Practical Aspects of Embedded System Design using Microcontrollers

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Foreword

My perception regarding embedded systems goes on the following lines "Embedded Systems are very simple. It just takes a genius to understand its simplicity" and I know that authors of this book are the genius in this subject. With their many years of experience in industry consultancy and academia they posses the arts and science of designing successful, working and useful Embedded Systems. The "Art", part comes with a mix of knowledge, experience, intuition and creativeness that the readers will witness from the various case studies developed in this book. While their "Science" and "Engineering" foundations are evident from the adopted design methodologies guaranteeing correctness with proper hardware selection and time as well as memory efficient code. In fact this is the second book on this subject by the same team. I have gone through the first one "Exploring C for Microcontrollers: A hands on Approach" published by Springer and found it very informative. I learnt that the book is popular with embedded designers in US and UK. The same approach of "Learning by Doing" as in explored in the first book has also been extended for this second book.

The most significant aspect about embedded systems that I like is its unique synergy between hardware and software. An Embedded Engineer is supposed to be an expert in multiple domains such as microcontrollers, FPGAs, digital logic, C programming, sensors, instrumentation and last but not the least even nuts and bolts i.e. mechatronics. With a continued interaction with some of the authors of this book, I found them to possess expertise in this field having multiple facets. Namely Dr. Gourish Naik has been instrumental since his IISc days to incorporate Embedded Systems aspects in academics. Dr. R.K. Kamat who was offered a position in Motorola in Europe possess great capability in design and the development of Embedded Systems.

Now let me focus on the very need of this book. As all of us are aware since their inception, embedded systems have caused a tremendous change in society, a change that is continuing from last few decades at a pace surpassing every imagination. With their increasing significance in world markets, there is a scarcity of experienced embedded system professionals. I learnt that embedded systems development professionals have handicapped Hong Kong industrialists' ability to exploit high added value market potentials in embedded systems products. In Europe, the European Commission has recognized the importance of embedded systems by

creating a new unit in the IST Directorate. The visions surrounding the AMI-space (embedded systems everywhere, described in the context of human life as 'ambient intelligence') have considerably influenced the 6th Framework Programme of the IST domain. However, with such growing activities in this field, the scarcity of experienced embedded systems development professionals is quite natural. This has spurred a growing emphasis on embedded systems education in most of the US, UK and Indian universities for nurturing quality human resource in this field of significant importance. While the academics are trying to do their best in inculcating the concepts, there are very few course wares or books that will practically cover the concepts. This book will help in filling up the supply-demand gap in training the Embedded Systems Professionals.

The book covers applications based on two widely used 8 bit microcontrollers viz. PIC series from Microchip and MCS51 series from Atmel. Authors have chosen the right microcontroller for the right application. The latest chips have been used in developing the applications. Self explanatory C code with proper documentation is given for each application. Routine things such as lengthy datasheets have been skipped. Good web resources have been identified so that the readers can simply find the details after going through the Web URLs.

With these few words, I strongly recommend this book for intermediate programmers, electronics, electrical, instrumentation engineers or any individual who is inclined to take up his/ her career in this field. I am sure that reader will welcome this book and gain great concepts by adopting the practical approach taken up throughout the book.

Dr. B. Selvan

Dr. Balakrishnan Selvan obtained a Ph.D. in 1991, from the University of Bradford's Postgraduate School of Studies in Information Systems Engineering. In 1983 he received a M.Sc. degree in Electrical Communication Engineering from the Indian Institute of Science, Bangalore. Between the years of 1984 and 1997 he held various teaching and research appointments, in the field of communications and computing, at universities in Singapore and UK. In 1997 he joined Alcatel Submarine Networks at Greenwich, London, as a Principal Engineer for design and development of DWDM terminal equipment. In 2003 he set up his own consultancy firm, which specialise in providing information technology solutions for small business in and around South East London.

Dr. Selvan is a Chartered Engineer (UK Engineering Council), and a member of the Institution of Engineering and Technology (UK).

Author's Profile

"Website of the research group may be seen at URL: http://www.rkkamat.in".

