CONTROL SYSTEMS, ROBOTICS, AND AUTOMATION

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Contents

Summary

Life support systems (LSS) are related with technical, economical, biological, or ecological fields. In almost all technical systems automatic control devices are used. Spectacular human achievements, such as energy generation by power plants, petroleum refining, space missions, traveling by airplanes, railways, and cars, to mention only a few, have been rendered possible only because of the progress of control technology. The question is not "what do control, automation and robotics have to do with LSS," but "how can LSS design and operation be improved by the support of control technologies"? Doubtless, control engineering represents one of the key technologies of the future, together with information technologies.

Control engineering has been essential for the evolution of, and revolutions in, automation. It is important that developments at low-level continue, although the main impacts for further research and development are nowadays mainly increasing at higher system levels, where new types of functionality and intelligent control systems are located. The computational infrastructure providing the necessary hardware and software is already available through the fast advances in information technologies.

This article tries to give a broad and, hopefully, easily understandable introductory survey of classical and modern theoretical methods and applications concerned with the theme "Control Systems, Automation and Robotics." It is not possible in such an introductory contribution to cover all theoretical and practical aspects of the field. Section 1 provides a short introduction to the basic elements of control systems and automation.

Section 2 outlines the difference between feedforward and feedback control structures. Section 3 covers the basic ideas of analysis and design for classical feedback control systems, whereas Section 4 presents the structures of higher-level modern control systems. Section 5 is concerned with applications in robotics and other engineering disciplines as well as in nontechnical areas. Section 6 provides an insight into the

historical development of automatic control systems, and, finally, in Section 7 some trends in future developments are discussed. Some critical remarks in Section 8 conclude this article.

Due to the relatively simple mathematical treatment, this article addresses a broad spectrum of readers who may only have elementary knowledge in engineering and mathematics. For those who would like a deeper insight, they can select from nearly forty topic-level contributions under this broad theme. Finally, those who wish to further specialize can find valuable information on the state of the art in around 180 article-level contributions under this theme.

1. Introduction

1.1. What is a Dynamical System?

Control can be found in technical as well as nontechnical systems. A system can be a single object, element, component, or a collection of objects by some form of interconnection or interdependence. A system is characterized by input and output variables for which there are cause–effect relationships. For example, a simple system is given by a thermometer the input variable of which is the temperature to be measured. The output is the indicated physical value on a standard scale.

If a thermometer indicating room temperature is put suddenly into hot water then the indication of the high temperature takes a short time to reach the high true scale value. Due to the time-dependent indication, a thermometer can be denoted as a *dynamical system*. The time-behavior can be described by the curve of the indicated temperature (output variable) after suddenly changing the ingoing temperature (input variable) from 20 ºC to 80 ºC as shown in Figure 1.

In such a system the cause-effect relationship is given by the arrows of the input and output variables representing the direction of the *signal* or information flow within the system. A **s**ingle-**i**nput/**s**ingle-**o**utput (SISO-) system is usually characterized by a symbolic block structure as in Figure 1.

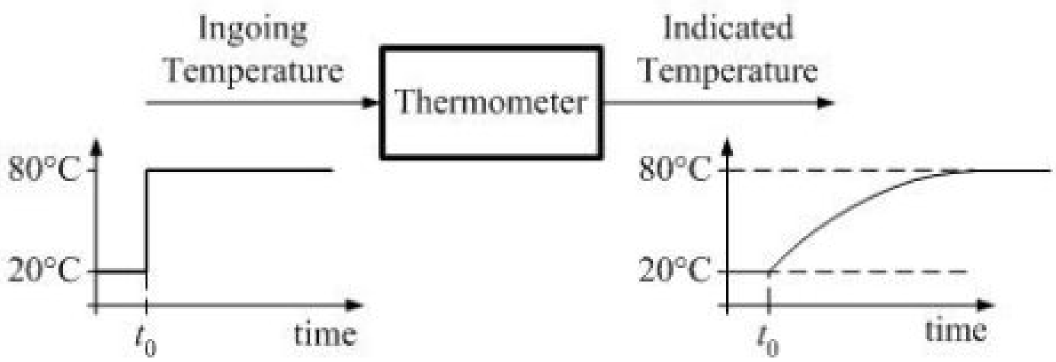

Figure 1. Block diagram and time response of a thermometer representing an example of a SISO system

