Control Systems Engineering

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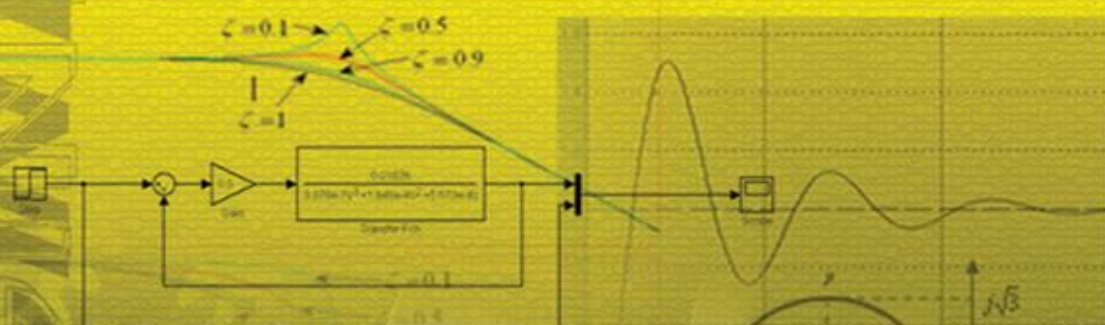Some of the authors of this publication are also working on these related projects:

Control System Design and Modellig View project

Tracking Error Compensation Of XYTable Ball Screw Driven System Using Cascade Fuzzy P+PI View project

CONTROL SYSTEMS ENGINEERING

Bode Diagram

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Preface

This book is designed to introduce students to the fundamentals of Control Systems Engineering, which are divided into seven chapters namely Introduction to Control Systems, Laplace Transform Review and Systems Representation, Physical Systems and Control Systems Modeling, Time Domain Analysis, Stability and Steady-State Error, Root Locus, and Frequency Response Analysis.

Chapter 1 covers the introduction of control systems engineering, basic terminologies, description and comparison between open-loop system and closed-loop system by taking examples from the surroundings for clearer view to readers. In this chapter, several examples of control system applications and test signals used to analyze the performance of a particular system are also discussed for better clarity.

Chapter 2 discusses the need to understand mathematics that involves Differential Equations and Laplace Transform as a foundation that enables a system to be represented in the form of mathematical equation. A simple method of using Laplace Transform Table is used to solve control system problems are explained to readers. It also covers a State-space approach as a unified method for modeling and analyzing a wide range of systems. At the end of the chapter, it is shown how to use MATLAB in solving the related problems.

Chapter 3 explains the modeling of several systems with examples of how a particular physical system can be represented through mathematical equations. Physical systems discussed, however, are limited to the selected systems; electrical, mechanical and a combination of both, but the same methods can be used as a guide to determine the models for other systems in certain cases. This chapter discusses the detailed review of an electrical system, which followed by mechanical system involving both translational and rotational mechanical system. The final system discussed involves an electromechanical system that related to a DC motor, which is more complex if compared to the other two systems above since it is a combination of both electrical and mechanical systems. Finally, this chapter explained how transfer functions that represent control systems can be obtained and analyzed to determine their performance.

Chapter 4 describes in detailed on the time-domain analysis for a system in order to analyze the system performance as a whole. Analysis that involves transient response for a second-order system is also discussed in detailed whereas only brief explanation introduced for the first-order system and the higher-order system due to the first-order system is considered not so difficult if compared to the second-order system that involves several damping cases. As for the higher-order system, on the other hand, it is solved by using computer software since it is difficult to manually analyze this system. The solutions using MATLAB software is given at the end of this chapter with reference to the discussed examples.

Chapter 5 discusses in detailed the stability of a particular system that is an important analysis in determining the performance of a system. There are several methods that can be used to establish the stability of a system but only the method through Routh Hurwitz Table. Several cases that involve the completion of the Routh Hurwitz Table are also described through relevant examples to assist readers in understanding them. Discussion with analysis refers to the steady-state error is also described extensively. As in the previous chapters, examples of MATLAB simulation for both analysis, which are the stability and the steady-state error is also included. This chapter has become the foundation for Chapter 6 where another common used technique to analyze a control system is discussed.