Jivan S. Parab, Goa University, Goa, India
After graduating from Goa University, Jivan was hired by Masibus Instruments Pvt. Ltd., as a design engineer. After working for a year in Masibus, Jivan shifted to academics and joined Goa University, Goa, as he was concerned about the increasing diabetic patients in India and abroad. He was passionate about development of low cost, portable glucometer for poor people. With his rich experience in designing heterogeneous Embedded Systems comprising of microcontrollers, FPGAs and onboard flash, he has almost completed the project and very soon will be launching the same with his completion of doctorate in the same topic.

Santosh A. Shinde, Shivaji University, Kolhapur, India
Santosh had a stint in Embedded Instrumentation by practically working in Wimson Electronics Pvt. Ltd., as an R&D Engineer in their SMD division. Santosh has worked with many of the popular microcontrollers from Intel, Atmel, Philips and Microchip. He is experienced in programming in C, C++, under LINUX, DOS, and Win9x, WinXP. He is also familiar with many EDA tools such as Handel-C, Modelsim, Gerber, Orcad, Mentor Graphics, Xilinx, and CAD software. He will be submitting his doctorate very soon on FPGA based programmable ASIC for circumventing SPAM.

Vinod G. Shelake, Shivaji University, Kolhapur, India

Vinod is always been fascinated about developing Embedded products for computer network security. In order to gain real life experience, he joined Software Technology Parks of India, an autonomous body under Government of India, who has build and maintains the countrywide backbone of Internet exchanges. As an avid embedded enthusiast, he left STPI to devote more time on R&D in this field. Currently he is busy in development of a FPGA based firewall with lots of novel features than those existing in market. Vinod holds Masters in Electronics specialized in Embedded Systems and soon he will submit his dissertation for Ph.D. in Embedded VLSI systems.

Dr. Rajanish K. Kamat, Shivaji University, Kolhapur, India

Dr. Rajanish K. Kamat loves Electronics, Internet and all the high tech latest things in the world. He's in them all the time. When he is not tapping keys for a research paper or a book like this, he is either teaching for Masters student or guiding research to Ph.D. students. Dr. Kamat is right now working with Shivaji University, Kolhapur where he is involved in teaching, research and consultancy. Besides he is also taking care of Internet gateway of Shivaji University. He has been exposed to almost every variant of mechanical and electronic computing device there is (and has been). This everyday contact with the electronic industry allows Dr. Kamat to bring this real-world experience to the books like this. His expertise has been recognized by the Department of Science and Technology, Government of India by awarding him a major project on Soft IP cores under the Young Scientist Scheme. He is a single point contact for all the authors.

Dr. Gourish M. Naik, Goa University, Goa, India

Embedded devices are not Dr. Gourish Naik's only love. He enjoys to be literally "on the road" to modify Electronics in cars. He's also walked among his share of optical communications too as a part of his Ph.D. work way back in 1987 from the prestigious Indian Institute of Science, Bangalore. Computers, Electronics, Robotics continued to be his hobbies and that's why he has taken up teaching and research as a full time profession. At Goa University, Dr. G.M. Naik is heading the Electronics as well as Instrumentation sections and has earned reputation as a consultant all over in India. He has been instrumental to incorporate the latest in Embedded Systems in the curriculum. University Grants Commission, the nodal body for the universities in India has recognized and appreciated his efforts by granting him "Innovative Program" in Embedded Systems.

