BASIC ELEMENTS OF CONTROL SYSTEMS

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Contents

Summary

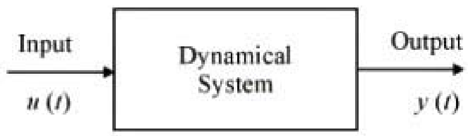
This article introduces the basic concepts of negative feedback as applied to several simple control systems and presents some important aspects of graphical representation of systems in block diagrams and signal flow graphs. The developments in the field of automatic control are briefly reviewed in the history of the field in four distinct periods.

1. Dynamical Systems

A dynamical system manipulates entities such as energy, material, information, capital investment etc. It is characterized by relationships among certain variables that are chosen in its description. Usually inputs (causes) and outputs (effects) are important variables, which are connected by relations. Although a relationship is a function of time, the properties embedded in it may be time-invariant.

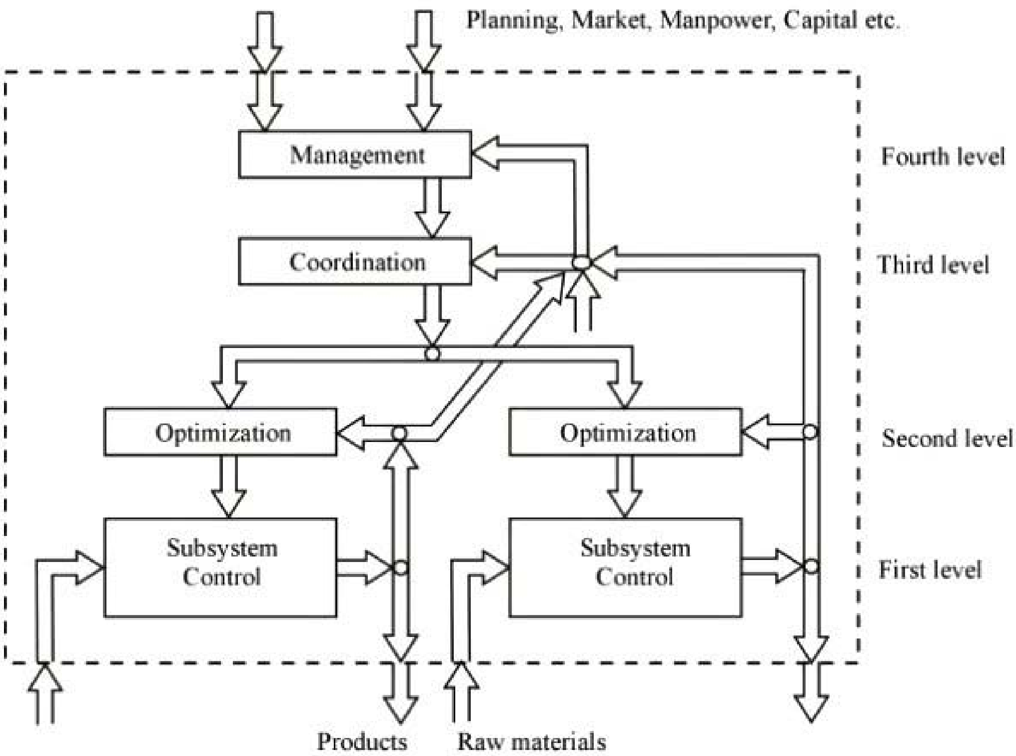
A system may have only one input and one output. Such a system is termed a single-input-single-output (SISO) system. Some may be multiple-input-multiple-output (MIMO) systems. Large systems are characterized by several levels of organization, in a hierarchy. Figure 1 shows the schematic diagrams of systems indicating such features.

The fields of systems, control and information processing are closely related to the science of cybernetics. Cybernetics attempts to understand the behavior of the system in nature. This understanding leads to the knowledge enabling us to improve the performance of natural or man-made processes. In recent years, techniques of systems, control and information processing, are handled with less reference to machines and other man-made physical processes, under the general name of “Systems Science” (see *Systems Science and Cybernetics*)



a) A SISO System

b) A MIMO System



(c) A hierarchical multilevel system

Figure 1. Schematic representation of systems

2. Graphical Description of Systems

Dynamic systems are denoted as transfer elements. Every transfer element has at least one input and at least one output. The transfer process in the element is denoted graphically in the form of a block diagram. The transfer elements are shown as blocks connected to one another. Figure 2 shows an example. Table 1 shows certain symbols in a block diagram representation of systems. Block diagrams are different from circuit diagrams or those showing effort and flow variables in that the output of a transfer element in a block diagram depends only on its own input but not on the elements connected to its output side, in other words, there is no loading effect. Transfer elements are also not reversible in their action, which is uniquely indicated by an arrow showing the direction of action.