Chapter 6 explains the Root Locus Method in detailed where it can helps analyzing a control system performance. Through graphical methods of Root Locus, direct portrayal of the system performance can be obtained as a whole especially referring to the transient response. Techniques of drawing root locus have been discussed systematically, which involve number of rules that need to be understood. As in the previous chapters, MATLAB simulation examples are also included where the procedures on how to plot root locus are shown. The Root Locus simulation analysis as a result of the step response output is also provided.

Chapter 7 covers the Frequency Response techniques where it is more effective compared to the Time Responses in order to model physical systems in the laboratory. The techniques provide not only the stability information but also the transient response information. This book only focuses on the technique called Bode Diagram or also known as Bode Plot where the plots of both magnitude and phase versus frequency are drawn in logarithm values using asymptotic approximations.

Aknowledgements

INTRODUCTION TO CONTROL SYSTEMS

1.1   INTRODUCTION

Control systems are the basis of many inventions which play an important role in the advancement of modern technology that has become more influential in current times. Among its functions that help people perform daily activities spanning various fields include:

a) Daily home appliances like refrigerators, automatic rice cookers, washing machines, etc.
b) Industrial needs like the manufacturing sectors such as vehicle factories, shoe factories, robotics etc.
c) Other needs like those used in the military sector, medical sector, electro-generation sector, astronomy and so on.

Apart from the above needs, the human self also has several control systems. For example, the human heart works to control the blood circulation to the whole body. Besides that, the lymph created by God functions as a glucose regulator in our blood while the brains acts as a guard who allows a person to think and take appropriate actions in certain matters. Imagine if one of these control systems go haywire in a person, that person will surely be unwell or in other words his condition is unstable. Hence, he will fall ill and his condition will deteriorate if he continues to be untreated, which may even lead to death. The same applies to machineries. For instance, a robot may react to hit itself or whatever is in its midst if the robot's control systems face problems. Therefore, with a good control system, it can be directed to perform certain duties automatically and precisely.

1.2   BASIC TERMINOLOGIES

There are several terms used in the learning of control systems. Among them are:

System   : An arrangement or combination of several different components that work together to achieve a primary objective.

Control   : To arrange or regulate a system to achieve a desired outcome.

Control Variable : Measureable quantity that can be controlled.

Manipulator Variable : Quantity that can be manipulated by a controller to affect a specific process.

Plant : Parts in a system that can be arranged or controlled.

Controller : A device which may be situated on the external of the system or is an element of the system itself. It functions as a control of a specific process or plant.

Input : A signal or stimulus put into a circuit in order to produce an outcome

Output : Actual response obtained from control systems based on the input signals delivered.

Disturbance : Undesirable signals that can hinder the output conditions of a system. These signals may originate from outside of the system or from within the system itself.

Feed-back : A mechanism responsible for measuring output that is obtained from a system for the purpose of delivering information to the controller so that the compensation process can be implemented.

Control systems : Components linked to the plant or, in other words, referred to as processes that can be controlled. A control system must consist of (1) input, (2) output, (3) a checklist, (4) a controller, (5) an activator and (6) feed-back.

Mathematical model : A structure or system that is described as a mathematical equation.

1.3 OPEN-LOOP CONTROL SYSTEMS

An open-loop control system is a kind of system whereby the output has no effect on the actual conditions encountered. This means the output is not measured against the input or, in other words, no feedback is involved in this particular system. An open-loop control system can be viewed in Figure 1.1 below:

Disturbance

```
┌───────────┐     ┌───────────┐       ┌──────────┐     ┌────────────┐
│ Reference │     │Controller │   ⊕   │ Actuator │     │Controllable│
│  Signal   │────▶│           │──▶(+)─▶│          │────▶│  System    │
└───────────┘     └───────────┘   +   └──────────┘     └────────────┘
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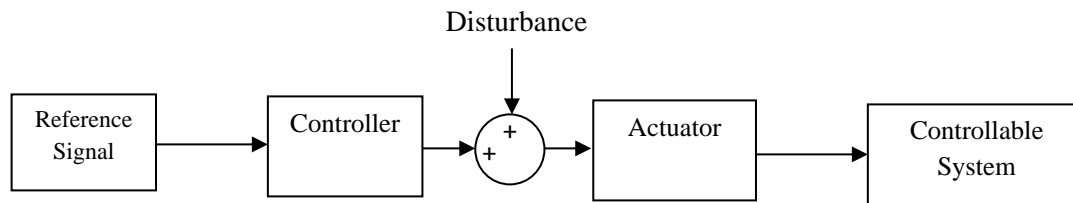
Figure 1.1: Open-Loop Control System

Most open-loop control systems are structured based on time, such as the bread toaster. It is difficult to gauge the acceptable standard a piece of bread is toasted. Therefore, the acceptable standard can only be ascertained by the duration of toast. The duration of toast depends on the consumers' requirements. This means the consumer have to rely on trial-and-error to ensure the piece of bread is toasted to their liking.

The open-loop control system is usually unsatisfactory because the system cannot compensate for any disturbance that occurs. This will cause the output not to meet the desired requirements. Thus, the open-loop control system is not suitable for systems that are difficult to control.

1.4   CLOSED-LOOP CONTROL SYSTEM

Closed-loop control system is also known as feedback control system. This form of control system has one or more feedback loops or circuits that seek to overcome the errors inherent in the system. This means the output from the system will be measured and compared with the input in order to ensure that the derived output is ascertained even before it is rectified by the controller. A closed-loop control system can be seen as in Figure 1.2 below:
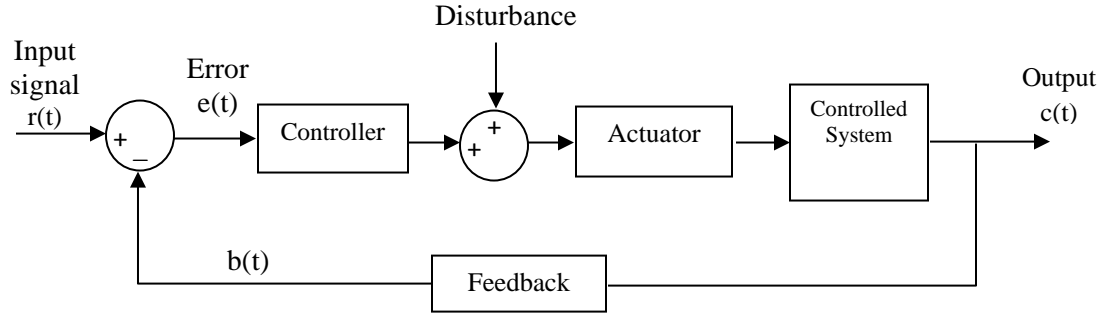
Figure 1.2: Closed-Loop Control System

The input signal, r(t) is also known as the reference signal whereby it becomes the set-point at the input to test the system. A closed-loop control system as in Figure 1.2 is a negative feedback control system because the b(t) signal is fed to the negative sign at the comparator. From this system, it can be deduced that the error signal can be expressed through the following equation:

$$e(t) = r(t) - b(t) \tag{1.1}$$

In the event of the b(t) signal is fed to a positive comparator then it is said to be a positive feedback control system. For this system, the error signal can be obtained through the following equation:

$$e(t) = r(t) + b(t) \tag{1.2}$$

The error signal e(t) that is produced is used as the input controller. The controller will act to ensure that the error can be eliminated. The effectiveness of the controller to eliminate the errors depends on the kind of the controller used. There are controllers that can totally eliminate the errors while there are others that can only reduce it significantly.

