



Optimal tracking performance of control systems with two-channel constraints[☆]



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ABSTRACT

This paper focuses on the tracking performance limitation for a class of networked control systems (NCSs) with two-channel constraints. In communication channels, we consider bandwidth, energy constraints and additive colored Gaussian noise (ACGN) simultaneously. In plant, non-minimal zeros and unstable poles are considered; multi-repeated zeros and poles are also applicable. To obtain the optimal performance, the two-parameter controller is adopted. The theoretical results show that the optimal tracking performance is influenced by the non-minimum phase zeros, unstable poles, gain at all frequencies of the given plant, and the reference input signal for NCSs. Moreover, the performance limitation is also affected by the limited bandwidth, additive colored Gaussian noise, and the corresponding multiples for the non-minimum phase zeros and unstable poles. Additionally, the channel minimal input power constraints are given under the condition ensuring the stability of the system and acquiring system performance limitation. Finally, simulation examples are given to illustrate the theoretical results.

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1. Introduction

Owing to the advantages of the NCSs over the traditional real-time control systems in information processing and decision-making, control and optimization of NCSs are rapidly developed and broadly applied [7,9,17–19,34]. However, system performance could be deteriorated, even leading to instability of the control plants, due to the limitations of the channel bandwidth [13,30], channel capacity [4,12,30], delays [15,27,37,38], quantization [1,28], congestions [11] and packet loss [5,23,27,28] and fault [36] in the communication channels of NCSs. Therefore, the analysis and design of NCSs are difficult and challenging.

The researches on performance of the control system attract a growing amount of interest in the control community, take [2,10,14,24] as examples. The above literatures mainly focus on minimizing tracking error by designing optimal controllers. The objective of this paper is to reveal the quantitative relationship between the intrinsic properties of NCSs and the tracking performance limitation via feedback control. The researches on the performance of NCSs mainly focus on two aspects. On one hand, by invoking the information theory, the relationship between information entropy and system performance is studied, such as [25,32]. On the other hand, by using Bode and Poisson integral, another branch reveals that the performance

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of the close-loop systems is fundamentally constrained by the intrinsic properties of the system, such as [2,10,13,21,31]. By importing appropriate entropies and distortions, the authors in [32] investigates the performance limitation for scalar systems with Gaussian disturbances, which implies that the achievable performance cannot be improved even if the maximum information constraint is relaxed to an average information constraint, the authors in [12] discusses a lower bound on the achievable performance in a finite time and shows that this bound can be achieved by using linear strategies, the authors in [33] studies the control problems for discrete-time single-input linear time-invariant plants over a signal-to-noise ratio constrained channel. In [10], by presenting the performance index constructed by tracking error energy, the authors investigate the optimal tracking of the NCSs with the down-link AWGN network channels, the authors in [21] considers the disturbance attenuation performance to minimize the variance of the plant output in response to a Gaussian disturbance over an AWGN channel. In [13], optimal tracking performance issues are studied for NCSs in the up-link channel with limited bandwidth and additive colored Gaussian noise channel.

It is noted that those results above provide useful guidelines in the design of NCSs, including the design of communication channels. However, it is shown in [10,13,22,30] that in order to obtain the optimal tracking performance, only up-link or down-link channel model is considered in the communication channel, while two-channel is often encountered in practice. In fact, there are two cases. In the first case, both the system sensor and the controller are far away from the plant. In the other case, only the controller is far away from the plant and the system sensor. The adopted model can be found in many real-world systems. For example, in the telemedicine system of robot-assisted neurosurgery, patient and robot are respectively the plant and the controller. The remote expert obtains information via the network transmission, and the instruction of the expert is then sent back to the robot via the network transmission. In addition, for leader-follower multi-agent systems [20], provided that the position, velocity and direction information of a leader are considered as the reference signal, the controller is designed to achieve the minimal tracking error between the leader and the follower. However, owing to the structural characteristics of the follower and the communication constraint between the leader and the follower, the minimal tracking error cannot be zero. Thus the study of the relationship among the tracking performance, structural characteristics of followers and communication parameters (bandwidth and noise in this paper) will give some guidance for leader-follower multi-agent systems (such as unmanned aerial vehicle formation systems and multi-robot system) on how to achieve consensus tracking, including static consensus and dynamic consensus. Moreover, the optimal performance for two-channel communication channels is worthy of careful study in the model of NCSs. Better performance can be obtained by using a more flexible two-parameter controller [16]. Moreover, with the development of science and technology, two-parameter controller is also frequently used in practice in terms of aerospace [26], robotics [3], power systems [6], etc. Meanwhile, the channel input of NCSs is often required to have an infinite power for the optimal tracking problem in [2,10,13], which generally cannot be met in practice. Additionally, communication constraints for bandwidth and additive colored Gaussian noise should be included in the communication model, which is more realistic than the corresponding models presented in [4,10,21]. As in the real world, many practical systems resort to random reference signals. Examples include a jolting of a warship in the surf, a communication interference noise, a random fluctuation generated by turbulence for the flying missile, and a real-time random-noise tracking radar [29,39]. More information can refer to [10,13,21].

The main goal of the present work is to adopt two-parameter controllers to investigate the best achievable tracking performance of networked control systems with two-channel constraints and the finite channel input power. This paper investigates the optimal tracking performance under bandwidth-limited, energy constraints and ACGN. The plant is described by the unstable and non-minimum phase system with multi-repeated poles and zeros. The reference signal is considered as random reference signals. The contributions of this paper can be summarized as follows. First, we consider both up-link and down-link channels with interference, which is more practical than most existing literatures which focus on either up-link or down-link channel models. Second, some fundamental constraints are incorporated in the communication channels, including bandwidth, ACGN and channel input power. Third, considering that the channel input energy cannot be infinite in the real-world communication channels, this paper constructs a novel performance index, which can quantificationally characterize the properties of the tracking capability and the communication ability. Finally, the channel minimal input power constraints are given under the condition ensuring the stability of the system and acquiring system performance limitation.

The rest of the paper is organized as follows. The problem formulation and preliminaries are given in Section 2. In Section 3, the main results of this paper are presented. We then proceed in Section 3 to formulate and solve the problem of optimal tracking for two-channel with bandwidth, energy constraints and ACGN. In Section 4, some illustrative numerical examples are given. The conclusion is finally stated in Section 5.

The notation used throughout this paper is described as follows. For any complex number z , its complex conjugate is denoted by $\bar{z}$. The transpose and conjugate transpose of a vector u are denoted by u^T and u^H respectively. The transpose and conjugate transpose of a matrix are denoted by A^T and A^H , respectively. All the vectors and matrices in this paper are assumed to have compatible dimensions.

2. Problem formulation

In this paper, we consider the NCSs depicted in Fig. 1, where up-link and down-link channels are affected by the limited bandwidth and ACGN. Other communication constraints are not taken into account and are assumed to be ideal.

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