

EXPLORING C FOR MICROCONTROLLERS

Exploring C for Microcontrollers

A Hands on Approach

JIVAN S. PARAB

*Goa University
India*

VINOD G. SHELAKE

*Shivaji University
Kolhapur, India*

RAJANISH K. KAMAT

*Shivaji University
Kolhapur, India*

and

GOURISH M. NAIK

*Goa University
India*

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 978-1-4020-6066-3 (HB)

ISBN 978-1-4020-6067-0 (e-book)

Published by Springer,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

www.springer.com

Printed on acid-free paper

All Rights Reserved

© 2007 Springer

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.

Contents

Foreword	ix
Preface	xiii
Acknowledgments	xvii
1	
Microcontrollers: Yesterday, Today, and Tomorrow	1
1.1 Defining Microcontrollers	1
1.2 Eagle's View: Microcontrollers and Other Competing Devices	2
1.3 Vignettes: Microcontrollers	3
1.4 Microcontroller Applications	5
1.5 Growth Economics	7
1.6 The Major Players in the Microcontroller Chip Market	8
1.7 Architectural Trends	10
1.8 Jump Starting Your First Embedded System Project	14
1.9 Execution of Embedded System Project: Is it a Gordian's Knot?	16
2	
Integrated Development Environment	19
2.1 Getting Familiar with the IDE	19
2.2 Working with Keil IDE	20
2.3 Development Flow for the Keil IDE	21
3	
Art of C Programming for Microcontrollers	29
3.1 Familiarizing with Your Compiler Capabilities	29
3.2 Whether to Use Headers or Not?	30
3.3 Basic C Program Structure	34
3.4 Differences from ANSI C	34

4		
Exploring the Capabilities of On-Chip Resources Programming for I/O Ports, Interrupts and Timer/Counter		37
4.1 Importance of Ports		37
4.2 Simple Ideas for Port Expansion		46
4.3 LED Interfacing		46
4.4 Relevance of LEDs in Today's Lightening Industry		48
4.5 Different Programs for LED Interfacing		48
4.6 More Projects on LED Interfacing to Microcontrollers		51
4.6.1 Running LEDs		51
4.6.2 Running Bicolor LED		51
4.6.3 Interfacing 6 LEDs Using 3 Microcontroller Pins by		51
4.6.4 The LED Dimmer Demoboard		51
4.6.5 Fading RGB LED		52
4.6.6 LED Moving Font		52
4.7 DIP Switch Interfacing: Getting Input to Your Embedded System		52
4.8 LCD Interfacing		54
4.9 Interrupts in Microcontrollers		57
4.9.1 Writing ISRs in C		58
4.9.2 A Word about Interrupt Latency		63
5		
Hyperterminal-Based Control		69
5.1 Hyperterminal		69
5.2 Packet-based Control Scheme		69
5.3 Mechanism and Lots of Possibilities		70
5.4 Application 1: Packet-based Interface for LEDs		71
5.5 Application 2: Packet-based Interface for Stepper Motor Control		74
5.6 Application 3: Home Automation from PC HyperTerminal		78
6		
Embedding Microcontroller in Routine Applications		85
6.1 Application 1: Podium Timer		85
6.2 Application 2: Front Desk Notifier		90
6.3 Application 3: Cafeteria Food Alert/Microcontroller-based Menu Card		94
6.4 Application 4: Chimney Sentinel		100
6.5 Application 5: Who's First Timer		104

<i>Contents</i>	vii
6.6 Application 6: Counting Cars	110
6.7 Application 7: Anonymous Voting	114
6.8 Energy Efficient Lighting Using Microcontroller	119
7	
Microcontroller-based Measurement and Control Applications	123
7.1 Application 1: Reading a PWM Waveform Using Microcontroller	123
7.2 Single Set-point On/Off Controller	127
7.3 Application 3: I ² C Interface with Serial EPROM	133
8	
Securing Your Embedded System Application	139
8.1 Security Challenges in Embedded Systems	139
8.2 Application 1: Authentication for Your Embedded System Application	140
8.3 Application 2: Timeout Waiting for Input Data	144
References	151
Index	155

Foreword

If we accept the premise that an embedded engineer is made rather than born, then how does one go about making a good one? The authors of this book *Exploring C for Microcontrollers: A Hands-on Approach* are certainly “good ones”. Not only do they explore some of the influences that shaped themselves but they also try to shape “would-be” embedded engineers. Research and developmental activities in embedded systems has grown in a significant proportion in the recent past. Embedded software design is not new to the world, but with the changing time, it has gained considerable momentum in the recent past, and many young engineers are strongly inclined to pursue their future in this field. The book is mainly targeted to these engineers who would like to understand in great depth the synergetic combination of hardware and software.

