LOGICAL SYSTEMS FOR INDUSTRIAL APPLICATIONS

by

JERZY JACZEWSKI

Technical University of Gdańsk,
Gdańsk, Poland

ELSEVIER SCIENTIFIC PUBLISHING COMPANY
Amsterdam—Oxford—New York
PWN—POLISH SCIENTIFIC PUBLISHERS
Warszawa
1978

Revised and enlarged translation from the Polish original
Układy logiczne dla zastosowań przemysłowych
published in 1970 by Państwowe Wydawnictwo Naukowe, Warszawa

Translated by *Tadeusz Przybylski*
Graphic design: *Zygmunt Ziemka*

Distribution of this book is being handled by the following publishers:

For the U.S.A. and Canada
ELSEVIER/NORTH-HOLLAND, INC.
52 Vanderbilt Avenue
New York, New York 10017

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ARS POLONA
Krakowskie Przedmieście 7,
00-068 Warszawa, Poland

For all remaining areas
ELSEVIER SCIENTIFIC PUBLISHING COMPANY
355 Jan van Galenstraat
P.O. Box 211, Amsterdam, The Netherlands

Library of Congress Cataloging in Publication Data
Jaczewski, Jerzy.
Logical systems for industrial applications.
Translation of Układy logiczne dla zastosowań przemysłowych.
Includes bibliographical references and index.
1. Logic circuits. 2. Logic design. 3. Sequential machine theory. 4. Digital control systems. I. Title.
TK7868.L6J3213 629.8'91 77-11173
ISBN 0-444-99804-7

Printed in Poland by D.R.P.

Preface to the Polish Edition

The automation of industry, transport, services and homes involves a large variety of mechanical, electrical, electronic, hydraulic, pneumatic, and other types of elements and components. No less varied are the methods of automation—ranging from signalling, relay protection, and constant value control, to remote control and adaptive and learning systems. However, among the multitude of control systems we can distinguish certain functional sub-systems which are common to all of them, namely:

setting devices	(which set the required control system in operation)
measuring devices	(transducers)
decision devices	(controllers—which generate sets of signals actuating servo-systems)
actuators	(servo-mechanisms—which execute the control algorithm).

This book deals with a particular class of decision devices called *logical systems*. These are systems whose operating rule or algorithm may, in principle, although not exclusively, be described by means of declarative sentences which express propositions concerning the operation of the system using the *laws of binary logic*. The elements from which the system is built are usually, therefore, *two-state* elements. We are thus dealing here with discontinuous (discrete) control in contradistinction to continuous (analogue) control.

This book is intended for engineers and for students of technical universities. Its purpose is to give the reader a better idea of the new concepts in the theory of finite automata which are applied extensively in the design of more complicated logical systems, especially those with memories. Logical systems also form the basis for digital techniques, the use of which is steadily increasing. The theory of finite automata involves the use of branches of mathematics generally less familiar to industrial design engineers. This book therefore endeavours to explain the fundamental concepts and methods of this theory and the principles of their application to the design of systems for industrial purposes. For this reason, problem-formulation principles based on the classical propositional calculus are given in Chapters 1, 2, and 3. These chapters are of a theoretical nature and thus, in them, the notation of a Boolean function, for example, is not related to its technical realization. Many binary combinational tables, matrices, and graphs are given to enable the reader to gain a thorough understanding of the methods described.

The problem of minimizing Boolean functions and graphs illustrating the operation of the logical system have deliberately been omitted from Chapters 1, 2, and 3. In my view, the essential problem is that of system optimization, this being understood as a compromise between minimization of the purchase cost of the equipment and maximization of the system's reliability. The design of a system which is optimal for a given performance factor (quality index) depends to a great extent on the choice of system of functors and logical operators and also on the structure of the system. For this reason, a wide variety of elements and two-state components, which are the subject of intensive research and development in technically advanced countries, is described in Chapters 4 and 5. At the present level of technological sophistication, semiconductor elements and systems of both multi-element and monolithic logical functors composed of these play a fundamental role. The development of monolithic and thin-film elements of high packing density and increased reliability puts a new slant on the fashionable problem of minimization.

Quite deliberately, I have devoted only limited space to such popular devices as electromechanical relays. These have been described in many papers and their use will decrease in the future. On the other hand, attention is drawn to the most recent development trends, such as optoelectronics, superconductivity and semiconductors with discontinuous characteristics. Considerable attention has also been devoted to pneumatic elements and to systems which underwent intensive development in the 'sixties; they may become important particularly in industrial or other special applications.

Chapter 6 is devoted to system design and optimization, which can be carried out only after proper formulation of the problem and choice of method for its solution.

The references listed at the end of the book are, for the most part, publications to which the author had recourse and cover the period up to 1968, when the final manuscript was completed. A short reference list is appended at the end of each chapter.

The author wishes to express his thanks to all those who enabled this book to be written and in particular to J. C. Gille, J. Kuntzmann, J. Lagasse and P. Naslin of France for their comments and help, to Professor W. Szukszta for his detailed criticisms, and to Professor W. Findeisen for his highly valued remarks.

Gdańsk, 1968 *Jerzy Jaczewski*

Preface to the English Edition

The English edition of this book is being published nine years after the completion of work on the Polish text. During this period extremely rapid development of semiconductor integrated circuits (IC, MSI, LSI), and further development of the theory of automata and logical systems took place. The use of digital techniques, mini-computers, and calculators in industry has become widespread. The English edition is thus a revised, enlarged, and up-dated version of the Polish one. It also incorporates the teaching experience of the author and his colleagues, as the Polish edition served as a text-book for both degree and post-graduate courses.