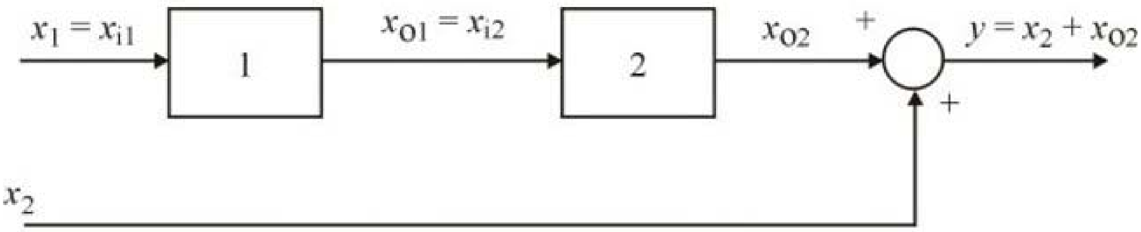


Figure 2. Example showing a system with several transfer elements in the form of a block diagram.

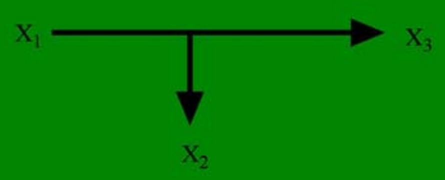
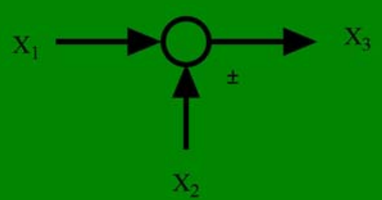
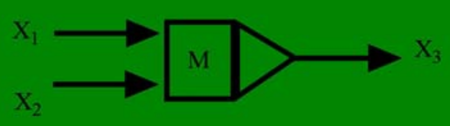
Element	Representation	Mathematical Model
Tapping point		$X_1=X_2=X_3$
Summing junction		$X_3=X_1 \pm X_2$
Multiplier		$X_3=X_1 \cdot X_2$

Table 1. Notation in block diagram representation of systems.

The transfer relation in an element can be represented in many forms in a block diagram. In the case of linear systems, usually one inserts the related differential equation between the input and output or the transfer function or frequency response (see *Description in Frequency Domain*) in the related blocks as shown in Figures 3(a) and (b).