The book is divided into eight chapters. Chapter 1 introduces a brief background about micro-controllers and explains how they are embedded into products commercially available in the market to emphasize the importance of these in the daily life of mankind. It also gives an insight into the architectural details and embedded system concepts for students’ projects to motivate them into this exciting field. The rest of the book concentrates on software development. The integrated development environment (IDE) is introduced in Chapter 2. Again the screen shots and step-by-step procedure will certainly make the students and engineers fully understand the development process. Chapter 3 differentiates the embedded C paradigm from the conventional ANSI C. Again the authors explain how to successfully overcome the memory and time constraints while developing an embedded C program. Chapter 4 gives an overview of program development for on-chip resources for MCS51 family of microcontrollers. Chapters 5–8 are devoted to live case studies.

The book has come out with an elegant presentation to aspiring students and engineers from the teaching experience and technical knowledge the authors have put over a long time in this field. I strongly recommend this book for intermediate programmers, electronics, electrical, instrumentation engineers or any individual who is strongly inclined

to take up his or her career in embedded C programming. I am sure the reader will experience learning embedded programming by example and learning by doing. Last but not the least, this book will certainly be a value addition to the world of embedded programming.

Dr. A. Senthil Kumar
Head
Data Quality Evaluation
National Remote Sensing Agency
Department of Space
Government of India

Dr. Senthil Kumar is Head of DQE and PQCD sections of National Remote Sensing Agency (NRSA) an autonomous operational center under Department of Space (DOS), Government of India. This is the nodal agency in the country for receiving, processing, and distributing the satellite and aerial remote sensing data and products. NRSA is also responsible for providing end-to-end solutions for utilization of data for geospatial applications and information services. NRSA has a huge archive of remote sensing data acquired through Indian and foreign satellites and also has the capability to acquire data pertaining to any part of the globe on demand. It is one of the important centers for promotion of remote sensing and geographic information system technologies in India. NRSA has set up satellite data processing facilities starting from data reception to utilization at various centers within India and across the globe.

Preface

The past few decades have witnessed evolution of microcontrollers. They have revitalized a number of products or equipment in almost all fields including telecommunications, medical, industrial, and consumer products. These embedded microcontroller systems now resides at the heart of modern life with a variety of applications in fields like consumer electronics, automotive systems, domestic, and even in aerospace products. Embedding a microcontroller in an electronics instrument or product requires a specialized design skill which requires a synergy of hardware and software skills.

In our day-to-day life we come across a number of embedded products. When we switch on the washing machine or send an SMS on a cell phone one cannot prevent without thinking the mechanism and the co-working of hardware and software in the background. The market for such smart embedded products is occupying newer and newer applications seemingly impossible few years back. Last year the IDC, a premier global market intelligence firm, revealed that the embedded industry product development was expected to be as high as \$75 billion. This entails the industry requirement of trained human resource with mixed skill set both in hardware and software. Unfortunately the synergetic demand of hardware and software or sometimes even referred to as firmware competency has led to a supply-demand gap of HR in this field. This gap expressed in numerical figures led to requirement of around 150,000 embedded engineers to serve the global embedded industry. This book is ideal for all those who would like to pursue their career in the exciting world of microcontroller-based embedded systems. The approach is pedagogical; first the hardware module is presented and then the associated software code in Keil C.

The hardware designed is useful for engineering graduates and practicing professionals with the required knowledge and practical hands on skills to design with embedded systems. However, the prerequisite for the book is background of theoretical aspects of architecture of microcontrollers especially the MCS-51 family. The book starts with initial

experiments, which provide familiarization with the capabilities and the limitations of the basic 8051 microcontroller using a simulator. Once the reader is comfortable with these primitive programs which covers almost all the on-chip resources, he or she can switch to more advanced ones.

The Scope of the Book

We now review the topics covered in sequence, chapter by chapter.

Chapter 1 provides an overview of microcontrollers and their applications in different domains. The architectural trends and the growth economics emphasizes the importance of the subject. The photograph of the setup and the hints toward project execution will definitely boost the confidence of the novice to kick-start the project with minimal resources.

