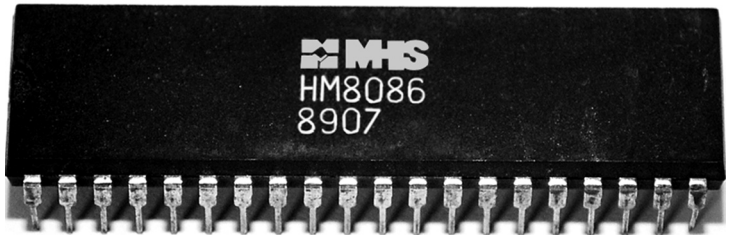
EMBEDDED SYSTEMS

The teacher, who is indeed wise, does not bid you to enter the house of his wisdom but rather leads you to the threshold of your mind.

—Khalil Gibran

EMBEDDED SYSTEMS

An Integrated Approach



LYLA B DAS

Department of Electronics and Communication Engineering
National Institute of Technology Calicut
Kozhikode, Kerala

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This book is dedicated
to my children
and
to all my students

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PREFACE

Preamble

Writing a book on Embedded Systems is not easy—let me list a few reasons to substantiate this statement. The first reason is that the field of embedded systems is very vast. The second is that there is no clear understanding on what exactly a student of engineering should learn about embedded systems. A great number of products which are classed as embedded systems are available, and the field is very sophisticated, well developed and rapidly expanding. Anything from a printer to an iPhone is an embedded system. To write a book on all this is quite difficult on account of not having a clear idea of where to start and where to end.

To complicate matters further, there are different families of embedded processors. A student cannot be expected to learn all of them, or even some of them. To make a decision on what to include and what not to, has been difficult, Besides that, 'embedded processors' is not the only topic to learn. There is a large set of various kinds of sensors, actuators, buses, operating systems, design methodologies, view points, development models and what not.

But after a lot of contemplation, finally, I converged on a few popular and upcoming processors, latest buses, new approaches, traditional as well as modern peripherals, real time operating systems and the like. A lot of literature for all these is available in the form of technical documents, data sheets and user manuals—right from the USB technical spec to PSoC's data sheets

Rummaging through all these highly sophisticated technical information, trying to make sense of it all, and finally presenting it in a way that a student, albeit an eager and enthusiastic one, will be able to enjoy reading and studying it—this is the challenge involved in writing this book. I have tried my best to address this challenge of making it a student-friendly presentation.

There are a number of books available under the title of 'Embedded Systems'. Except for a few, most of them have simply concentrated on the architecture and application details of one particular processor. Others have concentrated on the software aspects alone. There are certain others that deal with both, but since the field of embedded systems is one in which fast evolution is the rule rather than the exception, some topics become outdated quite fast.

Approach

I have started from the hardware basics, proceeded to discuss some important processors and systems, and then moved on to the software aspects. The book ends with a presentation on embedded design from a system point of view. Along with the basics, I have also tried to focus on the latest and most relevant topics in the field, from the latest processors and buses to the latest trends in embedded computing.

Pre-requisite

A student of CS, EC or EE branch who has done a first course in digital logic and a second course in 'microprocessors and microcontrollers', is best placed to take up a course on Embedded Systems.

But it is possible also to study Embedded Systems as a second course—that is why some very basic ideas of microprocessors and microcontrollers are included in the initial chapters.

Organization of the Book

This book is organized as twenty chapters numbered from 0 to 19. It is divided into five logical parts from Part I to Part V.

Part I

This part, which includes chapters 0 to 6, deals with the basics, the hardware aspects including sensors, actuators, buses etc. and the tools commonly used in system development.

Chapter 0 is a revision of computer arithmetic and computer architecture. One needs to be very thorough in these two basic topics—then the path ahead becomes very comfortable.

Chapter 1 introduces readers to what an embedded system is, and what its mandatory parts are. Examples of practical and popularly used embedded systems are listed to make the introduction clear. The classifications, history and current trends in the embedded industry are also touched upon.

Chapter 2 is a very important chapter—any student who needs to use/learn embedded hardware should become conversant and confident about all the topics covered in this chapter. Not only are the important aspects of typical embedded processors covered here, related topics such as semiconductor memory (RAM and Flash), low power design, concepts of pullup and pulldown resistors are also touched upon.

Chapter 3 is very important for practical design of systems. Most students are likely to do hardware based projects as part of academic requirements—this chapter, which gives an in-depth discussion on sensors and actuators will definitely find use then.

Chapter 4 is meant for a light reading on some of the applications of embedded systems. Mobile phones, robotics, RFIDs, automotive electronics, medical electronics etc. are discussed as popular applications. A new idea called 'brain machine interface' is also introduced in this chapter.

Chapter 5 is meant to be studied as a very important topic. It contains explanations of some of the popular buses used in embedded systems. A student is not expected to study all buses in detail, but a general idea of buses, and a study of some of the important ones is advised. On-board and off-board buses, wired and wireless buses, bus standards, bus arbitration etc are the important topics covered here.

Chapter 6 is a brief introduction to the development tools that are needed to take a project to completion. The discussion is meant to guide students in the right direction when they are confused about the techniques for writing programs, testing them and burning them into hardware.