A system having several input and/or output variables is denoted as **m**ulti-**i**nput/**m**ulti-**o**utput (MIMO-) or multivariable system, as for example a boiler with temperature and pressure of the superheated steam as output and fuel, and air and water flow rates as input variables. In many cases SISO- and MIMO-systems can be arranged in several interconnected and hierarchically organized levels, as it is the case in complex production or economic processes. Such systems are defined as multi-level or large-scale systems.

1.2. Introductory Examples for Simple Closed-Loop Control Systems

The terms, *control* and *system* are closely interrelated. Control is the process of forcing a system output variable to conform to some desired value, called reference value. Control can be performed manually, automatically or semi-automatically. In order to gain a better understanding of the task of control, some simple examples are considered. Driving a car is an excellent example of manual control. The driver has to follow the given direction of a road. He/she observes the actual path of the car and then forces the car, operating the steering wheel, to track the desired path as closely as possible. The driver performs the following steps in detail:

- The driver uses his eyes as sensors for obtaining *measurements*, both of the car's actual path and the road course.
- Then he/she compares both directions and generates an *error signal,* which is used to decide in which direction to move the steering wheel.
- The driver *actuates* the steering wheel according to his decision, making the car, the controlled object, move to the desired direction.

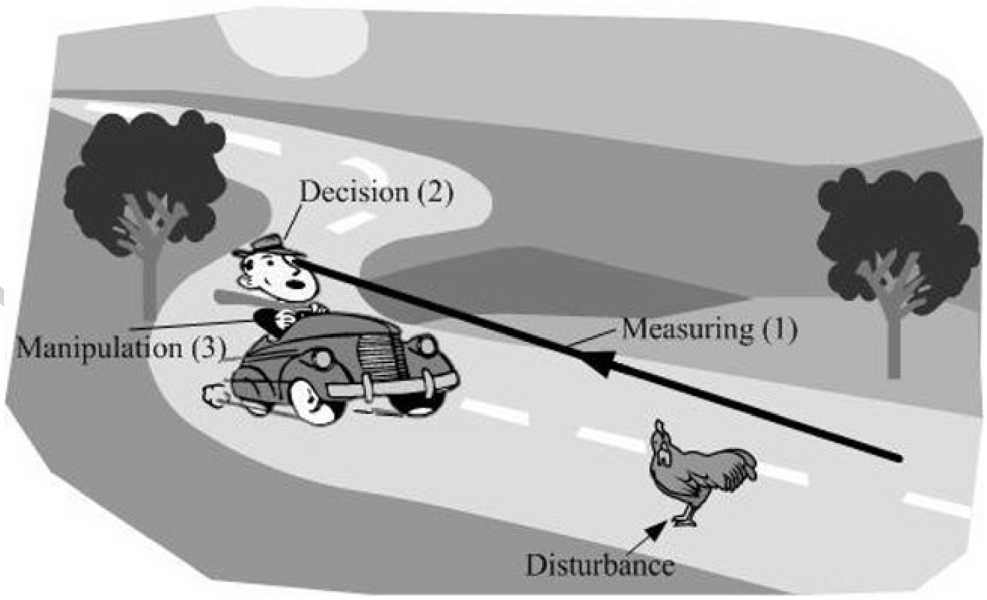

Figure 2. Manual control of a car's direction of travel

An animal or any hindrance on the road acts as a disturbance and should be avoided if possible. After reaching such a disturbance, the driver must return the car to the desired direction. These three steps of measuring, decision, and manipulation are characterizing the driver's manual control action (see Figure 2).