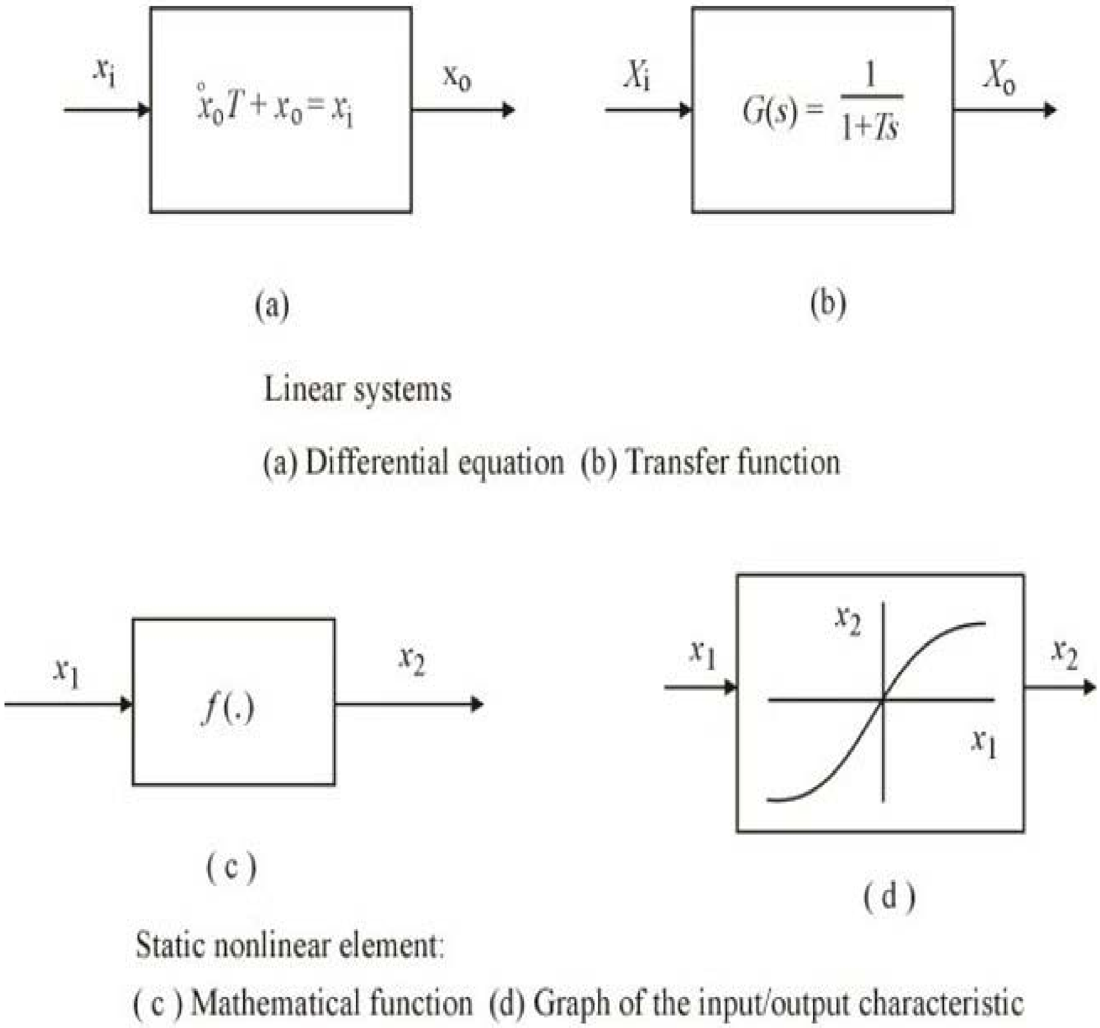


Figure 3. Some possible descriptions of transfer elements (a) Differential equation (b) Transfer function (c) Mathematical function (d) Graph of the input/output characteristic.

In the case of static non-linear elements, the description in the block symbol is either the mathematical functional description of the non-linear characteristic or the graph of the non-linear function as shown in Figures 3 (c) and (d).

Variables in frequency domain are denoted by capital letters.

Alternatively, signal flow graphs may also be used to describe systems. Signal flow graphs are close in spirit to block diagrams. In a signal flow graph, the nodes represent signals and the branches between the nodes represent the transfer relations. Figure 4 shows some examples of block diagrams and the corresponding signal flow graphs.

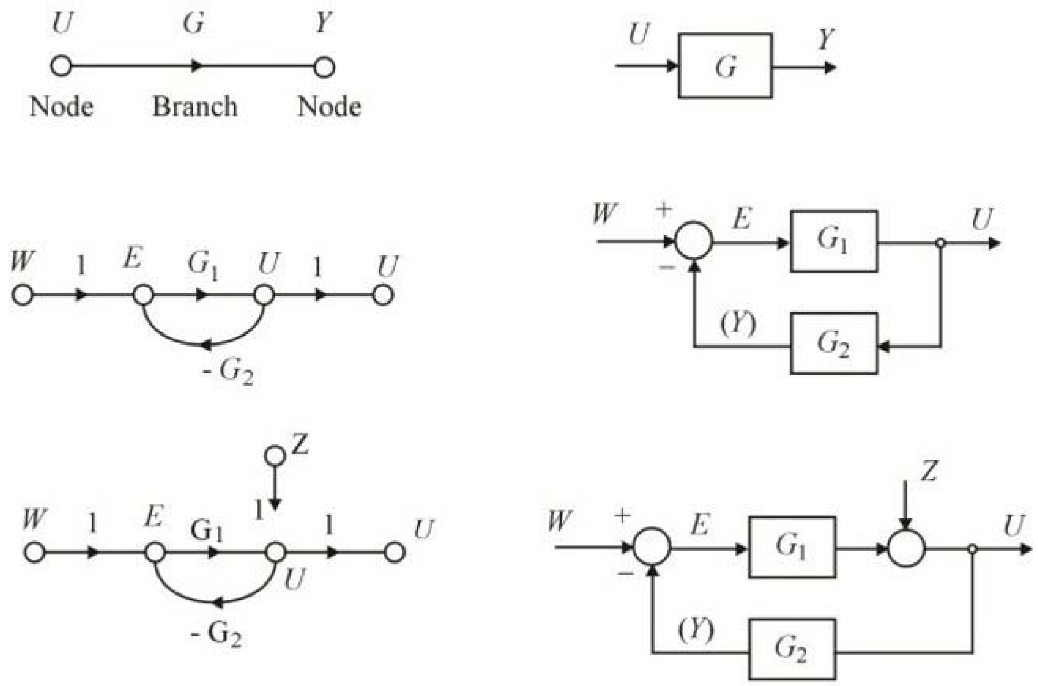


Figure 4. Correspondence between signal flow graphs and block diagrams.