Part II

This is the second part of the book, and there are three chapters here. This part deals with software design aspects. Chapter 7 is quite lengthy, but it should mandatorily be learned because it gives answers to many aspects of computers and embedded systems that are seen and experienced in everyday life. This chapter covers operating system concepts in detail and then offers codes/pseudo codes where OS concepts are tried out.

Chapter 8 is about 'real time operating systems'. This should be considered as a continuation of the previous chapter, But here the special requirements and scheduling policies for a special class of embedded systems i.e., real time systems, are taken up. Numerical problems are worked in both these chapters to understand the scheduling mechanism used in operating systems.

Chapter 9 is a short chapter, being at best a basic introduction to Embedded C. It assumes that the reader has a basic knowledge of the constructs of 'C'. How this high-level language is used for processor programming is the focus of the discussion, which is based on the 8051 architecture. Some codes for PIC are also included. Later chapters of PSoC and ARM contain more coding using Embedded C, but basic ideas are introduced here, in Chapter 9.

Part III

This part consists of Chapter 10 to Chapter 15. The architecture, programming and applications of some of the most widely used and popular processors are covered in reasonable depth.

Chapters 10 and 11 are devoted to the ARM processor, which is the most popular processor used in 32-bit and high-end applications. Chapter 10 explains the core of ARM and follows it up with assembly language programming. Chapter 11 expands ARM architecture to make it a microcontroller. A specific ARM-based MCU is chosen and its peripherals are studied. Programming of some peripherals using C is done. These two chapters are likely to be sufficient to get a good grip on ARM architecture.

Chapter 12 is about a new processor. It is not new in the embedded design world, but the academic world is just getting familiarized with it – the chapter discusses PSoC, an MCU series, which makes life easier for a product designer. This is because of the graphical IDE it has, and other special features that are covered (with programming examples in Embedded C) in the chapter.

Chapters 13 and 14 are about one of the most widely used 8-bit microcontroller i.e., the 8051. This MCU is simple and the first that a student should study. These two chapters discusses this MCU with assembly language programming. All the peripherals are covered, and programming is explained with worked-out examples.

Chapter 15 contains a general coverage of DSP processors. Such processors are increasing in relevance and the time is just right to learn the special features of such chips. The special features of such processors are first explained, and then some popular DSP processors (BlackFin, SHARC, OMAP etc) have been identified, and their features elaborated.

Part IV

This part includes Chapters 16, 17 and 18.

Chapter 16 deals with ASIC design. It starts with the classification of digital ICs, continues with programmable devices and then gives a step-by-step explanation of how a digital IC is designed, tested and fabricated. The reader can get a good idea of what terms such as front-end design, back-end design etc. mean, without going very deep into the process of ASIC design.

Chapter 17 introduces two new terminology. One is 'Hardware Software Co-design' and the other is 'Embedded Product Development Lifecycle'. Both these terms are explained and elaborated upon, with relevant examples.

Chapter 18 is very special. After all the previous chapters, it looks upon an embedded product as a system, and suggests the steps needed to apply embedded systems to make useful products as demanded by users. The user/users might have their viewpoint expressed before the design starts. New concepts like user research, ergonomics, anthropometry etc are introduced. Starting from the desires of users, the design steps reach the final stage of product manufacture and resting.

Part V

This part has just one chapter. Chapter 19 has a concise discussion of three projects done by students. The projects pertain to embedded hardware and software and use advanced processors—ARM, OMAP and PIC. This chapter is meant to encourage students to take up challenging and innovative ideas and build products based on these ideas.

Appendices

The book has appendices from A to K. Only Appendix A to D are in the text book, The rest are available in the website of the book www.pearsoned.co.in/lylabdas/embeddedsystems.

The contents of the appendices are as listed:

A - The instruction set of 8051
B - A step-by-step guide to using the Keil RVDK for 8051 and ARM
C - A step-by-step guide to using the PSoC Designer
D - Pin configuration and PINSEL register configuration of LPC 2148
E - A manual with experiments for PSoC1
F - A step by step guide to using PSoC Creator
G - A tutorial on Keil RVDK for 8051 and ARM
H - A program for interfacing a Graphical LCD to PSoC3
I - A program for interfacing an SD card to ARM7 (LPC 2148)
J - A program for using the I2HC interface of PSoC1
K - User manual of ARM LPC 2148

In addition, PowerPoint presentations and solution manual of the chapters are available for instructors.

Contact

Your suggestions and feedback are welcome. In spite of my best efforts, it is possible that some errors may have crept in. Please point them out to me.

My contact id is lbd@nitc.ac.in

ACKNOWLEDGEMENTS

This is my second major book, and as I complete it, I would like to acknowledge all those who have helped and encouraged me in this Herculean task. Truly, it has been a great effort to write it, and there are a lot of people who have directly or indirectly helped me. Let me start from the beginning.

The team at Pearson Education provided a lot of inputs, suggestions and support and brought the project to fruition. I feel that Sojan Jose, my editor, and Ramesh M. R and Vijay Pritha, the production editors have done a tremendous job.