An example of the closed-loop control system that is frequently being used today is the air-conditioning system with an adjustable temperature controller. The air-conditioning system will operate according to the needs of the user. It will operate according to the temperature set by the user despite disturbance from external environmental temperature. For instance, if the

temperature is set at 18°C, then the air-conditioning system will operate to ensure that the temperature in the room stays at 18°C although the temperature outside is almost reaching 30°C. Other examples of a closed-loop control system are processing control system, missile launching system, voltage stabilizers, so on and so forth.

1.5   COMPARISON BETWEEN OPEN-LOOP AND CLOSED-LOOP SYSTEMS

Table 1 below shows the pros and cons comparison between the open-loop and closed-loop systems.

Table1: Comparison of the Open-Loop and Closed-Loop Systems

	Open-Loop System	**Closed-Loop System**
1. 2. 3. 4.	Advantages An easy system Inexpensive Usually this kind of system faces many instability problems Suitable for systems that involves output that is difficult to measure	Advantages Not sensitive towards external influences Has high levels of accuracy Able to reduce instability
1. 2. 3.	Disadvantages Sensitive towards external influences Inability to influence instability Constant calibration of the controller is required to ensure the quality and accuracy of the system	Disadvantages System is usually complex The system can become unstable

1.6   FEEDBACK EFFECTS

With the availability of feedback, hence the error that exists between the input and the output of a system can be reduced. Besides that, there are also other effects, namely:

(i)   Sensitivity improvement

(ii)   Multiplication reduction as per the following factors:

$$\frac{1}{1+G(s)H(s)} \tag{1.3}$$

1.7   EXAMPLES OF CONTROL SYSTEM APPLICATIONS

Example 1: *Liquid Level Control System*

This system is aimed at controlling the levels of liquid that flows in a tank. This is considered a closed-loop system whereby it is controlled automatically. The controller within the system functions to control the valve opening of the inflow of the fluid to ensure that the water levels remain at the suitable level in order to avoid shortages and overflow in case of excess of supply.
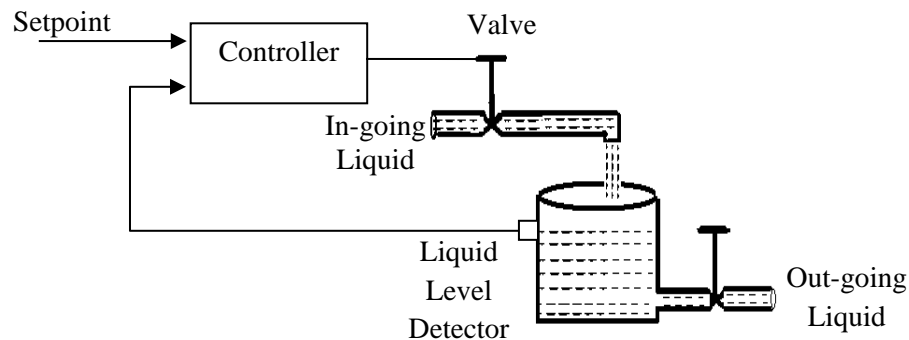

