused by the in-

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creasing number of the agents, and distributed control method has been an effective way to improve the robustness of the multi-agent system. Various distributed control methods for multi-agent systems have been reported. Recent studies focused on the event-triggered control strategy, which can reduce the cost of energy and bandwidth, since less communication, calculation and actuation updates are required. Ref. [5] considered eliminating the effect caused by the triggering of the neighbors which existed in previous researches. A self-triggered approach was proposed where the current state was used to calculate not only the input of the system, but also the next time instant when the control law should be recomputed. Thus it is independent and it is effective to reduce the number of triggering of the whole system. In addition, the continuous monitoring of measurement errors can be avoided. Apart from complex motion control in discrete-time system, researchers also focused on continuous time system with imperfect information recently. The distributed coordination problem for multiple Lagrangian systems under a directed graph was discussed in ref. [6], where two cases were considered, namely, the distributed tracking control problem with a dynamic leader and the leaderless synchronization problem. To overcome the difficulty that only positions can be measured, a new distributed observer was designed to estimate the velocity for each follower. As for the leader-following attitude consensus problem of multiple rigid spacecraft systems, two assumptions were widely used that all the parameters of the spacecraft systems are known exactly and the information flow among the followers is bidirectional in previous work. These assumptions may not be held in real world. Ref. [7] considered removing these two assumptions. A new Lyapunov function was designed to make the communication network directed. And by converting the leader-following consensus problem into an adaptive stabilization problem of a well-defined error system, a distributed adaptive control law was employed to solve this problem. Thus incomplete information problem about the actual parameters was solved. Besides, game theoretic control of multi-agent systems has been focused on recently. Many methods have been proposed for specific cases. Ref. [7] gave a theoretic framework about game based control problem with fixed and time-varying topologies. It provided a theoretic tool to convert the control problem into a potential game using the semi-tensor product of matrices and potential equation mainly.

In order to perform complex motions, cooperation with human is often adopted for robot agents. It aims at making human and robotic agents effective teammates. From the perspective of human, supervisory control is an active research area, which is often regarded as the human-in-loop problem. One single operator's supervisory control of multi-agent had been modeled using discrete-event simulation. But the workload with multiple agents could easily exceed the capacity of the single operator. Ref. [9] has considered modeling the teamwork of operators during supervisory control, predicting their performance and exploring the role of backup behavior in team coordination. Moreover the effect of team structure and scheduling notification on operators' performance, subjective workload, work process, and communication was investigated. However the assumption that the agent is highly autonomous could not suit the actual application. On the other hand, from the perspective of agents, how to coordinate with humans is an important problem. To coordinate with human, a multi-agent system needs to understand human behaviors to recognize, anticipate and adapt to human motions. Various methods exist, which focused on recognizing the activity of a single human. While "one human, one robot" paradigm is rarely seen in ecological settings, robots need to understand a team's dynamics, which makes the motion control problem become complex. Ref. [10] considered how to understand a team's dynamics using an anticipation method which takes high-level group behaviors into account.

From these recent researches, we noted several trends that have emerged about complex motion control in single-agent systems and multi-agent systems.

(1) The environment is more complex. Adaptive models considering complex environment are proposed.

(2) The effect of imperfect information on designing controllers is considered. New control methods about estimation and anticipation emerge to handle this problem.

(3) The cooperation between human and multiple agents is becoming more and more important in multi-agent systems.

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