The first batch of students I taught Embedded Systems was the B070EC batch and the next year, the B080EC batch came in. Both batches expressed enthusiasm and interest in the topics I taught, and this is the primary factor that gave me the courage to embark on the venture of writing a book on the subject. I would like to thank each and every one of them for this.

During the process of writing, a few students helped me directly in bringing the book to this form. They gave suggestions, performed reviews, and three of them have contributed by writing a few sections of the book. All of them are working in reputed companies and I would like to list their names, along with expressing my heartfelt thanks to them.

Nithin Gopinath (Texas Instruments, Bangalore), Sabu Paul (Texas Instruments, Bangalore) and Sai Krishna K. (Broadcom, Bangalore) are the three who have contributed directly by writing a few sections in the book.

The list of those who have done reviews of the chapters are: Nithin Gopinath (Texas Instruments, Bangalore), Jayalal Vijayan (Synopsis, Bangalore), Sai Krishna K. (Broadcom, Bangalore), Harikrishnan M. (McAfee, Bangalore), Srijit R. (Deloitte, Hyderabad) and Sushmitha Dandeliya (Assistant Professor, Engineering College, Gwalior).

A few of my colleagues also have helped me in this endeavor, and I extend my gratitude to them. Raghu C. V., my colleague in the department, has done the writing of Chapter 18, and has also given me suggestions at various stages of this work. The names of others with whom I have had discussions on some topics are Sameer S. M., Deepthi P. P., Sudheesh George, Bhuvan B. and Rajiv T. R., my department colleagues, and Jayaraj B. and Anu Mary Chacko of the Computer Science Department. I am grateful to Anand, senior mechanic at the Embedded Systems Lab, who assisted me in all the hardware work associated with the book. I thank Beljit, Anju and Aswathi who have drawn the diagrams in the book. I would also like to make a note of acknowledgement to my son Sagar, for his suggestions on the theme of the front cover of the book.

Two engineers at Cypress Semiconductors, Narayana Swamy, and Geethesh N. S., made a detailed review of the chapter on PSoC. Their inputs have enhanced the quality of the chapter. I am obliged to them and also to Benoy Jose, and Karthikeyan Mahalingam of Cypress Semiconductors for co-ordinating this activity.

It is only because my department gave me free time without the hassles of regular work that I have been able to complete the book on schedule. All my colleagues have been helpful in this and I feel that words are not sufficient to express my feelings of gratitude to all of them. I am deeply indebted to my institute for giving me the freedom to grow and follow the path I chose.

Chapter 19 of the book contains the project work of a few teams of students. They have worked systematically and enthusiastically to do projects of good standard, which require a lot of background study. I congratulate them for the work they have done and would like to mention their names here. They are: Nithin Gopinath, Jayalal Vijayan, Ashwin Harikumar, Kurian Abraham, Ebin George, Sushmita Dandeliya, Fahim Bin Basheer, Jinu J. Alias, Mohammed Favas C., Navas V. and Naveed Farhan K.

I am happy that my family has always been a source of solace for me.

Last, but not the least, I thank all my students once again for the inspiration they have always been, and continue to be.

Lyla B. Das

ABOUT THE AUTHOR

Lyla B. Das is Associate Professor, Department of Electronics Engineering, National Institute of Technology Calicut (NITC), Kerala. She has a diverse mix of industrial, teaching and research experience spanning about 30 years. As a young graduate specializing in Electronics and Communications from the College of Engineering, Trivandrum, Lyla B. Das joined Keltron Controls as Deputy Engineer in 1981. She joined NITC (then Regional Engineering College, Calicut), as lecturer in 1985 and proceeded to complete her master's degree in digital communications from the same college. Over the years, she was successively elevated as Assistant Professor and then Associate Professor, a position which she currently holds.

Keen to actively seek and impart knowledge, Lyla B. Das currently teaches courses on microprocessors, microcontrollers, digital system design using VHDL, and system design using embedded processors at the undergraduate as well as postgraduate level. She has presented research papers in conferences of national and international stature and has worked on numerous projects based on microprocessors and microcontrollers, such as microprocessor-based voting machines and microcontroller-based rail track switching system. An avid reader of contemporary research material, she keeps herself abreast of the current trends in her chosen field and guides students in their M.Tech. research theses. This book on *Embedded Systems* is her second book with Pearson Education, the first one being *The X86 Microprocessors*, which was published in 2010 and received with wide acclaim.

Lyla B. Das has worked on various projects funded by the ministry of human resource development (MHRD) in thrust areas of growth including the setting up of an embedded systems laboratory in 2005–2008. She has delivered expert lectures on image compression using wavelets, advanced microprocessors and microcontrollers, FPGA based systems and embedded systems at several engineering colleges across Kerala. She has also participated in numerous tutorials and workshops conducted by the Indian Institute of Technology (IIT) and the Indian Institute of Science (IISc). She was a Fellow in the national conference on 'VLSI Design and Embedded Systems' held at IISc Bangalore (2003) and IIT Mumbai (2004). She is a life member of the System Society of India and a member of the Indian Society for Technical Education and the Computer Society of India.