Introduction to Control Systems Design Using Matlab

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ABSTRACT

Control systems theory is a wide area covering a range of artificial and physical phenomena. Control systems are systems that are designed to operate under strict specifications, to satisfy certain aims, like safety regulations in the industry, optimal production of goods, disturbance rejection in vehicles, smooth movement and placement of objects in warehousing, regulation of drug administration in medical operations, level control in chemical processes and many more. The present work provides an introduction to the fundamental principles of control system’s analysis and design through the programming environment of Matlab and Simulink. Analysis of transfer function models is carried out through multiple examples in Matlab and Simulink, analyzing the dynamics of 1st and 2nd order systems, the role of the poles and zeros in the system’s dynamic response, the effects of delay and the possibility to approximate higher order systems by lower order ones. In addition, examples are given from the fields of mechanical systems, medically induced anesthesia, neuroprosthetics and water level control, showcasing the use of controllers that satisfy certain design specifications.

KEYWORDS

Control Systems Engineering, Matlab, Simulink, Linear Systems, Computer Aided Control, Education, Anesthesia, Neuroprosthetics, Water Level Control, PID

1. INTRODUCTION

1.1. What is a Control System

By the term control systems theory, we refer to the discipline that studies the behavior of dynamical systems, physical or artificial, and their control. By system, we refer to a collection of processes or objects, which interact with each other or with the environment and produce a specific outcome. The purpose of control is to manipulate certain parameters of the system in such a way that the outcome of the system will be the desired one. So as can be intuitively understood, dynamic control systems are subject to the axiomatic principle of causality, meaning that a certain action will produce an effect on the system’s behavior.

Control systems refer to a very wide area, covering many disciplines and phenomena. So by this term we do not only refer to systems found in the industry but in any system that operates with the purpose of fulfilling a specific goal. Biology for example is a field that is governed by natural control systems, see for example Liu et al. (2008); Zhang et al. (2012) and the references therein.

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A characteristic example of a control system found in nature is the human body, which constantly operates by satisfying certain goals such as balance, movement, adjustment of heartbeats according to the body’s functions and more. In medicine as well, automated control systems are found in artificial machinery used for supporting patients (Timms, 2011), for regulating drug dosages in anemic or diabetic patients (Luspay & Grigoriadis, 2016; Parker & Doyle, 2001) and control theory can be applied for formulating strategies for dealing with chronic diseases like HIV or Hepatitis (Craig & Xia, 2005; Moysis, Kafetzis & Politis, 2016; Rivadeneira & Moog, 2012). Other man-made examples used in everyday life is a car that operates according to the driver’s commands, a washing machine, a house’s heating system, an oven, an elevator and other everyday objects. On a larger scale, digital controllers are used in all kinds of industries to control the operating functions of large machinery and keep them functioning under safety regulations, see for example Aström & Kumar (2014); Azar & Serrano (2016a, 2015a, 2015b, 2015c, 2015d, 2014); Azar, Vaidyanathan (2015a, 2014); Azar & Zhu (2015); Bissell (2009); Dorf & Bishop (2011); Ghou Delbourk et al. (2016); Kumar & Daoutidis (1999); Li & Chong (2006); Meghni et al. (2016); Meghni, Dib & Azar (2015); Mekki, Boukhetala & Azar (2015); Nise (2015); Spong (1987); Stroe et al. (2017); Stroe & Andrei (2016); Qin & Badgwell (2003); Zhu & Azar (2015) and the references therein. Even more abstract systems like a nation’s economy are considered control systems, since there is a collection of inputs that the government tries to manipulate, like the amount of taxes and the production of goods to improve the outputs that can be considered the overall salaries or the Gross Domestic Product, see for example the Leontief model for a multisector economy (Campbell, 1982).

1.2. Open and Closed Loop Systems

In general, control systems can be divided into two fundamentally different categories: open loop and closed loop systems. Open loop systems are designed to operate on a predefined manner specified by their operator (e.g. an oven). In closed loop systems or feedback systems, the output is constantly compared to the desired system’s response, and through this comparison the input is adjusted accordingly, in order to eventually match the system’s output to the desired one. This simple idea of measuring the output and “feeding” it back into the system makes a substantial difference in the capabilities of the control system.

Feedback systems are much more complex and offer much more possibilities in control design. Feedback controllers can be used to guarantee the stability of an operating system, that is, to make sure that the system will operate under specific limits and the output will not diverge to infinity, which would mean the physical damaging of the system’s components. Feedback controllers are also used to change many characteristics in the response of the system like its rise and settling time, that indicate how slow or fast the system reaches its final value, its response overshoot, which indicates if the system’s output shoots high above its desired value before settling around it, and also the steady state error, which is the difference between the actual output and the desired one. Feedback controllers can also minimize or even eliminate possible oscillations that may occur in the output and are the result of the system’s transfer function having complex poles. In addition, such systems can be highly automated using computers, which makes it possible to operate with high precision for a long time, be more economic, ensure the quality of the final product with minimum waste on raw materials, operate under the safety regulations of the working environment and all these with minimum human supervision.

Overall, closed loop systems are the best choice for control design and are used in engineering applications. Open loop systems are mostly used in simpler applications that can be observed by the user and can be turned off at any time, like many household objects (oven, washing machine etc.).
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