Chapter 2 is devoted to the IDE for the MCS-51 family. The simulation and single stepping as described in this chapter will solve all the project intricacies of the readers. Chapter 3 illustrates the basic difference in traditional C programming and embedded C. Chapter 4 deals with the programming of on-chip resources of MCS-51 family microcontrollers in C. The theoretical details of these on-chip resources such as ports, timers, etc., are completely eliminated. As the book aims at hands-on approach, the programs for the on-chip resources have been developed and their execution is illustrated in the Keil simulation environment.

The last four chapters, i.e., 5–8 deal with various project case studies. Several case studies in various application domains such as lighting, measurement and control, security, and domestic applications are developed from scratch. The hardware and software developed in the form of case studies also caters to a set of mini projects, which are discussed in detail from the design phase to the actual implementation on a target system. There are 17 case studies given in this book on various systems that you may encounter in day-to-day life. Overall the hardware and software developed in this book can be reused for any embedded system project and is expected to act as a rapid prototyping unit for the embedded systems industry.

Reasons for Proposing this Book

The market is flooded with a number of good books on embedded systems designed especially with the most popular MCS-51 family. These books are traditional in nature, i.e., they start with the routine architectural features of 8051, description of registers, ports, interrupts, etc. Most of these are already covered in the device data sheet and application notes. In the present book all such routine features are skipped. The focus is on programming microcontrollers to be specific MCS-51

family in ‘C’ using Keil IDE. The book presents 20 live case studies apart from the many basic programs organized around every on-chip resource like port, time/counter, interrupt, serial I/O, etc. Rather than introducing the underpinning theory or reproducing lengthy data sheets, our approach is “learning-through-doing” and one that appeals to busy electronics designers. The ‘C’ codes given are well supported by easy-to-understand comments wherever required. Mastering the basic modules and hands-on working with the projects will enable the reader to grasp the basic building blocks for most 8051 programs. Whether you are a student using the MCS-51 family of microcontrollers for your project work or an embedded systems programmer, this book will give you a kick start in using and understanding the most popular microcontroller.

Authors through their interaction with the undergraduate and post-graduate students as well as industry professionals have found that such a book is the need of the microcontroller community interested in C programming. The book will bridge the gap between the microcontroller hardware experts and the C programmers.

Major Features

The objective of this book is to introduce the readers to the design and implementation of an embedded system. It covers the unique requirements and limitations of operating in an embedded environment. It also covers microcontrollers as the most widespread example of embedded systems. In particular, it focuses on the MCS-51 family of microcontrollers, their programming in C language, and interfacing techniques.

Special emphasis is to provide hands-on experience for the readers using a hardware and interfacing modules described in this book. The aim is to empower the reader to actually solve his or her problem with a practical hands-on pedagogy through the hardware and software presented in this book. The principle of “Design Reuse” is explained effectively.

Further, the readers will also learn how to follow the sequence of data flow through the microcontroller when a program is executed. Additionally, the readers will learn the operation of the microcontroller’s I/O functions and the external devices driven by the microcontroller. Hardware and software design issues are discussed for specific systems implemented using MCS-51 as the embedded microcontroller.

Acknowledgments

We would like to take the opportunity to thank all those who have contributed or helped in some way in the preparation of this text. Particular thanks must go to our heads of the institutions – Professor M.M. Salunkhe, Vice Chancellor, Shivaji University, Kolhapur, India, and Professor P.S. Zacharias, Vice Chancellor, Goa University, Goa, India – for the encouragement and support. We would also like to thank Mr. P. Venugopal, Director, Software Technology Parks of India, Maharashtra Region, for his support. Dr. Kamat and Dr. Naik would like to thank their respective wives for their understanding and patience shown when the preparation of the book took time which could have been spent with the family. Our thanks then to Kamat’s wife Rucha and Naik’s wife Deepa.

Additionally, Mr. Shelake and Mr. Parab would like to express gratitude to their parents for their encouragement and support over the years. Kamat would like to dedicate his contribution to this book to the memory of the late Professor G.G. Tengshe and the late Dr. V. Rao Indolkar, ACD Machine Control Tools Ltd., Mumbai.

Dr. Kamat would also like to thank to his teacher in this field Mr. S. Ramgopal, Indian Institute of Science, Bangalore, and Dr. Senthil Kumar, Dr. Raghurama, Deputy Director (Academic) of BITS Pilani as well as Mr. K.S. Deorukhkar for help in reviewing and critical suggestions. The past batches of M.Sc. Electronics students of both Shivaji University and Goa University especially Mr. Roy, Mr. Rupesh from Satyam Computers must be thanked for generation of problems for programs developed in this book.

- Jivan S. Parab
- Vinod G. Shelake
- Dr. Rajanish K. Kamat
- Dr. Gourish M. Naik