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Original articles

Challenging simulation practice (failure and success) on implicit tracking control of double-integrator system via Zhang-gradient method

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Highlights

- The design processes of the Zhang-gradient (ZG) controllers with explicit and implicit tracking control of the double-integrator (DI) system are presented.
- The examples of static and time-varying systems are investigated to show the effectiveness of ZG controllers for the tracking control problem solving.
- It is shown that different settings of simulation options in ordinary differential equation (ODE) solvers may lead to different simulation results.
- Successful and failed simulation practice helps establish the referential rules for users to choose appropriate settings.

Abstract

Zhang-gradient (ZG) method is a combination of Zhang dynamics (ZD) and gradient dynamics (GD) methods which are two powerful methods for online time-varying problems solving. ZG controllers are designed using the ZG method to solve the tracking control problem of a certain system. In this paper, the design process of the ZG controllers with explicit as well as implicit tracking control of the double-integrator system is presented in detail. In addition, the corresponding computer simulations are conducted with different values of the design parameter λ to illustrate the effectiveness of ZG controllers. However, even though the ZG controllers are powerful, there is still a challenge in the simulation practice. Specifically, different settings of simulation options in MATLAB ordinary differential equation (ODE) solvers may lead to different simulation results (e.g., failure and success). For better comparison, the successful and failed simulation results are both presented. The differences in simulation results remind us to pay more attention to MATLAB defaults and options when we conduct such simulations.

Keywords: Zhang-gradient (ZG) controllers; Double-integrator system; Tracking control; MATLAB ODE solver; Options

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1. Introduction

Recently, Zhang dynamics (ZD) and gradient dynamics (GD) methods have shown their powerful performance in solving online time-varying problems, especially, time-varying control problems [2,4,26,31,34]. The ZD method is based on an indefinite error-monitoring function [33,34] while the GD method is usually designed from a norm- or square-based energy function [34]. By combining the two powerful online problem solving methods, Zhang-gradient (ZG) dynamics method is thus obtained. The tracking control problem commonly arises in many applications [6,7,13,19,23,24]; e.g., the tracking control of optical disc systems [18], real-time navigation of mobile robots [25] and so on [3,8]. Owing to the effectiveness for solving online problems, the ZG method has been successfully applied to many practical real-time systems, such as ship course system [27], Lu chaotic system [29], inverted-pendulum-on-a-cart system [36], and robot-manipulator system [32]. Both the online tracking control problems and the singularity problems are handled elegantly by the ZG method. In this paper, the ZG method is used to design the ZG controllers to solve the tracking control problem of the double-integrator (DI) system. The DI system is a typical model in dynamics, which is widely studied in a variety of areas [11,37], and can be formulated as

$$\begin{cases}\dot{x}_1(t) = x_2(t),\\ \dot{x}_2(t) = u(t),\end{cases} \tag{1}$$

where $x_1(t)$ and $x_2(t)$ are the states of the DI system with $\dot{x}_1(t)$ and $\dot{x}_2(t)$ being the time derivatives of $x_1(t)$ and $x_2(t)$ respectively. Besides, $u(t)$ denotes the input of the DI system. For better understanding, the tracking control problem is to design a controller of the input $u(t)$ for the system such that the tracking error $y(t) - y_{\mathrm{d}}(t)$ is kept within an acceptable tolerance, where $y(t)$ is the output tracking trajectory, and $y_{\mathrm{d}}(t)$ is the desired path for $y(t)$.

The MATLAB is one of the most commonly used computational softwares and has wide applications in various research areas [1,5,9,10,15,22]. For example, it can be easily found in digital image processing [22], digital signal processing [1], artificial intelligence [10], automatic control [5] and so on [9,14–16,21,38]. The ordinary differential equation (ODE) encounters in many fields of science and engineering [28,35], in which many researchers devote themselves [17,20]. Note that, as for the explicit tracking control, e.g., $y(t) = x_1(t)$ or $y(t) = x_2(t)$, the desired output (or say, target output) $y_{\mathrm{d}}(t)$ can uniquely and directly determine the (steady) value of a single state, e.g., $x_1(t)$ or $x_2(t)$. Conversely, for the implicit tracking control, e.g., $y(t) = x_1(t)x_2(t)$ or $y(t) = x_1^2(t) + x_2^2(t)$, the desired output $y_{\mathrm{d}}(t)$ cannot explicitly (i.e., uniquely and directly) determine the (steady) value of a single state, such as $x_1(t)$ or $x_2(t)$. Generally speaking, the explicit tracking control is usually linear, and the implicit tracking control is usually nonlinear in practice. However, rigorously speaking, explicit or implicit tracking control is not directly or certainly corresponding to linear or nonlinear control, respectively. In other words, explicit tracking control can be presented as either linear or nonlinear relationship between $y(t)$ and $x(t)$. For example, the output $y(t) = x_1(t)$ of explicit tracking control is linear, and the output $y(t) = x_1^3(t)$ of explicit tracking control is nonlinear. Likewise, implicit tracking control can also be presented as either linear or nonlinear relationship between $y(t)$ and $x(t)$. For example, the output $y(t) = x_1(t) + x_2(t)$ of implicit tracking control is linear, and the output $y(t) = x_1^2(t) + x_2^2(t)$ of implicit tracking control is nonlinear. Besides, both the explicit tracking control and implicit tracking control have their relative advantages and disadvantages. For the explicit tracking control, it can be achieved more easily by the controller, and the corresponding system has the relatively low computational and structural complexities. However, for the reasons that (i) the output of most practical systems may not uniquely and directly relate to a single state, (ii) the output function may generally be nonlinear, and (iii) the states may have to satisfy some coupling constraints, the explicit tracking control is thus not much applicable in practical applications. On the contrary, the implicit tracking control has a more complicated output and thus has the relatively high computational and structural complexities. Beside, it would be more difficult for a practitioner to design an appropriate controller for such a system with an implicit tracking control purpose. However, the implicit tracking control would have wider applications on practical systems for the above reasons (i) through (iii). In this paper, computer simulations of explicit and implicit tracking control of the DI system using the ZG method are conducted based on the MATLAB ODE solvers. However, different settings of simulation options in ODE solvers may lead to different results (e.g., failure and success), which is very interesting and thus deserve further investigation.

The rest of this paper is organized in six sections. Section 2 shows the detailed design process of the ZG controller for explicit tracking control of the DI system with a typical output being $y(t) = x_1(t)$. In Section 3, computer simulations on the ZG controller designed in Section 2 with successful results are presented. To illustrate