

# CONTENTS IN DETAIL

## ACKNOWLEDGMENTS

XXII

### 1

#### GETTING STARTED

1

The Possibilities Are Endless . . . . .	2
Strength in Numbers . . . . .	4
Parts and Accessories . . . . .	4
Required Software . . . . .	5
macOS . . . . .	6
Windows 10 . . . . .	7
Ubuntu Linux . . . . .	7
Using Arduino Safely . . . . .	8
Looking Ahead . . . . .	8

### 2

#### EXPLORING THE ARDUINO BOARD AND THE IDE

9

The Arduino Board . . . . .	9
Taking a Look Around the IDE . . . . .	14
The Command Area . . . . .	14
The Text Area . . . . .	16
The Output Window . . . . .	16
Creating Your First Sketch in the IDE . . . . .	16
Comments . . . . .	17
The setup() Function . . . . .	18
Controlling the Hardware . . . . .	18
The loop() Function . . . . .	18
Verifying Your Sketch . . . . .	20
Uploading and Running Your Sketch . . . . .	20
Modifying Your Sketch . . . . .	21
Looking Ahead . . . . .	21

### 3

#### FIRST STEPS

23

Planning Your Projects . . . . .	24
About Electricity . . . . .	24
Current . . . . .	24
Voltage . . . . .	25
Power . . . . .	25
Electronic Components . . . . .	25
The Resistor . . . . .	25
The Light-Emitting Diode . . . . .	29
The Solderless Breadboard . . . . .	31

<b>Project #1: Creating a Blinking LED Wave</b>	<b>33</b>
The Algorithm . . . . .	33
The Hardware . . . . .	33
The Schematic . . . . .	33
The Sketch . . . . .	34
Running the Sketch . . . . .	35
Using Variables . . . . .	35
<b>Project #2: Repeating with for Loops</b>	<b>36</b>
Varying LED Brightness with Pulse-Width Modulation . . . . .	37
<b>Project #3: Demonstrating PWM</b>	<b>38</b>
More Electric Components . . . . .	39
The Transistor . . . . .	39
The Rectifier Diode . . . . .	40
The Relay . . . . .	41
Higher-Voltage Circuits . . . . .	41
Looking Ahead . . . . .	43
<b>4</b>	
<b>BUILDING BLOCKS</b>	<b>45</b>
Using Schematic Diagrams . . . . .	46
Identifying Components . . . . .	46
Wires in Schematics . . . . .	48
Dissecting a Schematic . . . . .	49
The Capacitor . . . . .	50
Measuring the Capacity of a Capacitor . . . . .	51
Reading Capacitor Values . . . . .	51
Types of Capacitors . . . . .	51
Digital Inputs . . . . .	53
<b>Project #4: Demonstrating a Digital Input</b>	<b>55</b>
The Algorithm . . . . .	55
The Hardware . . . . .	55
The Schematic . . . . .	55
The Sketch . . . . .	59
Understanding the Sketch . . . . .	60
Modifying Your Sketch: Making More Decisions with if-else . . . . .	61
Boolean Variables . . . . .	62
Comparison Operators . . . . .	62
Making Two or More Comparisons . . . . .	63
<b>Project #5: Controlling Traffic</b>	<b>64</b>
The Goal . . . . .	64
The Algorithm . . . . .	64
The Hardware . . . . .	64
The Schematic . . . . .	65
The Sketch . . . . .	66
Running the Sketch . . . . .	68
Analog vs. Digital Signals . . . . .	69
<b>Project #6: Creating a Single-Cell Battery Tester</b>	<b>70</b>
The Goal . . . . .	70
The Algorithm . . . . .	70
The Hardware . . . . .	71

The Schematic . . . . .	71
The Sketch . . . . .	72
Doing Arithmetic with an Arduino . . . . .	73
Float Variables . . . . .	73
Comparison Operators for Calculations . . . . .	73
Improving Analog Measurement Precision with a Reference Voltage . . . . .	73
Using an External Reference Voltage . . . . .	74
Using the Internal Reference Voltage . . . . .	75
The Variable Resistor . . . . .	75
Piezoelectric Buzzers . . . . .	77
Piezo Schematic . . . . .	77
<b>Project #7: Trying Out a Piezo Buzzer</b>	<b>78</b>
<b>Project #8: Creating a Quick-Read Thermometer</b>	<b>79</b>
The Goal . . . . .	80
The Hardware . . . . .	80
The Schematic . . . . .	80
The Sketch . . . . .	81
Looking Ahead . . . . .	82