Figure 1.3: Liquid Level Control System

Referring to Figure 1.3, the operation of the valve at input will always be activated according to the errors from the difference between the set point and the reading from the liquid level

detection. The controller will act to ensure the valve is closed if the reading sensor shows that it is at the maximum level. On the other hand, the valve will be opened if the sensor is unable to detect the existence of the fluid. Figure 1.4 shows the diagram of the block that represents this system.
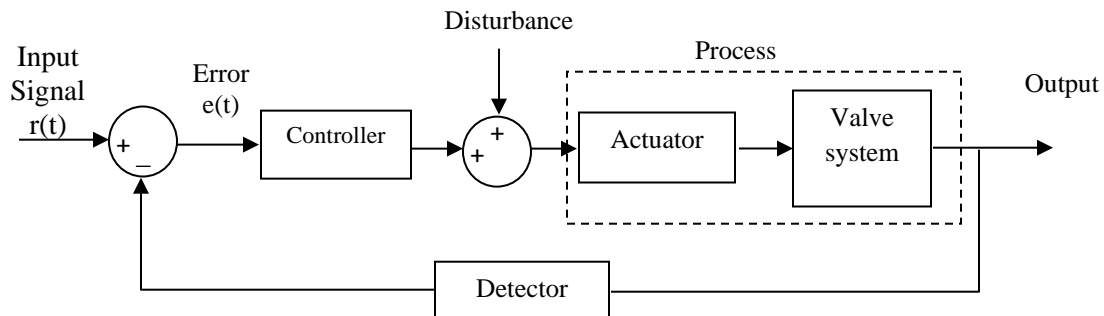

Figure 1.4: Block Diagram of Closed-Loop Liquid Level Control System

Example 2: *Room Temperature Control System*

Figure 1.5 shows a physical diagram of a temperature control system that functions by controlling the temperature in a room or space. Based on the diagram shown, the controllable variable is the temperature through the open-close valve which is the definitive element that can be controlled to produce temperature that it required by the heater. The thermometer functions continuously to measure the temperature in the room and channel the information to the controller to ensure the temperature is the same as the input system's setting. If there is a difference between the two, the controller has to ensure the resulting error can be rectified and hence send the signals to the solenoid valve with the purpose of rearranging the gas flow into the said space.
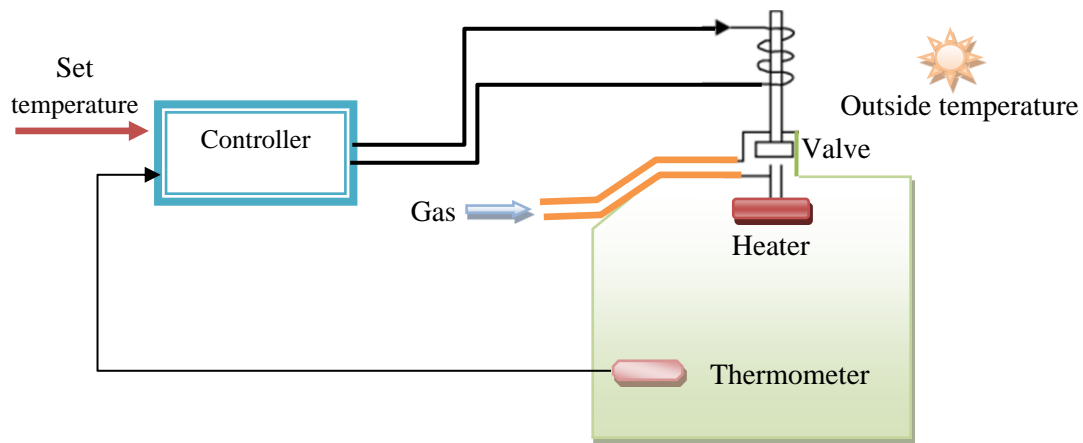
Figure 1.5: Room Temperature Control System

For this system, the final value also known as the steady-state value can only be achieved if the actual temperature in the space is the same as the temperature that is set at the input of the system. Figure 1.6 shows the block diagram that represents this system.
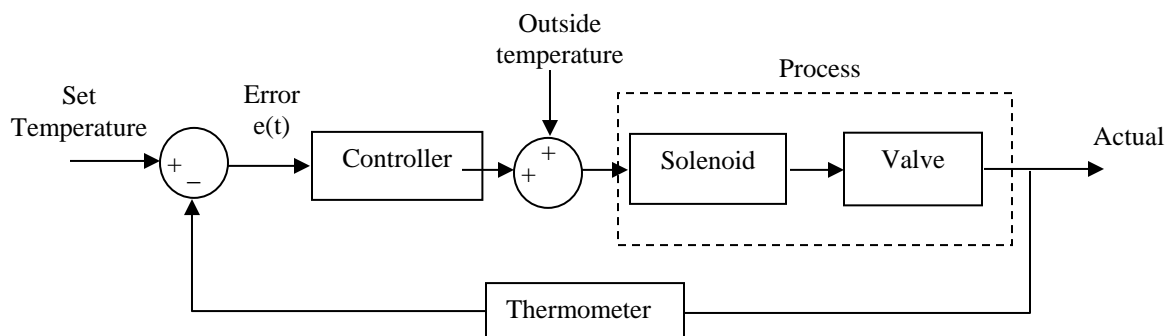

Figure 1.6 : Block Diagram of Closed-Loop Room Temperature Control System

1.8   TEST SIGNALS

There are many types of test signals that can be used to test a particular system. Among the common test signals that are being used are:

(i)   Steps input

(ii)   Ramp input

(iii) Parabolic input

(iv)   Impulse input

In this book, only step, ramp and parabolic input that will be discuss seen there are the most common of test input signals used in control systems.

1.8.1 STEP INPUT

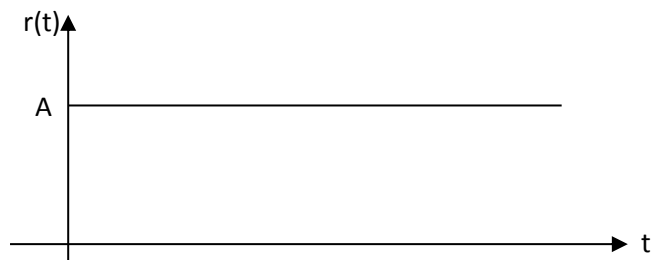The steps input can be viewed as per Figure 1.7 below:

Figure 1.7 : Steps Input Signal

The step input can be mathematically represented as follows:

$$\left.\begin{array}{l} r(t) = 0 \ untuk \ t < 0 \\[2mm] r(t) = A \ untuk \ t \geq 0 \end{array}\right\} \qquad (1.4)$$

Based on the Eq. 1.4, if A=1, function r(t)=u(t)=1. In this case, this is called unit step. This step signal is often used to test a particular system because the shift in its amplitude is easier to explain the transient response of the system.

1.8.2   RAMP INPUT

The ramp input is considered a signal that can change with time as seen in Figure 1.8 below:
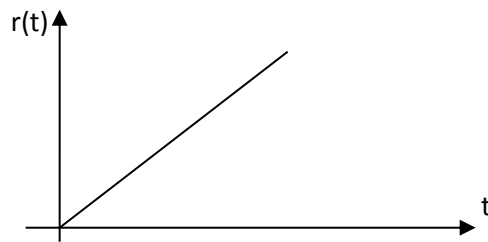

Figure 1.8 : The Ramp Input Signal

Mathematically, the ramp input can be represented as follows:

$$\left.\begin{array}{l} r(t) = 0 \ untuk \ t < 0 \\[2ex] r(t) = At \ untuk \ t \geq 0 \end{array}\right\} \tag{1.5}$$

1.8.3 PARABOLIC INPUT

Figure 1.9 shows the parabolic input signal:
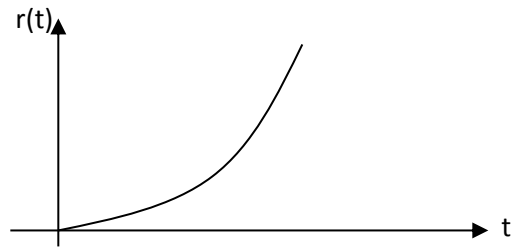

Figure 1.9 : Parabolic Input Signal

In terms of Mathematics, the equation can be represented in 1.6 below:

$$\left.\begin{array}{l} r(t) = 0 \ untuk \ t < 0 \\ \\ r(t) = At^2 \ untuk \ t \geq 0 \end{array}\right\} \qquad (1.6)$$

1.8.4 IMPULSE INPUT

Impulse input can be defined by the mathematic equation below:

$$\left.\begin{array}{l} \delta(t) = 0 \ untuk \ t \neq 0 \\ \\ \delta(t) = 1 \ untuk \ t = 0 \end{array}\right\} \qquad (1.7)$$

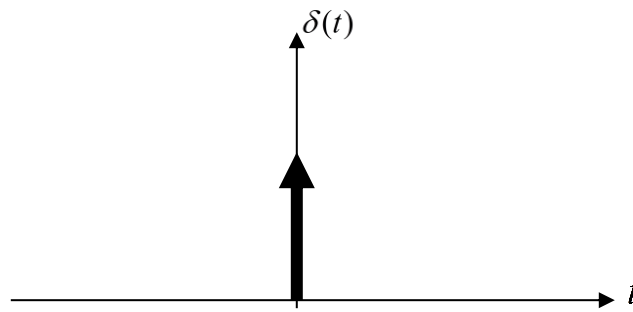In clearer terms, it can be viewed through the following Figure 1.10:

Figure 1.10: Impulse Input

The impulse input is usually used to test how a particular system will react to input that changes momentarily. For instance, the suspension system of a car when going through uneven roads.

1.9   SUMMARY

In this chapter, the introduction to control system has been briefly discussed which covers several fields in the technical form as well as otherwise. Basic terminologies contained in control systems are also explained for ease of understanding and application in discussions in the following chapters. Description and comparison between open-loop system and closed-loop system have also been discussed clearly by taking examples from our surroundings so that it can be illustrated and understood easily. Further in this chapter, there are several examples of control system applications aimed at ensuring that the reader is able to understand what has been described in this chapter with better clarity. Test signals used to analyze the performance of a particular system is also discussed in brief at the end of this chapter. Understanding of this chapter will be used as a platform to value the following chapters.

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