As another example, let us briefly consider the tiresome problem of controlling body weight. Let us assume that an overweight person decides to reduce his/her weight to the desired amount by following a recommended diet. Every day he/she measures his/her weight and compares it with the desired one. The error or difference between actual and desired weight is used for deciding whether to continue or to stop the diet. His/her action, when continuing, is to resist all culinary temptations, so he/she may reach, after a few weeks, the desired ideal weight.

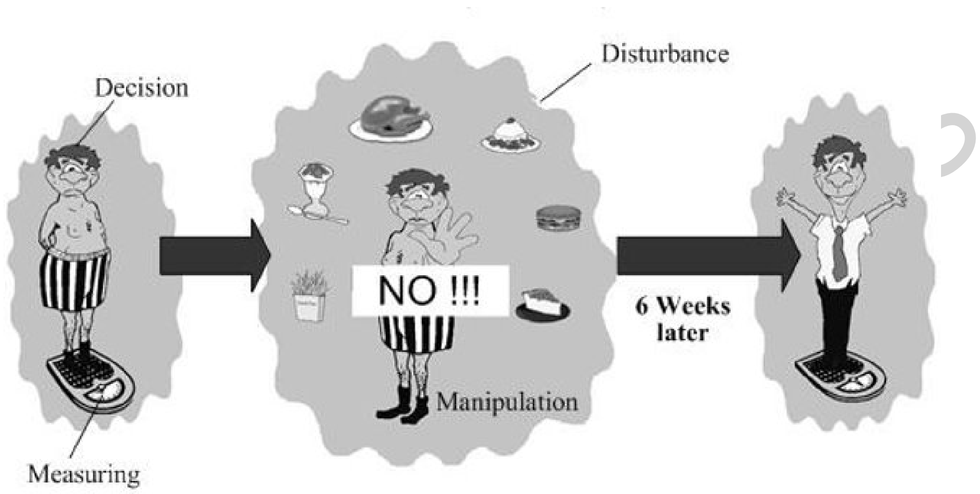

Figure 3. Body weight control problem

The procedure of measuring, decision, and manipulation again represents a typical control task (see Figure 3).

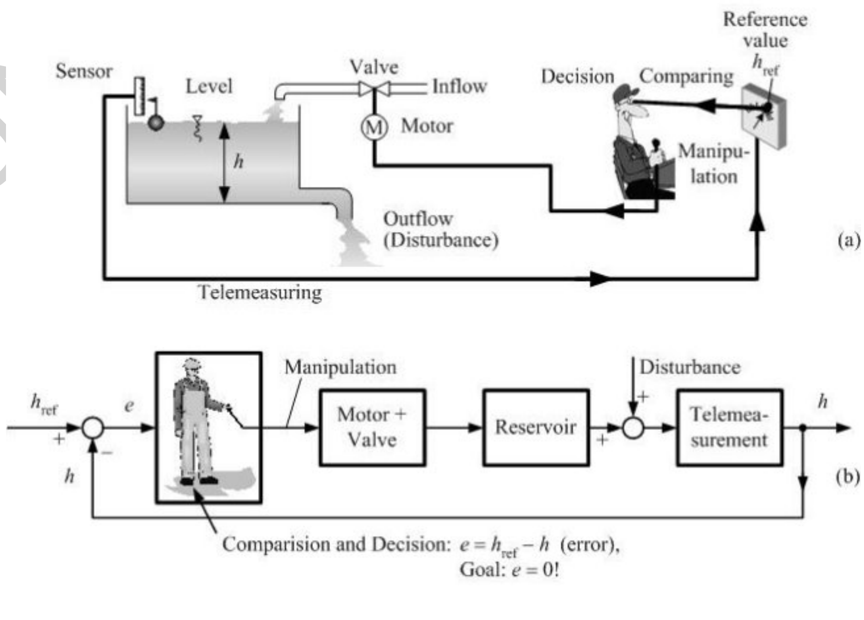

Figure 4. Manual level control (a) and corresponding block diagram (b)