Preface

Embedded Systems: A Component Based Software Industry

According to Business Communications Company Inc. (BCC) research report the embedded software business is predicted to grow from about $1.6 billion in 2004 to $3.5 billion by 2009, at an average annual growth rate (AAGR) of 16%. The growth rate for the Embedded hardware will reach $78.7 billion in 2009. The estimated growth rate is propelled by several key themes: namely the penetration of Applications Specific Processors (ASPs) as well as stand-alone chips such as microprocessors and microcontrollers, which has cannibalized their sells as compared to the consumption volume of stand-alone Micro-Processing Units (MPUs), Application Specific Integrated Circuits (ASIC), Field Programmable Gate Arrays (FPGA) and Digital Signal Processors (DSP). In general the growth of system-on-a-chip components has really revitalized the embedded system market. Another report by the Indian Semiconductor Association (ISA) and Frost & Sullivan supports the flourishing growth rate statistics. It states that semiconductor and embedded industry is projected to bloom from $3.25 billion in 2005 to $43.7 billion by 2015. With such an attractive growth statistics, the field of embedded systems now influences many industrial sectors including automotive, aerospace, consumer electronics, communications, medical and manufacturing. Today it is the fastest growing sector in IT and still open with many opportunities. Traditional research in Embedded Systems is in progress in good number of research fields such as software, Real Time Operating System (RTOS), new communication protocols, microcontroller based system, low power design, immunity to Electro-Magnetic Interference EMI, etc. to name a few. We have taken up the design aspects of Microcontroller based Embedded Systems with more emphasis on the software.

Who This Book is For

Last year the ‘IDC’ a premier global market intelligence firm’s analysis revealed that the embedded industry product development is 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 some times even referred to as firmware competency has lead to a supply-demand gap of HR in this field. This gap expressed in numerical figures lead to requirement of around 150,000 embedded engineers in the current year and more in years to come to serve the global embedded industry. Our previous as well as the current book published under the realm of Springer are the ultimate solutions to bridge the supply – demand gap of Embedded System professionals. The book is intended for graduate and postgraduate students from the Electrical, Electronics, Computer and Instrumentation Engineering. It is equally beneficial for industry professionals, hobbyists and software people who would like to try their luck with Embedded Systems. Undoubtedly, some people can use this book in laboratory courses. Experience programmers can skip some basic part and get right into the application case studies.

We promise that the potential readers can lessen the steepness of the learning curve for Embedded Systems by using this book. Through this book, we hope for you to be able to switch to Microcontrollers and Embedded Systems in the shortest possible timeframe. Back when we started our career in this field, we weren't lucky enough to have a book like this to learn from! As such, a reader will find lots of information for newcomers, even those who have not programmed much before. On the other end of the scale, we have worked hard to put in this book lot of information on advanced functionality in Embedded Systems such as I^2C. If you are a veteran user looking to take your microcontroller based design skills above and beyond where they are right now, we are hoping you will find there is lots to be had here.

"Hands on Approach"

As Aristotle said: "What we have to learn to do, we learn by doing." The approach adopted by us is "Practical Design" and will definitely inspire the student and design community to learn on their own. A quote from W. McKeachie, "Professors known as outstanding lecturers do two things; they use a simple plan and many examples." Yes!! We have given the bare minimum theoretical aspects and rest all is the practical circuit diagrams and complete C code with 33 case studies so as to enjoy implementing the stuff in laboratory. The book is developed with the main goal of making the task of learning Embedded C something fun that you do not have to worry about. There is a famous quotation by Jim Rohn, "Formal education will make you a living; self education will make you a fortune." With this book we are offering the potential readers an opportunity to learn on their own and enter into the ubiquitous world of Microcontroller based Embedded Systems.

What is Different about this Book?

A.A. Hodge said "He is wise who knows the sources of knowledge – who knows who has written and where it is to be found." True enough! We have skipped the routine theoretical aspects of microcontrollers such as lengthy description of registers,

on –chip memory map, pinout, sinking sourcing current values, etc. (Open any textbook, and these things are right there). Instead we assume that either the potential reader is aware of these things or he will resort to the web references listed at the end of the book.

Some of the salient features of the book are as follows:

- The book is presented so as to refer in whatever order you want. Once you have the prerequisite basics down, we encourage you to flick through the table of contents, find something that interests you most, and start reading from there.
- It covers design based on the representative members of both RISC and CISC architectures.
- The most interesting are the 33 number of case studies. We have undertaken several tasks necessary for building a good source of case study material. A good taxonomy is built, and a large collection of primary sources is presented as web based resources.
- The devices chosen for the applications are from the industry leading vendors such as Atmel, Microchip, Philips, Maxim and so on.
- It is made sure that all the above mentioned devices are available in the market and most of them are cost effective.
- Clear and precise circuit diagrams along with complete listing of C source code per application will enable the reader to experiment the given stuff in his laboratory.
- A lucid flow of the resource material and the participatory style will definitely make you friendly with the subject matter.
- Actual screenshots taken and embedded in the text to illustrate the concepts.
- Another feature is reusability of the code. With little modification the codes developed in this book may fit in your embedded application saving you from the labor of reinventing the wheel.
- Yet another feature is Simulate-ability of the code that will boost the confidence of the readers and enable them to go one step forward towards testing the same on the hardware platform.

