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A non-uniform multi-rate control strategy for a Markov chain-driven Networked Control System

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ABSTRACT

In this work, a non-uniform multi-rate control strategy is applied to a kind of Networked Control System (NCS) where a wireless path tracking control for an Unmanned Ground Vehicle (UGV) is carried out. The main aims of the proposed strategy are to face time-varying network-induced delays and to avoid packet disorder. A Markov chain-driven NCS scenario will be considered, where different network load situations, and consequently, different probability density functions for the network delay are assumed. In order to assure mean-square stability for the considered NCS, a decay-rate based sufficient condition is enunciated in terms of probabilistic Linear Matrix Inequalities (LMIs). Simulation results show better control performance, and more accurate path tracking, for the scheduled (delay-dependent) controller than for the non-scheduled one (i.e. the nominal controller when delays appear). Finally, the control strategy is validated on an experimental test-bed.

1. Introduction

An NCS is a control system where different devices share a common communication link. Advantages such as cost reduction and easy maintenance have motivated a wide study about NCS in the last years (see, for instance, in [16,48,52]). Nevertheless, some drawbacks arise when using a shared link, being the fundamental one the existence of time-varying delays when transmitting information between devices (usually, from sensor to controller and from controller to actuator) [51,47,24,7]. Also, in some cases, networks introduce packet dropouts [20,46,8], packet disorder [32,8,53], and bandwidth constraints [30,31]. Dealing at the same time with all the drawbacks involved in an NCS becomes a complex problem, and hence, some simplifying assumptions are usually made.

The present work is focused on facing time-varying network-induced delays and avoiding packet disorder in a kind of NCS where the plant to be wirelessly controlled is a UGV. Most of papers treating this scenario (for instance, [30,31,43,22,44]) does not cope with the packet disorder phenomenon, and in addition, are characterized by:

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- Performing the main control tasks (that is, path tracking and delay compensation) at the remote side (with no direct communication to the plant). At the local side (close to the plant), a simple PID is located to control the instantaneous rotational velocity.
- Compensating for round-trip time delays from estimated remote-to-local delays (since at the remote side only the current local-to-remote delay is known).
- Requiring estimated UGV states so as to generate the proper path references to be followed when the packets reach the local side. At this moment, the references are compared to the current, instantaneous velocities, and the consequent error signal is controlled by the simple PID.

The main problem of the approach considered in these papers is working with estimated values, since the worse the estimation is, the higher performance degradation could be. In order to avoid this problem, a proposal which deals with actual values for the round-trip time delays and the UGV states is proposed in the present work. This approach considers a Multi-Rate Input Control (MRIC) strategy [18,36,6,9] (i.e., the sensing rate is N times slower than the actuation rate), with the next features:

- The control tasks are separated into two control levels working at different rates: the path tracking control is located at the remote side generating slow-rate references from the actual UGV state, and the delay compensation is situated at the local side generating a fast-rate control signal from the actual delay. Concretely, the path tracking controller implements a network-based adaptation of the Quadratic Curve (QC) algorithm by [49], and the delay compensation controller applies a version of the gain scheduling approach introduced in [35].
- The sensing period is chosen to be greater than the longest delay.[1] In this way, the packet disorder problem is avoided. But, from a single-rate control framework, this period could then be too great to reach the desired control performance (the greater the sampling period is, the worse the control performance should be expected [28]). However, by adopting the MRIC strategy, since control actions are applied at N times faster rate than the sensing rate, the control performance can be maintained [3,19].
- As a consequence of existing time-varying network delays, the fast-rate control signal will be non-uniformly applied, resulting in a non-uniform multi-rate control approach.
- Actual round-trip time delays can be measured and compensated at the local side, since a local timer is shared by every local device. In addition, the remote controller needs no synchronization to develop its tasks, and hence no time-stamping techniques are required.

As a result of these features, our control proposal implies a straightforward implementation, being not required additional prediction stages for the delay and the UGV state (used in [30,31,43,22,44]), and the possibility of reducing the network utilization (since information travels through the network at the slower rate).

The present work contemplates a Markov chain-driven NCS [21,10,33,38,39], which is an special case of stochastic NCS [40,25,11]. Driving the NCS by a finite state Markov chain enables to consider not only states with different delay distributions (the stochastic case) but also transition probabilities among states. This kind of NCS model can be useful to be applied to most of Internet applications [26,41]. In an Internet environment is usual to find different network load scenarios, where heavy traffic situations can appear (loaded network) and disappear (unloaded network) following some transition probabilities. This will be the case considered in the present work. However, Markov chains can also be used to model other aspects of the NCS. For example, to drive activation states of subsets of actuators [13,14], or subsets of sensors and actuators [15,23]. In any case, in order to assure stability in the jumping system, some conditions can be enunciated in terms of LMIs [5] under the consideration of transmission delays both in system output measurements and in control signals.

Summarizing, the paper includes the following sections. In Section 2, the proposed NCS is described. Section 3 presents the remote and local controllers. Then, in order to prove global mean-square asymptotical stability for the Markov chain-driven NCS, Section 4 introduces a decay-rate based sufficient condition in terms of probabilistic LMIs. In addition, in this section, several cost functions are presented in order to be used when analyzing NCS performance. A simulation example in Section 5 illustrates the main benefits of the control proposal, which is validated by means of an experimental test-bed in Section 6. Finally, Section 7 enumerates the main conclusions of the present work.

2. Description of the NCS scenario

The proposed NCS is described in Fig. 1, where the next devices are considered:

- A UGV as a process to be controlled, which includes two motors (for right and left wheels).

[1] From experimental or simulated data, network-induced delay distributions are assumed to be known.