

# Microprocessors in Signal Processing, Measurement and Control

*edited by*

SPYROS G. TZAFESTAS

# Microprocessors in Signal Processing, Measurement and Control

*edited by*

SPYROS G. TZAFESTAS

*Electrical Engineering Department,  
University of Patras, Patras, Greece*

D. REIDEL PUBLISHING COMPANY

A MEMBER OF THE KLUWER



ACADEMIC PUBLISHERS GROUP

DORDRECHT / BOSTON / LANCASTER

Library of Congress Cataloging in Publication Data

**CIP**

Main entry under title:

Microprocessors in signal processing, measurement and control.

(International series on microprocessor-based systems engineering)

Includes index.

1. Microprocessors. 2. Signal processing—Digital techniques.  
3. Digital control systems. I. Tzafestas, S. G., 1939— . II. Series.  
TK7895.M5M53 1983 001.64 83-11067  
ISBN 90-277-1497-5

---

Published by D. Reidel Publishing Company  
P.O. Box 17, 3300 AA Dordrecht, Holland

Sold and distributed in the U.S.A. and Canada  
by Kluwer Academic Publishers,  
190 Old Derby Street, Hingham, MA 02043, U.S.A.

In all other countries, sold and distributed  
by Kluwer Academic Publishers Group,  
P.O. Box 322, 3300 AH Dordrecht, Holland

All Rights Reserved

© 1983 by D. Reidel Publishing Company, Dordrecht, Holland

No part of the material protected by this copyright notice may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without written permission from the copyright owner.

Printed in The Netherlands

## PREFACE

In recent years the LSI technology has witnessed a revolutionary development, and allowed substantial reductions in the size and cost of digital logic circuitry. Computer system building blocks have progressed from the level of discrete components to the level of complex ICs involving many logic circuits on a single "chip". The invention and wide applications of microprocessors have changed the philosophy of the signal processing, measurement and control engineering fields. The microprocessor-based digital signal processing systems and controllers have replaced the conventional ones based on standard analog and digital computing equipment. The first microprocessors and "on-chip" computers have appeared towards the end of 71 beginning 72. Their evolution since then and the number of applications, in which they have been utilized, have both been extremely spectacular. New system concepts and hardware/software tools are steadily under development to support the microprocessor in its multiple and complex tasks.

The goal of this book is to provide a cohesive and well-balanced set of contributions dealing with important aspects and applications of microprocessors to signal processing, measurement and system control. The majority of contributions include sufficient review material and present rather complete treatments of the respective topics. Although an exhaustive presentation of all existing microprocessor-based applications in the signal processing, measurement and control field is not possible in a single volume, the reader can find here the major aspects, tools and techniques employed in most applications. An outline of the material contained in the book, along with a general introduction to microprocessors and their applications is given in chapter 1.

This book is certainly not intended to cover introductory aspects of microprocessors and the application fields dealt with. The reader is assumed to have acquired some background know-

ledge prior to reading the book. Of course each chapter is self-contained, and hence the reader can restrict his study to the chapters of his special interest without any particular difficulty. Since the book involves a blend of the experience of a large number of experts working in different environments, a multiplicity of approaches and angles of attack are offered which are of great value to those seeking for alternative designs and solutions.

I would like to thank my colleagues for their acceptance to offer some of their valuable experience for the book. Without their contribution this book would not have been possible.

Despite the variations in the organization and flavour of the particular chapters, I am convinced that students, scientists and engineers will find this volume a useful guide to current microprocessor-based modelling, signal processing, measurement, control system design, and automation techniques.

Patras 1983

Spyros G. Tzafestas

## CONTRIBUTORS

- M. BERTINO*, System and Software Engineering, Soft Power,  
Torino, Italy.
- F. M. CADY*, Department of Electrical Engineering and Computer  
Science, Montana State University, Bozeman, USA.
- C. S. CHEN*, Electrical Engineering Department, The University  
of Akron, Akron, Ohio, USA.
- P. CIVERA*, Department of Electronics, Politecnico di Torino,  
Torino, Italy.
- D. DELCORSO*, Department of Electronics, Politecnico di Torino,  
Torino, Italy.
- F. GREGORETTI*, Department of Electronics, Politecnico di  
Torino, Italy.
- R. GRONDIN*, Systems Engineering and Electronics, Research  
Institute of Hydro-Quebec (IREQ), Varennes, Quebec,  
Canada.
- F. HARASHIMA*, Institute of Industrial Science, University of  
Tokyo, Tokyo, Japan.
- R. M. HODGSON*, University of Canterbury, Christchurch, New  
Zealand.
- A. HOLMBERG*, Systems Theory Laboratory, Helsinki University  
of Technology, Espoo, Finland.
- R. D. JACKSON*, Engineering Department, Cambridge University,  
Cambridge, England.
- A. ST. JACQUES*, Systems Engineering and Electronics, Research  
Institute of Hydro-Quebec (IREQ), Varennes, Quebec,  
Canada.