The division of the book into three basic parts has been retained: I—The Abstract Theory of Logical Systems (Chapters 1, 2, 3); II—Realization of Logical Functors and Operators. Systems (Chapters 4 and 5); III—Design of Logical Systems (Structural Synthesis) (Chapters 6, 7, 8, 9). In Part I the author has made several additions to Chapter 2, such as Zhegalkin algebra, Boolean function derivatives, three-valued algebra; Chapter 3 has been rewritten and supplemented with language representations, non-deterministic automata, and composition of automata. In Part II, Chapter 5 on integrated circuits has been completely rewritten. Part III has undergone extensive changes. The previous Chapter 6 has been split up into four chapters and the sequence of the text has changed. In the author's opinion, it is better first to outline logical system design as a whole and then discuss the design of combinational logical systems or logical systems with memory. The two final Chapters 8 and 9 differ substantially from the corresponding chapters in the Polish edition and take into account the development of integrated circuits.

As before, it has been the intention of the author to present the subject while using only a small number of methods and to afford as similar a treatment as possible to logical systems with memory and combinational logical systems. Since the main purpose of the book is to facilitate self-education, an extensive list of references is given. The references reflect the sources used by the author; for the most part, the works and papers are from Central and Eastern Europe. The author believes that the presentation of these achievements to the English-speaking reader is one of the merits of the book.

In conclusion, the author wishes to express his thanks to all who helped to make this English edition possible: to the publishers for their initiative; to the translator, Dr T. Przybylski, for his hard work and kind co-operation; and to Mr A. Delacour of UNESCO, for his kind forbearance without which this text could not have been written.

Gdańsk 1977 *Jerzy Jaczewski*

Contents

I. The Abstract Theory of Logical Systems

1. Introduction

1.1 Processing of information signals

Automatic control of a machine or process consists in control signals affecting the flow or state of energy of the system being controlled. The rule according to which the signals exert this influence is called the *control algorithm*. As a prerequisite for automatic control, data concerning certain physical quantities which may change during the operation of the system must be available.

Information about physical processes comes from measuring transducers in the form of signals which represent the measured quantities of interest to us. A *signal* is here understood to be some physical means of transmitting information about the physical quantity. Every signal possesses the following three types of features: (a) qualitative—mechanical, electrical, thermal, etc., (b) quantitative—value in appropriate units, (c) morphological—form. The choice of signal quality and morphology is not arbitrary.

A signal must be transmitted and frequently has also to be converted. During this period it is subject to *internal* and *external interference* with the result that the information may be distorted. The susceptibility to interference varies with the form of signal. The choice of form of the signal also depends on the *time* allowed for information *transmission* or *conversion*. The *reliability* of transmission and conversion (reliability of equipment), as well as *investment* and *operating costs*, must also be taken into account. At the same time, one cannot overlook such factors as the possibility of data being *stored* for later use and the possibility of manual or automatic *modification of the control algorithm* (adaptive or learning systems). Consideration of all these factors implies that under given conditions certain forms of signal are more suitable than others.

The signals may be continuous (sometimes called *analogue*) or may be discontinuous, i.e., discrete. In this book we shall be concerned only with *discrete signals*. An explanation is in order as to why data are frequently transmitted or processed in discrete form, although in macroscopic phenomena all temporal processes are, in principle, continuous. To begin with, the most important factor is the loss of part of the information in the change from continuous to discrete form.

Consider the course of information from source (*transmitter*) to receiver. The conversion of the signal from continuous to discrete form is based

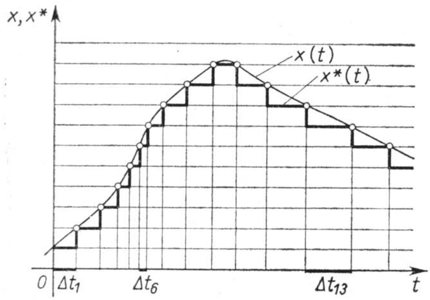

Fig. 1.1. Level quantization, that is, adaptive conversion of a continuous function $x(t)$, yields a step curve $x^*(t)$. Here, Δt_i = var, for example $\Delta t_6 < \Delta t_{13}$.

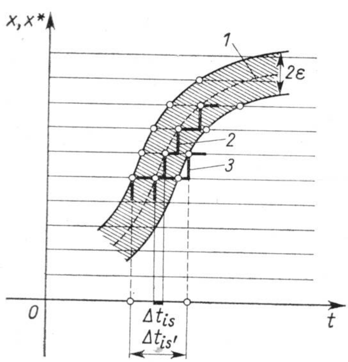

Fig. 1.2. Discretization errors due to measurement error band, 2ε in width. *1* — $x(t)$ mean; *2* — $x^*(t)$ obtained by quantization of mean curve; *3* — $x^*(t)$ obtained on the basis of the error band as extreme case ($\Delta t_{is'}$).

on *quantization at the signal level* (Fig. 1.1). The error with which the signal is measured is smaller than the quantum of measurement. Note that every measurement contains some random errors so that the measurement gives an interval inside which the true value lies instead of the exact value. Since the probability of positive and negative measuring errors is the same, the