## 5

### **WORKING WITH FUNCTIONS 83**

#### **Project #9: Creating a Function to Repeat an Action 84**

#### **Project #10: Creating a Function to Set the Number of Blinks 85**

Creating a Function to Return a Value . . . . . 86

#### **Project #11: Creating a Quick-Read Thermometer That Blinks the Temperature 86**

    The Hardware . . . . . 87

    The Schematic . . . . . 87

    The Sketch . . . . . 88

Displaying Data from the Arduino in the Serial Monitor . . . . . 89

    The Serial Monitor . . . . . 89

#### **Project #12: Displaying the Temperature in the Serial Monitor 91**

    Debugging with the Serial Monitor . . . . . 92

Making Decisions with while Statements . . . . . 93

    while . . . . . 93

    do-while . . . . . 93

Sending Data from the Serial Monitor to the Arduino . . . . . 93

#### **Project #13: Multiplying a Number by Two 94**

long Variables . . . . . 95

#### **Project #14: Using long Variables 95**

Looking Ahead . . . . . 97

## 6

### **NUMBERS, VARIABLES, AND ARITHMETIC 99**

Generating Random Numbers . . . . . 100

    Using Ambient Current to Generate a Random Number . . . . . 100

#### **Project #15: Creating an Electronic Die 101**

    The Hardware . . . . . 101

    The Schematic . . . . . 102

    The Sketch . . . . . 102

    Modifying the Sketch . . . . . 104

A Quick Course in Binary . . . . .	104
Binary Numbers . . . . .	104
Byte Variables. . . . .	105
Increasing Digital Outputs with Shift Registers . . . . .	106
<b>Project #16: Creating an LED Binary Number Display</b>	<b>107</b>
The Hardware . . . . .	107
The Schematic . . . . .	107
The Sketch . . . . .	109
<b>Project #17: Making a Binary Quiz Game</b>	<b>110</b>
The Algorithm . . . . .	110
The Sketch . . . . .	110
Arrays . . . . .	112
Defining an Array . . . . .	113
Referring to Values in an Array . . . . .	113
Writing to and Reading from Arrays . . . . .	113
Seven-Segment LED Displays . . . . .	114
Controlling the LED . . . . .	115
<b>Project #18: Creating a Single-Digit Display</b>	<b>117</b>
The Hardware . . . . .	117
The Schematic . . . . .	117
The Sketch . . . . .	117
Modifying the Sketch: Displaying Double Digits . . . . .	119
<b>Project #19: Controlling Two Seven-Segment LED Display Modules</b>	<b>119</b>
The Hardware . . . . .	119
The Schematic . . . . .	119
Modulo . . . . .	120
<b>Project #20: Creating a Digital Thermometer</b>	<b>122</b>
The Hardware . . . . .	122
The Sketch . . . . .	122
Looking Ahead . . . . .	123

## **7 EXPANDING YOUR ARDUINO** **125**

Shields . . . . .	126
ProtoShields . . . . .	128
<b>Project #21: Creating a Custom Shield</b>	<b>129</b>
The Hardware . . . . .	129
The Schematic . . . . .	129
The Layout of the ProtoShield Board . . . . .	130
The Design. . . . .	130
Soldering the Components . . . . .	131
Testing Your ProtoShield . . . . .	133
Expanding Sketches with Libraries . . . . .	133
Downloading an Arduino Library as a ZIP File . . . . .	134
Importing an Arduino Library with Library Manager . . . . .	136
SD Memory Cards . . . . .	137
Connecting the Card Module . . . . .	138
Testing Your SD Card. . . . .	139
<b>Project #22: Writing Data to the Memory Card</b>	<b>140</b>
The Sketch . . . . .	140

