Chapter 9
Identifiability and Detectability of Lyapunov Exponents in Robotics

Nikolay Nikolayevich Karabutov
https://orcid.org/0000-0002-3706-7431
MIREA-Russian Technological University, Moscow, Russia

ABSTRACT

Lyapunov exponents (LE) are one of the most effective tools for analyzing the quality of systems in robotics. They are used to optimize the robot work, evaluate the quality of their work, and solve various tasks in control systems with robots. Calculating the full spectrum of LE is a complex problem. It relates to the identifiability recoverability and detectability of LE. The identifiability recoverability and detectability issues of Lyapunov exponents were not considered. This problem is relevant. The authors propose an approach to verify these characteristics for the linear dynamical system. It bases on the analysis of geometric frameworks (GF) that depends on the structural properties coefficient (SPC). The SPC reflects the change in Lyapunov exponents, and GF guarantees decision-making on the LE type. They obtain (1) conditions of fully detectable LE (these conditions correspond to the determination of an indicators complete set in the robot control system) and (2) s-detectability conditions with level v-no recoverability if the system contains no recoverable lineals.

INTRODUCTION

Lyapunov exponents (LE) widely used to analyze the qualitative behavior of robotic systems and solve various control problems. Usually, the largest Lyapunov exponents (LLE) determines. So, LE (Szaniewski et al., 2015) uses to select the controller structure for the control of an industrial robot. The stability improvement of the prototype bipedal robot (Yunping et al., 2013) is also based on the LLE estimation. LLE is the basis for the stabilization problem solution of a passive bipedal robot. Reddy and Ghoshal (2016) consider the stabilization problem of the robot described by nonlinear differential equations. LE changes analysis guarantees the compensation of chaotic robot movements. Schramm et al. (2020) con-

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siders improving the quality of robot control based on the apple of neural networks. It shows that models trained on a small sample of data give chaotic or divergent behavior in some areas. Improving the model properties based on the LLE estimation. Influence compensation of vibrations on the control quality of flexible robots considers by Ban et al., (2021). Various approaches based on the frequency approach, LE identification, Poincaré maps analyzed. The effectiveness of the proposed approaches shown. Puzikov et al., (2019) consider the stabilization task of a robotic system (RS) in the neighbourhood of a steady state. The resulting faults RS detective based on the LE estimation. Some issues of LE analysis and application in robotic systems consider by Nasr et al., (2018), Azar and Vaidyanathan, (2014).

Most often, LE estimates base on time series analysis. It assumes that a priori information knows about the system structure. Sokos (2010) represented an overview of LLE computation for systems various classic. An estimating Lyapunov exponents algorithm (Gencay et al., (1992)) proposes an unknown dynamical system. It bases on the method for evaluating multidimensional networks with direct communication.

Several approaches were proposed for the evaluation of LE (see, for example, Sano and Suwada, 1985; Wolf, 1985). In the future, these approaches were changed (see, for example, Rosenstein et al. (1993); Balcerzak et al. (2018). Reconstruction of the systems attractor and time series analysis is the basis of the proposed algorithms. The basis of these algorithms is the Takens theorem (Takens, (1981). Similar ideas were implemented by Rosenstein et al. (1993).

Soloviev et al., (2020) presented an overview of other procedures and algorithms for LE estimation. Glyzin et al., (2005) propose a modification of the Benetti algorithm for calculating LLE. The proposed approach develops methods for reconstructing the system attractor.

Most approaches and methods of evaluating LE do not contain input impacts. As a rule, these algorithms and methods give the LLE estimate. Explain this by the class of systems and the difficulties of the Lyapunov exponents spectrum evaluating.

Note that the study of the qualitative behavior of the system is the main direction of research on LE. It does not affect other issues of identification theory. But the LE estimation and analysis provide the other identification problems solution for the system. The structural identification problem is one of the directions for using LE. Calculating the full spectrum of LE is the complicated problem. It links to the identification, recoverability and detectability of Lyapunov exponents. The problem of the LE identifiability, recoverability and detectability not considered.

The approach to estimating the LE identifiability of a robotic system proposes below. It is the basis for deciding on the LE detectability under a priori uncertainty. Karabutov (2015; 2018) proposes the approach on LE spectrum estimation. The approach analyzes the properties of geometric frameworks describing LE changes dynamics. The case of stationary and periodic RS considers.

PROBLEM STATEMENT

Consider the dynamic system describing the movement of a robot

$$\dot{X} = AX + BU, \quad Y = C^T X, \tag{1}$$