3. Open-loop Control and Closed-loop Control.

The distinction between open-loop and closed-loop control can be well understood with the help of the example of room temperature control. In the open-loop control scheme for room temperature shown in Figure 5, the ambient temperature θ_A is measured and given to a controller, which controls the motor M, which in turn operates a valve *V* to control the flow *Q* of the heating fluid in accordance with a relation $Q = f(\theta_A)$. The controller is preset to follow this relation. If the room temperature θ_R changes, say due to an opening in the window, denoted as a disturbance z_1, the valve *V* remains unaffected since only the ambient temperature influences the flows of warm fluid. In this case, which is termed as open-loop control, the effects of disturbances are not countered.

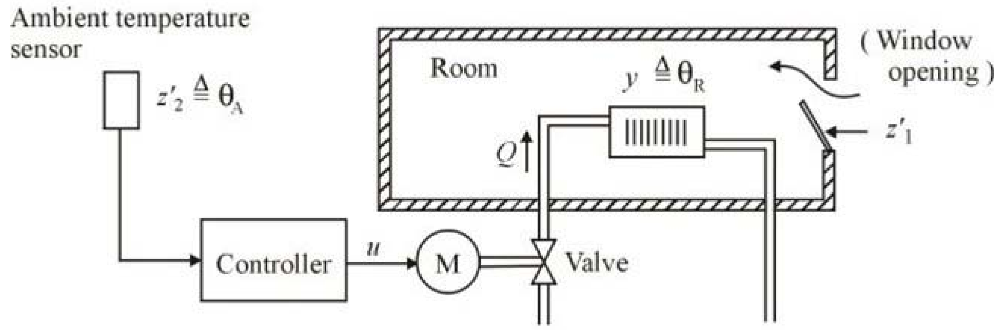


Figure 5. Open-loop room temperature control system

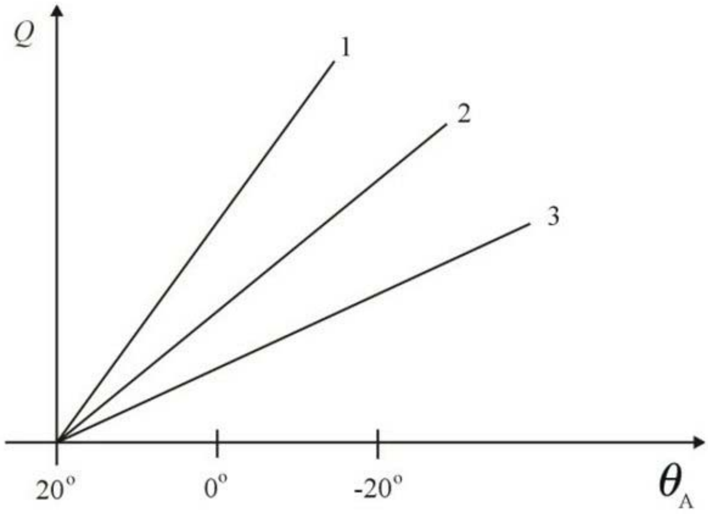


Figure 6. Pre-determined control strategies for three different settings.

In the closed-loop control scheme that is shown in Figure 7, the room temperature θ_R is measured and compared with the desired or reference value *w* and the controller is driven by the disparity between θ_R and *w* to alter the flow *Q* of the heating fluid.

