THE AVR MICROCONTROLLER
AND EMBEDDED SYSTEMS

Using Assembly and C

Muhammad Ali Mazidi
Sarmad Naimi
Sepehr Naimi

Prentice Hall
Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montreal Toronto
Delhi Mexico City Sao Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo
## CONTENTS

### CHAPTER 0: INTRODUCTION TO COMPUTING
- SECTION 0.1: NUMBERING AND CODING SYSTEMS 2
- SECTION 0.2: DIGITAL PRIMER 9
- SECTION 0.3: SEMICONDUCTOR MEMORY 13
- SECTION 0.4: CPU ARCHITECTURE 29

### CHAPTER 1: THE AVR MICROCONTROLLER: HISTORY AND FEATURES
- SECTION 1.1: MICROCONTROLLERS AND EMBEDDED PROCESSORS 40
- SECTION 1.2: OVERVIEW OF THE AVR FAMILY 44

### CHAPTER 2: AVR ARCHITECTURE AND ASSEMBLY LANGUAGE PROGRAMMING
- SECTION 2.1: THE GENERAL PURPOSE REGISTERS IN THE AVR 56
- SECTION 2.2: THE AVR DATA MEMORY 59
- SECTION 2.3: USING INSTRUCTIONS WITH THE DATA MEMORY 61
- SECTION 2.4: AVR STATUS REGISTER 71
- SECTION 2.5: AVR DATA FORMAT AND DIRECTIVES 75
- SECTION 2.6: INTRODUCTION TO AVR ASSEMBLY PROGRAMMING 80
- SECTION 2.7: ASSEMBLING AN AVR PROGRAM 82
- SECTION 2.8: THE PROGRAM COUNTER AND PROGRAM ROM SPACE IN THE AVR 85
- SECTION 2.9: RISC ARCHITECTURE IN THE AVR 93
- SECTION 2.10: VIEWING REGISTERS AND MEMORY WITH AVR STUDIO IDE 97

### CHAPTER 3: BRANCH, CALL, AND TIME DELAY LOOP
- SECTION 3.1: BRANCH INSTRUCTIONS AND LOOPING 108
- SECTION 3.2: CALL INSTRUCTIONS AND STACK 118
- SECTION 3.3: AVR TIME DELAY AND INSTRUCTION PIPELINE 128

### CHAPTER 4: AVR I/O PORT PROGRAMMING
- SECTION 4.1: I/O PORT PROGRAMMING IN AVR 140
- SECTION 4.2: I/O BIT MANIPULATION PROGRAMMING 149

### CHAPTER 5: ARITHMETIC, LOGIC INSTRUCTIONS, AND PROGRAMS
- SECTION 5.1: ARITHMETIC INSTRUCTIONS 162
- SECTION 5.2: SIGNED NUMBER CONCEPTS AND ARITHMETIC OPERATIONS 170
- SECTION 5.3: LOGIC AND COMPARE INSTRUCTIONS 176
- SECTION 5.4: ROTATE AND SHIFT INSTRUCTIONS AND DATA Serialization 183
- SECTION 5.5: BCD AND ASCII CONVERSION 190

### CHAPTER 6: AVR ADVANCED ASSEMBLY LANGUAGE PROGRAMMING
- SECTION 6.1: INTRODUCING SOME MORE ASSEMBLER DIRECTIVES 198
- SECTION 6.2: REGISTER AND DIRECT ADDRESSING MODES 202
- SECTION 6.3: REGISTER INDIRECT ADDRESSING MODE 208
SECTION 6.4: LOOK-UP TABLE AND TABLE PROCESSING 216
SECTION 6.5: BIT-ADDRESSABILITY 226
SECTION 6.6: ACCESSING EEPROM IN AVR 233
SECTION 6.7: CHECKSUM AND ASCII SUBROUTINES 238
SECTION 6.8: MACROS 244

CHAPTER 7: AVR PROGRAMMING IN C 255
SECTION 7.1: DATA TYPES AND TIME DELAYS IN C 256
SECTION 7.2: I/O PROGRAMMING IN C 263
SECTION 7.3: LOGIC OPERATIONS IN C 265
SECTION 7.4: DATA CONVERSION PROGRAMS IN C 275
SECTION 7.5: DATA SERIALIZATION IN C 280
SECTION 7.6: MEMORY ALLOCATION IN C 282

CHAPTER 8: AVR HARDWARE CONNECTION, HEX FILE, AND FLASH LOADERS 289
SECTION 8.1: ATMEGA32 PIN CONNECTION 290
SECTION 8.2: AVR FUSE BITS 294
SECTION 8.3: EXPLAINING THE HEX FILE FOR AVR 300
SECTION 8.4: AVR PROGRAMMING AND TRAINER BOARD 305

CHAPTER 9: AVR TIMER PROGRAMMING IN ASSEMBLY AND C 311
SECTION 9.1: PROGRAMMING TIMERS 0, 1, AND 2 313
SECTION 9.2: COUNTER PROGRAMMING 348
SECTION 9.3: PROGRAMMING TIMERS IN C 353

CHAPTER 10: AVR INTERRUPT PROGRAMMING IN ASSEMBLY AND C 363
SECTION 10.1: AVR INTERRUPTS 364
SECTION 10.2: PROGRAMMING TIMER INTERRUPTS 369
SECTION 10.3: PROGRAMMING EXTERNAL HARDWARE INTERRUPTS 376
SECTION 10.4: INTERRUPT PRIORITY IN THE AVR 381
SECTION 10.5: INTERRUPT PROGRAMMING IN C 385

CHAPTER 11: AVR SERIAL PORT PROGRAMMING IN ASSEMBLY AND C 395
SECTION 11.1: BASICS OF SERIAL COMMUNICATION 396
SECTION 11.2: ATMEGA32 CONNECTION TO RS232 403
SECTION 11.3: AVR SERIAL PORT PROGRAMMING IN ASSEMBLY 405
SECTION 11.4: AVR SERIAL PORT PROGRAMMING IN C 419
SECTION 11.5: AVR SERIAL PORT PROGRAMMING IN ASSEMBLY AND C USING INTERRUPTS 422

CHAPTER 12: LCD AND KEYBOARD INTERFACING 429
SECTION 12.1: LCD INTERFACING 430
SECTION 12.2: KEYBOARD INTERFACING 452

CHAPTER 13: ADC, DAC, AND SENSOR INTERFACING 463
SECTION 13.1: ADC CHARACTERISTICS 464
SECTION 13.2: ADC PROGRAMMING IN THE AVR 469