How This Book Was Prepared?

The book is a result of author's many years of experience in academics, research and industry. With the overwhelmed response received to the first book "Exploring C for Microcontrollers: A hands on approach" published by Springer in May 2007, authors were more than happy. However, many readers expressed a balanced coverage of RISC and CISC architectures. Authors acted on these suggestions and framed the existing book. Looking at I^2C popularity a chapter was devoted for the same. Similarly the most popular PIC16F877 was chosen for the case studies. For the sake of comparison another equally popular microcontroller from CISC architecture AT89S52 was chosen for a set of case studies covered in last chapter. Thanks to our student community who is now largely placed in reputed industries for identifying the problem statements for the case studies.

Chapter Descriptions

We recommend you to begin by reading through the summary paragraphs of each chapter below, which introduce each section and provide you with a good overall picture of how the book is organized.

Chapter 1 is the "Welcome Speech" for inspiring the potential readers. It focuses on the importance of the subject. In this chapter there are several references of many forecasts, that visualizes the growing importance of embedded systems in years to come. After reading through one gets a realization that the traditional academic courses focusing either mostly on hardware as in many Electronics/ Electrical Engineering programs or mostly on software as in many Computer Science programs will not suffice the expertise in this synergetic domain. Latest trends and statistics from leading marketing and research firms will convenience the reader to kick start their venture in this field. Coverage of MPLAB for PIC will introduce to the IDE environment for PIC. The IDE for the AT89s52 has been skipped as it is already been found its way in the earlier book by the same authors.

Rest of the book proceeds towards a systematic building block approach. Chapters 2–5 are based on PIC16F877 while the Chapter 6 applications use AT89S52 microcontroller.

Chapter 2 covers the fundamental aspects of microcontroller based system design from interaction to ambient environment point of view. It begins with the basic LED interfacing and its variation and moves on to the more complex interfaces such as seven segment LED, LCD, buzzer interfacing, etc. In many situations the embedded device resorts to polling a switch status for intelligent branching of the code. Sometimes in more complicated circumstances the status of a number of signals coming from the switch needs to be sensed. In this chapter we have taken care of both of them. A basic DIP switch interfacing and the thumbwheel switch interfacing is presented in depth.

Analog signals are very common inputs to embedded systems. Transducers and sensors such as temperature, pressure, velocity, humidity are truly analog. Therefore we need to convert these analog signals in to digital so that the PIC can read it. Upon processing in digital domain again the PIC has to enable/disable or control the actuators back in analog domain. This core issue of digitization and control is taken up in Chapter 3. This chapter will further boost your interest as it covers lots of interesting variations such as using onchip ADC of PIC, interfacing external ADC for mutichannel data logging applications. PWM based DAC is certainly more competent with the theoretically infinite resolution. Again the combination of ADC and a port pin of PIC is used for the temperature control application avoiding the power hungry DAC. Temperature being chosen owing to its universality in most of the control systems. Generation of PNR signal and waveforms serves the testing applications for the embedded products.

Although hyper terminal was more used with Win 98, but still in the age of Win XP it has become a serial gateway for group of embedded appliances to be controlled from a PC terminal. Many embedded systems compliant for the PC serial

communication now use their own propriety terminal emulation programs. But with out experience there is nothing robust like a hyper terminal for the serial emulation. In Chapter 4 we have revised a step by step procedure for setting up the hyper terminal for communicating with the embedded board. The case studies developed here comprises of displaying data on Hyper Terminal from the PIC processor, getting sensor output (LM35) on the hyper terminal and actuating a relay. Additionally, we have demonstrated stepper motor control by outputting the speed, direction, etc. from the hyper terminal. A potential developer may take these applications to a greater heights such as domestic appliance control, home light control, home security opening, closing the door with camera interface using a single PC with the hyper terminal. Other intention is to motive the user for writing such a GUI (may be using Visual Basic or Visual C++) for serial communication or even for the upcoming USB.