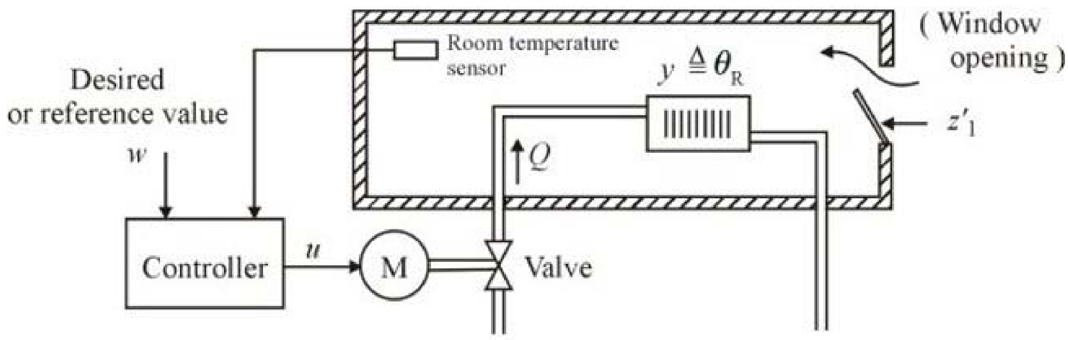


Figure 7. Closed-loop room temperature control system.

Unexpected changes may occur in θ_R either due to the opening of the window or through sunlight entering the room, or both, but these are countered by the controller in closed-loop control. The block diagrams of these two schemes, namely open-loop and closed-loop control systems, shown in Figures 8 and 9, make the difference between them clear. Closed-loop control is characterized by the following steps:

Measurement of the controlled variable *y* or the actual value of the controlled plant output

Determination of the control error $e = w - y$ by comparison of the actual and the desired values of the controlled variable

Use of the error to change u, the plant input, to reduce the control error e to zero or to a negligible value.

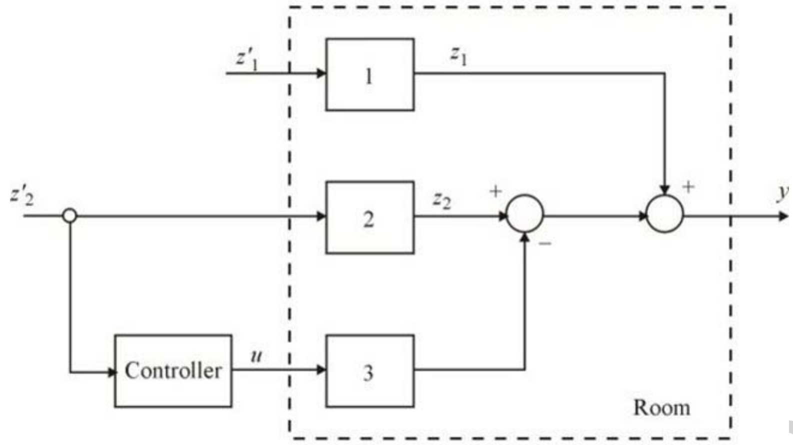


Figure 8. Block diagram of open-loop room temperature control system.

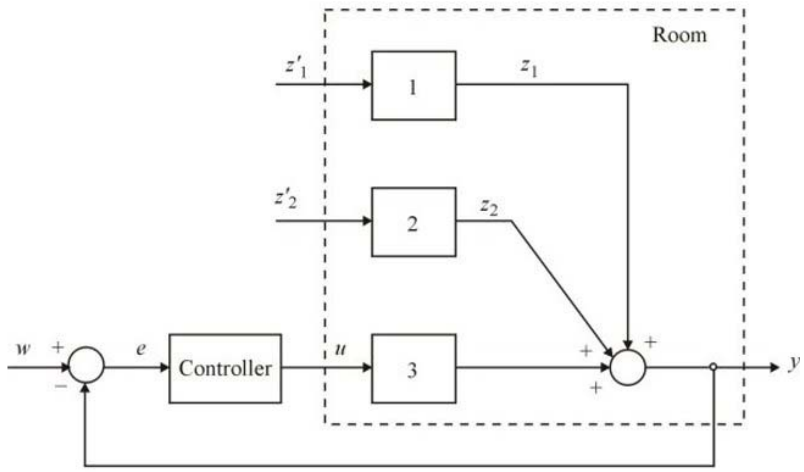


Figure 9. Block diagram of closed-loop room temperature control system.

Open-loop and closed-loop control differ from each other in the following aspects:

Close loop control

- involves closed-loop operation or feedback,
- counters the effects of disturbances due to the action of negative feedback, and
- may be unstable, i.e., the controlled variable (plant output) can either oscillate or grow beyond bounds.

Open-loop control

- involves open-loop operation,
- can counter the effects of known disturbances only while other

disturbances cannot be taken into account, and

- if the controlled object (plant) is itself stable, the control system remains stable.

