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# Velocity observer design for the consensus in delayed robot networks

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**Abstract**

The consensus problem for networks of multiple agents consists in reaching an agreement between certain coordinates of interest using a distributed controller. It may be desirable that all the agents find a consensus at a given desired leader coordinate (Leader Follower Consensus Problem LFCP), or it may be only necessary that they agree at a certain coordinates value (Leaderless Consensus Problem LCP). Consensus has many practical applications in robot networks systems, where the interconnection of the agents may present variable time delays, hence rendering the stability analysis and control design more complex. Another problem that may arise is the possible lack of velocity measurements. In this work, a Proportional plus damping injection (P + d) controller together with a linear velocity observer is introduced. Our approach is able to solve both the LFCP and the LCP in networks of robots modeled as undirected weighted graphs with unknown asymmetric (bounded) variable time delays. Local (semi global) asymptotic stability is proven and simulation results are provided to test the performance of the proposed scheme.


## 1. Introduction

The consensus problem for networks of multiple agents consists in reaching an agreement between certain coordinates of interest using a distributed controller. For instance, it may be

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desirable that all the agents find a consensus at a given leader coordinates (Leader Follower Consensus Problem LFCP), or it may be only necessary that the agents agree at a certain coordinates value (Leaderless Consensus Problem LCP). Solutions can be found in the literature for different classes of linear and nonlinear systems in a variety of fields such as biology, physics, control theory and robotics [2,5,17,23,30]. It has many practical applications, e.g. formation control of multiple unmanned aerial vehicles, synchronization of mobile robots swarms, robot teleoperation systems, etc. However, when time delays are present in the communication channel, the stability analysis and control design are more complex [6,15]. A result for position tracking in the presence of time variable delays can be seen in [13]. When it comes to a robot network, there are multiple possible communication channels, each of them with a corresponding different time delay. A common way to analyze the consensus problem for this case is by using algebraic graphs [20]. Usually, the graph is assumed to be *undirected*, roughly meaning that when two manipulators of the network have communication, then this is bilateral. Furthermore, in order for the consensus problem to be solved, the graph must be *connected*, meaning that there is always an (undirected) path between two manipulators of the network. In [29], leader–follower guaranteed–cost consensus analysis and design problems for high–order linear time–variant swarm systems with switching topologies are investigated. Xi et al. [28] deal with admissible output consensus design problems for high–order linear time–invariant singular multi–agent systems with constant time delays. Abdessameud et al. [2] have solved the delayed leader–follower consensus problem with a dynamic leader and assuming that the interconnection directed graph has a spanning tree rooted at the leader node. Wang et al. [26] investigate the output formation–containment problem of coupled heterogeneous linear systems with intermittent communications. Each heterogeneous system, whether leaders or followers, has different dimension and different dynamics.

Another problem that may arise when working with robot manipulators is the possible lack of velocity measurements, for which many observers have been proposed [7,25]. Few previously proposed controllers do not rely on velocities, e.g. to solve the leaderless consensus for undelayed networks of EL–systems, [19] uses a bounded controller and [4] a velocity filter. Abdessameud et al. [3] solve the consensus problem for the attitude of rigid bodies by using a *virtual* system for each agent. The same problem is solved in [1] for linear second–order systems. Zheng and Wang [31] solve the leaderless consensus problem for linear heterogeneous–first and second order systems, but without interconnecting delays. Wang and Yi [27] investigate the consensus problem of second-order multi–agent systems (MASs) via impulsive control using only position information with communication delays, which are different and can be larger than one impulsive period. Recently, some schemes for the control of delayed bilateral teleoperation without velocities measurements have been proposed [12,22], based on the notions of Immersion and Invariance ($I$ & $I$) speed observers [8].

In this work, the Proportional plus damping injection (P + d) controller proposed in [12,16] is used, together with a modified version of the velocity observer given in [7]. A similar observer can also be found in [11], where the control of cooperative robots is studied. Our approach is able to solve the LCP and the LFCP in networks of fully actuated robots modeled as undirected weighted graphs, under the assumption that unknown asymmetric (bounded) time variable delays are present in the communication channel. Semi global asymptotic stability is proven. It should be underscored that, up to the authors' knowledge, this is the first work where this particular observer design is used for the consensus problem of systems with variable time delays.