- H. H. LE*, Systems Engineering and Electronics, Research Institute of Hydro-Quebec (IREQ), Varennes, Quebec, Canada.
- C. T. NGUYEN*, Systems Engineering and Electronics Research, Institute of Hydro-Quebec (IREQ), Varennes, Quebec, Canada.
- I. OKUMURA*, Technical Research Institute, Japanese National Railways, Tokyo, Japan.
- J. ORAVA*, Systems Theory Laboratory, Helsinki University of Technology, Espoo, Finland.
- J. B. PLANT*, Graduate Studies and Research, Royal Military College of Canada, Kingston, Ontario, Canada.
- E. J. PRENDERGAST*, Engineering Department, Cambridge University, Cambridge, England.
- N. K. SINHA*, Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada.
- S. SONE*, Engineering Research Institute, Faculty of Engineering, University of Tokyo, Tokyo, Japan.
- A. SOWIŃSKI*, Industrial Institute of Electronics, Warsaw, Poland.
- D. TABAK*, Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Beer Sheva, Israel.
- G. A. TENDULKAR*, Department of Control and Automation Systems, Siemens AG, Erlangen, FRG.
- H. TOFFER*, Physics and Engineering Analysis, Operations Division, UNC Nuclear Industries, Richland, Washington, USA.
- S. K. TSO*, Electrical Engineering Department, University of Hong Kong, Hong Kong.
- S. G. TZAFESTAS*, Control Systems Laboratory, Electrical Engineering Department, University of Patras, Patras, Greece.
- P. URONEN*, Department of Process Engineering, University of Oulu, Linnanmaa, Oulu, Finland.

## CONTENTS

Preface	v
Contributors	vii

### *PART I GENERAL ASPECTS*

#### Chapter 1 MICROPROCESSORS AND THEIR APPLICATIONS — OUTLINE OF THE BOOK *S. G. Tzafestas*

Introduction	3
Microprocessor Capabilities	4
Microprocessor Applications	5
Teaching Control System Design Using Microprocessors	6
Outline of the Present Book	8
References	12

#### Chapter 2 MICROCOMPUTER SYSTEMS IN REAL-TIME APPLICATIONS *P. Civera, D. DelCorso and F. Gregoretti*

Real-Time Processing	13
Real-Time Hardware Design	15
Real-Time Programming Environment	20
Distributed Real-Time Systems	27
References	30

#### Chapter 3 HARDWARE AND SOFTWARE ASPECTS OF CONTROL APPLICATIONS OF MICROPROCESSORS *D. Tabak*

Introduction	33
Hardware Aspects	34
Software Aspects	41



Concluding Comments	42
References	43

## PART II SIGNAL PROCESSING

### Chapter 4 DESIGN AND IMPLEMENTATION OF THE DIGITAL FILTER VIA THE SIGNAL PROCESSOR *C. S. Chen*

Introduction	47
Infinite-Impulse-Response (IIR) Filter Design	48
Finite-Impulse-Response (FIR) Filter Design	56
Digital Filter Realization Structure	58
Digital Filter Implementation	65
References	68
Appendix	71

### Chapter 5 MICROCOMPUTER-BASED WAVEFORM ANALYZERS AND THEIR APPLICATIONS *R. D. Jackson and E.J. Prendergast*

Introduction	75
System Components	80
Signal Processing Algorithms	89
Applications	93
References	98

### Chapter 6 MICROCOMPUTER-BASED INTERACTIVE IMAGE PROCESSING *F. M. Cady and R. M. Hodgson*

Introduction	99
Interactive Image Processing Systems	100
A $\mu$ P-Based Interactive Image Processing System	107
Advanced Microcomputer-Based Image Processing Systems	114
Conclusion	118
Acknowledgements	118
References	118
Appendix	120