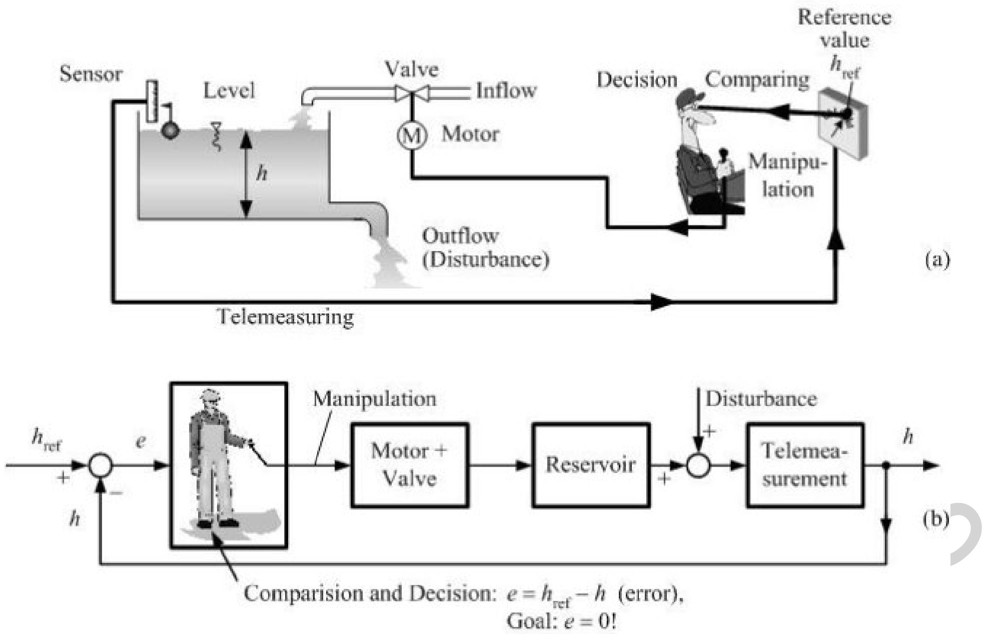

Figure 5. Block diagram of an automatic closed-loop control system (*r* reference value; $e = r - y$ error or actuating variable; *d* disturbance; y' controlled variable; *y* measured controlled variable; *u* control variable; u' manipulating variable)

The last example is concerned with the problem of keeping the level in a water reservoir constant. Figure 4 shows that the information of the level sensor is directly transmitted to the operator's panel board.

The operator compares the measured and desired (reference) values. If the measured level deviates from the desired level, the operator actuates a motor-driven valve to increase or decrease the water flow until the reference level is reached again. Changes in the water flow rate at the outlet have to be considered as disturbances for the level control. All steps performed by the operator are typical *manual control* actions. Of course, in this case the operator can easily be replaced by a device, denoted as controller. Thus the complete control action is performed by an *automatic control* system, as shown in Figure 5. In all examples discussed above we have a similar block structure as in Figure 5.

1.3. Block Diagram Representation

From Figures 4 and 5 we see that the operation of control systems can easily be represented by a block diagram in which single blocks are connected by signals, characterized by straight lines with arrows.

A box is used as a symbol for a system in which the input signal is processed, by a special operation (or operator), to obtain the corresponding output signal. A circle is the symbol to indicate, with the corresponding sign, a summing or subtracting operation. Block diagrams have the advantage of characterizing very realistically the actual processes that are taking place, because blocks can be combined to form the overall block diagram for an entire system.

1.4. Automatic and Manual Control

Automatic control systems can be found in many places. In engineering applications they range from simple, switch-controlled thermostats used in every electric iron or coffee machine, up to highly advanced autopilots for supersonic aircrafts. The human's capability to build such devices, which automatically control the broad range of machines and technical processes, represents a cornerstone in the development of modern technology. Control systems have influenced our way of life and have become an integral part of modern society.

Their applications are ubiquitous and exist all around us. They are often referred to as stealth technology, and are sometimes a big secret, because they are usually invisible as an integral part of a plant, and the user is more interested in the desired result. Automatic control has played an important role in the development of engineering and science by controlling all kinds of devices required for increasing productivity and maintaining quality of life. In an advanced society automatic control systems are necessary for the production of goods required by an increasing world population. Nevertheless, manual control is still applied in many cases, especially where safety is involved, as in supervisory roles, such as an operator in a power plant or a driver of a car or bicycle.

