Lecture Notes on Dynamic Systems
Fundamentals

Author:

Ernesto Flores G.

UAEH - ESTi

Automation Technologies Engineering

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Introduction

System dynamics deals with the mathematical modelling of dynamic systems and response analyses of such systems with a view toward understanding the dynamic nature of each system and improving the system's performance.

- ***System***: combination of components acting together to perform a specific objective.
- ***Component***: a single functioning unit of a system.

A system is called *dynamic* if its present output depends on past input; if its current output depends only on current input, the system is known as *static*.

- *Mathematical model*:

  Any attempt to design a system must begin with a prediction of its performance before the system itself can be designed in detail or actually built. Such prediction is based on a mathematical description of the system's dynamic characteristics. This mathematical description is called a ***mathematical model***. For many physical systems, useful mathematical models are described in terms of ***differential equations***.

- *Differential equations*:
  - Linear and Nonlinear
  - Time-invariant and Time-varying
  - Ordinary and Partial

- Kinds of Dynamical Systems
  - Deterministic and Stochastic
  - Lumped parameters and Distributed parameters
  - Linear and Nonlinear
  - Continuous-time and Discrete-time
  - Time-invariant and Time-varying

On the Mathematical Modelling

Mathematical modelling involves descriptions of important system characteristics by sets of equations.

By applying ***physical laws*** to a specific system, it may be possible to develop a mathematical model that describes the dynamics of the system.

- *Physical laws*:
  - Newton’s laws (mechanical systems)
  - Kirchoff’s laws (electric circuits)

… on the mathematical modelling

Sometimes the physical laws governing the behaviour of a system are not completely defined, and formulating a mathematical model may be impossible; if so, an experimental modelling process can be used.

In this process, the system is subjected to a set of known inputs, and its outputs are measured. Then a mathematical model is derived from the input-output relationships obtained.

… on the mathematical modelling

- Mathematical Modelling Procedure
  1. Draw a schematic diagram of the system.
  2. Define variables.
  3. Using physical laws, write equations for each component, combine them according to the system diagram, and obtain a mathematical model.
  4. To verify the validity of the model, its predicted performance, obtained by solving the equations of the model, must be compared with experimental results.

On the Analysis and Design

- ***Analysis***: System analysis means the investigation, under specified conditions, of the performance of a system whose mathematical model is known.

The first step in analyzing a dynamic system is to derive its mathematical model. Since any system is made up of components, analysis must start by developing a mathematical model for each component and combining all the models in order to build a model of the complete system.

It should always be remembered that deriving a reasonable model for the complete system is the most important part of the entire analysis.

… on the analysis and design

- ***Design***: System design refers to the process of finding a system that accomplishes a given task. In general, the design procedure is not straightforward and will require trial and error.

The ***basic approach*** *to the design of any dynamic system* necessarily involves trial-and-error procedures.

Trial-and-error techniques are almost always needed.

… on the analysis and design

The engineer begins the ***design procedure*** knowing the specifications to be met and the dynamics of the components, the latter of which involve design parameters.

Important!!! The specifications may be changed as the design progresses; detailed analysis may reveal that certain requirements are impossible to meet.

Next, the engineer will apply any applicable synthesis techniques, as well as other methods, to built a mathematical model of the system.

… on the analysis and design

With the mathematical design completed, the engineer simulates the model on a computer to test the effects of various inputs and disturbances on the behaviour of the resulting system.

If the initial system configuration is not satisfactory, the system must be redesigned and the corresponding analysis completed. This process of design and analysis is repeated until a satisfactory system is found.

Then a prototype physical system can be constructed.

… on the analysis and design

The prototype is a physical system that represents the mathematical model with reasonable accuracy.

Once the prototype has been built, the engineer tests it to see whether it is satisfactory.

If it is, the design of the prototype is complete.

If not, the prototype must be modified and retested.

The process continues until a satisfactory prototype is obtained.

Reference(s)

- Katsuhiko Ogata, *System Dynamics*. 4th Edition, Pearson Prentice-Hall, 2004. ISBN 0-13-142462-9.