Chapter 7  
STATE OBSERVER IMPLEMENTATION VIA  
MICROCOMPUTERS WITH APPLICATIONS  
*N. K. Sinha*

Introduction	121
The State Estimation Problem: Practical Considerations	122
Microcomputer Implementation of State	
Observers: Linear Noise-Free Case	124
State Observers for Noise-Contaminated Outputs	129
Observers for Nonlinear Systems	131
Results of Simulation	133
Conclusions	137
References	137
Appendix: Details of Hardware and Software	138

Chapter 8  
STATE ESTIMATION USING MICROPROCESSORS  
FOR PROCESS SUPERVISION AND CONTROL  
*A. Holmberg and J. Orava*

Introduction	141
State-of-the-Art	142
State Estimation Algorithms	143
Applications	148
Conclusions	156
References	157

PART III MEASUREMENT

Chapter 9  
MICROPROCESSOR-BASED MEASUREMENT SYSTEMS  
*A. Sowiński*

Introduction	161
Structure and Organization of $\mu$ P-Based Systems	164
Microprocessors in Measurement Systems	171
The Future	187

Chapter 10  
MICROCOMPUTERS IN NUCLEAR PLANT DATA  
MEASUREMENT  
*H. Toffer*

Introduction	189
A Description of the Hanford N Reactor	190

Discussion of Examples	192
Microprocessor Based Evolution* and Analysis System	193
Linked Microprocessor-Minicomputer Data Communications Network	196
High Speed Data Processing for Control Room Displays	200
References	204

#### *PART IV CONTROLLERS*

##### Chapter 11 MICROPROCESSOR-BASED INDUSTRIAL CONTROLLERS. *G. A. Tendulkar*

Introduction	207
The Application of Industrial Controllers	207
Microprocessor Architectures	211
Programmable Controllers	212
Programmable Logic and Closed-Loop Controllers	221
Architectural Convergence	227
Conclusion	228
References	229

##### Chapter 12 DIGITAL CONTROLLERS AND THEIR MICROPROCESSOR-BASED IMPLEMENTATION *S. G. Tzafestas*

Introduction	231
Microprocessors and Microcontrollers	232
Classical Digital Controllers	241
Minimum-Variance and Self-Tuning Controllers	253
Digital State Feedback Controllers	260
Examples of Microprocessor -Based Controllers	268
Concluding Remarks	275
References	276

#### *PART V APPLICATION TO CONTROL AND AUTOMATION*

##### Chapter 13 SPEED CONTROL OF MOTOR DRIVES VIA MICROPROCESSORS *F. Harashima*

Introduction	283
--------------	-----

Basic Concept of Microprocessor-Based Speed Control System	285
Application of Modern Control Theory	287
DC Drive System	292
Induction Motor Drive	294
Synchronous Motor Drive	295
Conclusion	297
References	297

Chapter 14  
MICROPROCESSOR ALGORITHM FOR THE CONTROL  
OF SCR MOTOR SYSTEMS  
*J. B. Plant*

Introduction	299
Motor Speed Control Model	302
Digital Speed Control	307
Digital Position Controller	314
Firing Angle Limitations	315
Experimental Results	317
References	319
Appendices	320

Chapter 15  
MICROPROCESSOR CONTROL OF PHASE-CONTROLLED  
CONVERTERS AND CYCLOCONVERTERS  
*S. K. Tso*

Introduction	323
Review of Basic Principles	324
Motivations for Microprocessor Control	331
Possible Scope for Digital Phase Control	332
Concluding Comments	342
References	343

Chapter 16  
INDUSTRIAL ROBOTS AND THEIR  
MICROCOMPUTER CONTROLS  
*M. Bertino*

Introduction	345
Types of Industrial Robots	345
Path Control for Serial Link Manipulators	351
Hardware Structure of a Control Unit for a Serial-Link Manipulator with Six Degrees of Freedom	356
Applications and Future Developments of Industrial Robots	361
References	364

## Chapter 17

MICROCOMPUTER APPLICATIONS IN POWER  
SYSTEM SUBSTATION AUTOMATION*C. T. Nguyen, R. Grondin, A. St-Jacques and  
H.H. Le*