1.5. Automation and Robotics

The control of industrial and other processes, mentioned above, by automatic rather than manual means is often called *automation*. Automation has played an integral part, and a vital role not only in modern industrial processes, but also in traffic, robotics, and automotive systems. Typical examples where automation takes place include: chemical, steel, electric power, and automobile industries, among others. Automation is characterized by self-acting machines and devices with integrated control systems that are often arranged in complex industrial processes or systems.

Automation of such processes as tooling, handling, and assembling consists of measuring, controlling, monitoring, supervising, and so on, and is usually arranged in several hierarchically structured levels and co-ordinated by a supervisory control system. Automation provides a means for attaining optimal product quality, increases productivity, and relieves humans of many monotonous, routine, and repetitive activities. Furthermore, automation can perform tasks, which are far beyond the physical abilities of humans, such as positioning accurately a large radio telescope at the predetermined location.

Nowadays, many automated industrial manufacturing processes are performed by multiple-link computer-controlled robots. Their links rotate in a co-ordinated manner corresponding to a variety of tasks, such as welding, spray-painting, or parts assembling in the automobile industry. The engineering discipline for developing and application of multi-link computer-controlled robots is relatively new and is denoted as "robotics." Control systems engineering, besides image processing and measurement techniques, represents essentially the background for robotics.

1.6. Cybernetics

However, control systems span not only the entire field of human engineered systems, they also exist in nature, which is equipped with superb engineering capabilities. In our body we have high-precision control systems for regulating the body temperature, blood sugar, blood pressure, eye-movement, hand position, up-right standing, and many more. In living objects, control systems have existed as long as life itself. But also many phenomena in economics and social systems can nowadays be considered as due to control.

The relationship between the dynamical behavior in technical, biological, economic, and social control systems is obvious and, therefore, has given rise to “cybernetics,” which was so named in 1948. Although this general definition describes all systems, living and technical, to be both information and control systems, it has not become very popular in engineering sciences. Nevertheless, all kinds of control systems can be dealt with using the same tools of control system theory.

2. Feedforward and Feedback Control

As already discussed, control systems widely exist and they are truly inter-disciplinary in terms of the knowledge associated with them. However, they all share common characteristics. Their primary function is to act and provide as an appropriate input signal to a dynamic process or plant such that a desired behavior in terms of the output signal is achieved. The cause–effect or input–output relationship represents the dynamic behavior of the process, and can be described by a mathematical model.

The plant input signal caused by the controller unit and physically realized by the actuator is called control signal and manipulating signal, respectively. Disturbances also acting as input signals onto the plant behavior can be either constant or time-varying. The desired behavior of the plant output signal is usually given by a reference input signal to the controller. Two basic control structures are available to accomplish the control task and will be described briefly in the following.

2.1. Feedforward or Open-Loop Control

In a feedforward control system (as depicted in Figure 6), the reference signal is directly processed by the controller. Each setting of the reference input determines the objective of the control element or controller to achieve, through the actuator, the desired behavior of the plant output. For properly achieving the goal of control, the controller must be calibrated precisely and, furthermore, no disturbances or plant variations are expected to occur. This calibration is necessary for establishing or reestablishing the input/output relation of the plant to obtain the desired system accuracy.

This control structure is, therefore, only effective in relatively simple situations, in which disturbances and variations of plant parameters do not influence significantly the actual plant output. Obviously, in this feedforward control structure, the control action is completely independent of the actual plant output. The result of the control action, that is the actual plant output, is not measured. A precise calibration of the controller provides a good control action only for the desired reference input, but cannot compensate for other inputs such as disturbances and parameter changes of the plant. A major advantage of feedforward control systems is that they are generally not troubled with problems of instability.