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Biographical Sketch

Ganti Prasada Rao was born in Seethanagaram, Andhra Pradesh, India, on August 25, 1942. He studied at the College of Engineering, Kakinada and received the B.E. degree in Electrical Engineering from Andhra University, Waltair, India in 1963, with first class and high honours. He received the M.Tech. (Control Systems Engineering) and Ph.D. degrees in Electrical Engineering in 1965 and 1970 respectively, both from the Indian Institute of Technology (IIT), Kharagpur, India. From July 1969 to October 1971, he was with the Department of Electrical Engineering, PSG College of Technology, Coimbatore, India as an Assistant Professor. In October 1971, he joined the Department of Electrical Engineering, IIT Kharagpur as an Assistant Professor and was a Professor there from May 1978 to June 1997. From May 1978 to August 1980, he was the Chairman of the Curriculum Development Cell (Electrical Engineering) established by the Government of India at IIT Kharagpur. From October 1975 to July 1976, he was with the Control Systems Centre, University of Manchester Institute of Science and Technology (UMIST), Manchester, England, as a Commonwealth Postdoctoral Research Fellow. During October 1981- November 1983, May-June 1985 and May-June 1991, he visited the Lehrstuhl fuer Elektrische Steuerung und Regelung, Ruhr-Universitaet Bochum, Germany as a Research Fellow of the Alexander von Humboldt Foundation. Since June 1992 he is on a visit to Abu Dhabi as Scientific Advisor to the Directorate of Power and Desalination Plants, Water and Electricity Department, Government of Abu Dhabi and the International Foundation for Water Science and Technology where he worked in the field of desalination plant control. He is presently a member of the UNESCO-EOLSS Joint Committee.

He has authored/coauthored four books: *Piecewise Constant Orthogonal Functions And Their Applications to Systems and Control*, *Identification of Continuous Dynamical Systems- The Poisson Moment Functional (PMF) Approach* (with D.C.Saha) , *General Hybrid Orthogonal Functions and their Applications in Systems and Control* (with A. Patra) all the three published by Springer in 1983, 1983 and 1996 respectively, *and Identification of Continuous Systems* (with H.Unbehauen) Published by North Holland in 1987. He is Co-Editor (with N.K.Sinha) of *Identification of Continuous Systems - Methodology and Computer Implementation*, Kluwer, 1991. He has co-authored (with A.Patra): *General Hybrid Orthogonal Functions and Their Applications in Systems and Control*, LNCIS-213, Springer,

1996. He has authored/coauthored over 150 research papers. He is on the Editorial Boards of *International Journal of Modeling and Simulation, Control Theory and Advanced Technology (C-TAT), Systems Science (Poland), Systems Analysis Modeling and Simulation* (SAMS) and *The Students' Journal of IETE(India).* He was Guest Editor of two Special Issues: one of *C-TAT on Identification and Adaptive Control - Continuous Time Approaches,* Vol.9, N0.1, March 1993, and *The Students' Journal of IETE on Control*, Vols. I&II, 1992-93. He is on the Honorary Editorial Advisory Board of *The American Biographical Research Institute*. He organized several invited sessions in IFAC Symposia on Identification and System Parameter Estimation, 1988, 1991, 1994 and World Congress 1993. He was a member of the IFAC Technical Committee on Modeling, Identification and Signal Processing in 1996. He was Chairman of the Technical Committee of the 1989 National Systems Conference in India. He is co-editor (with A. Sydow) of the book series "*Numerical Insights Series*" published by Gordon and Breach. He is a member of the Advisory Board of the Internal Study Group on Water and Energy Systems (ISGWES). Over the last several years, he has devoted himself to the development, from concept to completion, of the *Encyclopedia of Desalination and Water Resources* (DESWARE-online) and *Encyclopedia of Life support Systems* (EOLSS), two major publications of EOLSS Publishers, Oxford, UK.

He has received several academic awards including the IIT Kharagpur Silver Jubilee Research Award 1985, The Systems Society of India Award 1989, International Desalination Association Best Paper Award 1995 and Honorary Professorship of the East China University of Science and Technology, Shanghai. The International Foundation for Water Science and Technology has established the 'Systems and Information Laboratory' in the Electrical Engineering Department at the Indian Institute of Technology, Kharagpur, in his honor. He is listed in several biographic publications. Professor Rao is a Life Fellow of The Institution of Engineers (India), Fellow of The Institution of Electronics and Telecommunication Engineers (India), Fellow of IEEE (USA) and a Fellow of the Indian National Academy of Engineering.