Introduction	367
Background: Power System Substation Automation	368
Basic Considerations for Hardware Design	371
Microcomputer Applications	373
Conclusions	383
References	384

## Chapter 18

MICROCOMPUTERS IN THE PULP AND  
PAPER INDUSTRY*P. Uronen*

Introduction	387
Situation Today	390
Typical Applications in the Pulp and Paper Industry	399
Future Trends and Conclusions	407
References	408

## Chapter 19

THE MICROPROCESSOR IN RAILWAY  
CONTROL SYSTEMS*S. Sone and I. Okumura*

Introduction	411
Approved Applications of $\mu$ Ps in Railway Systems	411
Novel Applications of $\mu$ Ps in Railway Systems	421
References	436
SUBJECT INDEX	437

**Microprocessors in Signal Processing, Measurement and Control**



# Part I      GENERAL ASPECTS

## CHAPTER 1

### MICROPROCESSORS AND THEIR APPLICATIONS—OUTLINE OF THE BOOK

S. G. Tzafestas  
Control Systems Laboratory  
University of Patras  
Patras, Greece

#### 1. INTRODUCTION

Microprocessors have already been recognized to be important tools for the electronic and system designer [1-9]. Microprocessor-based computing systems have shown a great influence on signal processing and control, similar to that of large-scale digital computers in the decade of sixties. Their success is mainly due to the cost reduction and design flexibility increase they offer. After the introduction of the PDP-5 (1963) and PDP-8 (1965) minicomputers a steady reduction rate in the cost of signal-processing and computer-control has occurred, (about 30 per cent per year) owing primarily to the improvements of semiconductor IC technology. The transition from PDP-8 (which is programmable mainly in machine and assembly language) to VAX-11 (a high-level language machine) needed 15 years, whereas analogous progress in microprocessors was made in less than half that time. The microcomputer offers a unique compactness and modularity in instrumentation, signal processing, and control, which makes now possible many new applications, that previously needed much more expensive dedicated computers. Actually, the application of microprocessors is limited more by the imagination of their users than by their technology. As more and more system designers are familiarized with the capabilities of microprocessors the number of new microprocessor-based applications increases very rapidly. It is remarkable that in only a few years we had a transition from the laboratory utilization of the microprocessor to a mass production and utilization of microprocessor based systems. Of course, in the early stages of the microprocessor revolution, the new technology has been used merely to replace TTL implemented systems, but presently an increasing number of products are surfaced which would be impractical without the microprocessors.



## 2. MICROPROCESSOR CAPABILITIES

Microprocessors are the result of the semiconductor industry effort to accommodate an ever-increasing number of transistors in a single integrated circuit, and can implement a given function with a smaller number of chips than older devices. They have replaced hardwired logic with programmed logic that can be placed into ROMs offering even more capability per chip. Any basic microprocessor module can be enriched with a great logic power by simply adding of few more IC's. The most important characteristics of today's microprocessor usage is not so much in replacing hardwired logic or the low-end minicomputers, as it is in a substantial shift in the philosophy of electronic design and in using them in the new applications where use of big computers is not economically justified. The major microprocessor disadvantage is its low speed. Compared to minis, the micros have smaller instruction repertory, fewer features, and weaker software support.

Compared to the hardwired logic, the microprocessor offers greater flexibility, since wired connections and SSI/MSI devices are being replaced by bits in memories. Thus, modifications, improvements, and product expansions, instead of requiring new hardware designs and/or replacing logic gates and interconnections, simply require reprogramming and substituting bits in memory. It is noted that, although microprocessors have in general low speed, quite fast real-time programs can be written especially for slow industrial applications (such as temperature sensing in a heating plant, reading synchro signals, etc). When higher speed requirements exist, for which the conventional single chip  $\mu P$  is not fast enough, one can use multi-chip microprocessors with bit sliced architectures, most of which are intended for microprogrammed applications.

Microcomputers can replace minis for controlling industrial processes, reducing the cost by a factor greater than two. Originally the microcomputers were scale-down versions of existing minicomputers. This allowed the utilization of the mini control software with nearly no change. Today many microcomputer systems are being designed from the beginning with unique properties.

The major advantages of microprocessor-based systems over their random logic counterparts are the following:

- (i) Lower manufacturing cost (60 to 20 percent of the TTL equivalents).
- (ii) Lower time and cost of original design and development.
- (iii) Faster production of new systems in closer corres-