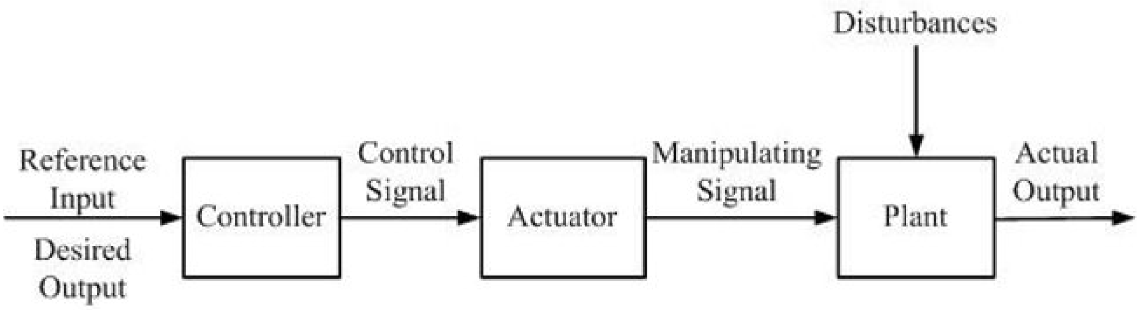

Figure 6. Block diagram of a feedforward control system

The application of feedforward control systems is recommended particularly when measuring the output signal is either difficult or not economically feasible. A typical example for a feedforward control system is a washing machine, where soaking, washing, and rinsing follow a desired time program. The cleanliness of the clothes, which represents the output variable, is not measured by the machine. Another example is a traffic control system controlled by traffic lights operating according to a time program.

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Zilouchian, A.; Jamshidi, M. (eds.) 2001. *Intelligent Control Systems Using Soft Computing Methodologies*, Boca Raton, Fl., CRC Press.472 pp. [This volume constitutes a report on the principal elements and important applications of soft computing as reported from some of the active members of this community.]

Some Important Journals

Automatica

European Journal of Control

IEE Proceedings on Control Theory and Applications

IEEE Transactions on Automatic Control

IEEE Transactions on Control Systems Technology

IEEE Control System Magazin

IEEE Transactions on Robotics and Automation

International Journal of Control

Some Important Conference Proceedings

IFAC (International Federation of Automatic Control)

CDC Control and Decision Conference (organized by the Institution of Electrical and Electronic Engineers (IEEE))

ACC (American Control Conference)

ECC (European Control Conference)

Biographical Sketch

Heinz D. **Unbehauen** is Professor Emeritus at the Faculty of Electrical Engineering and Information Sciences at Ruhr-University, Bochum, Germany. He received the Dipl.-Ing. degree from the University of Stuttgart, Germany, in 1961 and the Dr.-Ing. and Dr.-Ing. habil. degrees in Automatic Control from the same university in 1964 and 1969, respectively. In 1969 he was awarded the title of Docent, and in 1972 he was appointed as Professor of Control Engineering in the Department of Energy Systems at the University of Stuttgart. Since 1975, he has been Professor at Ruhr-University of Bochum, Faculty of Electrical Engineering, where he was head of the Control Engineering Laboratory until February 2001. He was dean of his faculty in 1978/9. He has been a visiting professor in Japan, India, China, and the USA. He has authored and co-authored over 400 journal articles, conference papers and seven books. He has delivered many invited lectures and special courses at universities and companies around the world. His main research interests are in the fields of system identification, adaptive control, robust control, control of multivariable systems, neuro-fuzzy control, predictive control, and control of mechatronic systems. He is Honorary Editor of *IEE Proceedings on Control Theory and Application and System Science*, Associate Editor of *Automatica*, and serves on the Editorial Board of the *International Journal of Adaptive Control and Signal Processing, Optimal Control Applications and Methods* (OCAM) and *Systems Science*. He also served as associate editor of *IEEE-Transactions on Circuits and Systems* as well as *Control-Theory and Advanced Technology* (C-TAT). He is also an Honorary Professor of Tongji University Shanghai. He has been a consultant for many companies as well as for public organisations, for example, UNIDO and UNESCO. He is a member of several national and international professional organisations and a Fellow of the IEEE.