Embedded world is witnessing incorporation of many new protocols for interconnectivity with each other. I^2C, SPI, CAN, UART are some of the latest protocol suites used with the embedded products. Chapter 5 is all about I^2C and application based on it. Why we have taken this particular suite? There are two reasons. First it is the most popular one. The popularity is realized by the fact that its 7 bit addressing space has been now upgraded to 10 bit to fit more client devices. Second reason being once you understand one protocol, other will follow on the similar lines with few differences here and there. The chapter begin with basic case studies such as I^2C based RTC and serial EPROM interfacing. Then it moves on to the interfacing of two different ADC chips viz. PCF8591 and AD1236. Main difference is the resolution offered by these ADCs. We want to emphasize here that the appropriate device with the desired specifications should be used for the intended application. After all we are embedded developers and we value the specifications more than any other engineering disciplines. An intelligent reader can make out the difference in resolution by comparing the above two interfacing approaches. An embedded application will be incomplete without making its impact in an analog world. Therefore the last application of this chapter In order to generate different wave, we have interface I^2C based DAC (MAX5822) to PIC. Here the values corresponding to respective waveform is sent to DAC serially using SDA line and then subsequently you may view it on the CRO.

The last chapter is an odd man out in the RISC domain. Most of the embedded system applications do not require more than what provided by the AT89S52 microcontroller a popular derivative of the basic 8051. With 8 Kbytes of Flash, 256 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry you have everything that is required in the world for a successful embedded application. More than this you will feel at home with the support of powerful tools IDEs and webforums of enthusiastic developers working with this device. We have developed many interesting case studies such as a night lamp controller, automation of a nylon rubber stamp making machine, digital IC tester, etc. The tiny BIOS opens yet another window of programming style based on the ISRs. Designers are always been wondered how to partition the things in analog and digital domains. The salinity measurement system evidences the benefits of accomplishing the nonlinearity correction in analog domain that reduces the

computing burden of the microcontroller and helps in getting optimized timing even with CISC architecture. The sensor interfacing being the universal application for microcontrollers, we have gone a step further towards making them fault tolerant and accurate measuring systems with their arrays. The common philosophy of applications developed in this chapter is their inherent computing complexity apart from the conventional stress on I/O and onchip resources for which the microcontroller is best suited. With this chapter a potential reader can compare the performance of PIC16F877 a RISC processor with the CISC AT89S52. Efforts towards interchanging the processors for the given application will give an insight as regards to the choice of a proper microcontroller for appropriate application. With this, we left the decision of the "RISC Vs CISC" debate to the wise reader. Not the least the universality of Embedded C and the almost unchanging program structure will prove its usefulness for the embedded paradigm.

Errors

Warning: The programs given in this book may contain errors. Authors assume no liability for any damage or accidents or any sort of mental harassment of the readers.

This note is not uncommon in these days of legal litigations. However, we promise you that we have taken all the efforts to make the book free of any sort of errors. But "To Err is Human". Should you come across any errors or would like to seek any clarifications regarding the hardware, software, availability of chips, etc. please feel free to give a shout by email to Dr. R.K. Kamat at rkk_eln@unishivaji.ac.in. He is a single contact point for all the authors.

At Last

The goal of the present book is to empower the potential reader having more or less programming or electronics experience, to build embedded systems using microcontrollers around the home, office, store, etc. We have tried our best to overcome the lack of hands on approach with our maturity in this domain The book will serve a good reference for the academic people and overcome the fear of the newbie's in this field. Because after all as teachers we believe in what Linda Conway has said, "It's not what is poured into a student that counts, but what is planted."

We wish you all the best for planting the concepts of embedded systems in your minds that will feel your life with happiness.

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Dr. R.K. Kamat
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