<b>Project #23: Creating a Temperature-Logging Device</b>	<b>142</b>
The Hardware	142
The Sketch	142
Timing Applications with millis() and micros()	144
<b>Project #24: Creating a Stopwatch</b>	<b>146</b>
The Hardware	146
The Schematic	147
The Sketch	147
Interrupts	149
Interrupt Modes	150
Configuring Interrupts	150
Activating or Deactivating Interrupts	150
<b>Project #25: Using Interrupts</b>	<b>151</b>
The Sketch	151
Looking Ahead	152

## 8

### **LED NUMERIC DISPLAYS AND MATRICES** **153**

LED Numeric Displays	154
Installing the Library	155
<b>Project #26: Digital Stopwatch</b>	<b>158</b>
<b>Project #27: Using LED Matrix Modules</b>	<b>160</b>
Installing the Library	161
Editing the Display Font	164
Looking Ahead	166

## 9

### **LIQUID CRYSTAL DISPLAYS** **167**

Character LCD Modules	167
Using a Character LCD in a Sketch	169
Displaying Text	170
Displaying Variables or Numbers	171
<b>Project #28: Defining Custom Characters</b>	<b>172</b>
Graphic LCD Modules	173
Connecting the Graphic LCD	174
Using the LCD	174
Controlling the Display	174
<b>Project #29: Seeing the Text Functions in Action</b>	<b>176</b>
The Sketch	176
Running the Sketch	177
Creating More Complex Display Effects with Graphic Functions	177
<b>Project #30: Seeing the Graphic Functions in Action</b>	<b>179</b>
The Sketch	179
<b>Project #31: Creating a Temperature History Monitor</b>	<b>181</b>
The Algorithm	181
The Hardware	181
The Sketch	182
Running the Sketch	184
Modifying the Sketch	184
Looking Ahead	184

<b>10</b>		
<b>CREATING YOUR OWN ARDUINO LIBRARIES</b>		<b>185</b>
Creating Your First Arduino Library . . . . .		186
Anatomy of an Arduino Library . . . . .		187
The Header File . . . . .		187
The Source File . . . . .		188
The KEYWORDS.TXT File . . . . .		189
Installing Your New Arduino Library . . . . .		190
Creating a ZIP File Using Windows 7 and Later . . . . .		190
Creating a ZIP File Using Mac OS X or Later . . . . .		192
Installing Your New Library . . . . .		193
Creating a Library That Accepts Values to Perform a Function . . . . .		195
Creating a Library That Processes and Displays Sensor Values . . . . .		197
Looking Ahead . . . . .		202
<b>11</b>		
<b>NUMERIC KEYPADS</b>		<b>203</b>
Using a Numeric Keypad . . . . .		203
Wiring a Keypad . . . . .		204
Programming for the Keypad . . . . .		205
Testing the Sketch . . . . .		206
Making Decisions with switch case . . . . .		206
<b>Project #32: Creating a Keypad-Controlled Lock</b>		<b>207</b>
The Sketch . . . . .		207
Understanding the Sketch . . . . .		209
Testing the Sketch . . . . .		209
Looking Ahead . . . . .		210
<b>12</b>		
<b>ACCEPTING USER INPUT WITH TOUCHSCREENS</b>		<b>211</b>
Touchscreens . . . . .		211
Connecting the Touchscreen . . . . .		212
<b>Project #33: Addressing Areas on the Touchscreen</b>		<b>213</b>
The Hardware . . . . .		213
The Sketch . . . . .		213
Testing the Sketch . . . . .		214
Mapping the Touchscreen . . . . .		215
<b>Project #34: Creating a Two-Zone On/Off Touch Switch</b>		<b>215</b>
The Sketch . . . . .		216
Understanding the Sketch . . . . .		217
Testing the Sketch . . . . .		218
Using the map() Function . . . . .		218
<b>Project #35: Creating a Three-Zone Touch Switch</b>		<b>218</b>
The Touchscreen Map . . . . .		219
The Sketch . . . . .		219
Understanding the Sketch . . . . .		221
Looking Ahead . . . . .		221

<b>13</b>		
<b>MEET THE ARDUINO FAMILY</b>		<b>223</b>
<b>Project #36: Creating Your Own Breadboard Arduino</b>		<b>224</b>
The Hardware . . . . .		224
The Schematic . . . . .		227
Running the Sketch . . . . .		230
The Many Arduino and Alternative Boards . . . . .		233
Arduino Uno . . . . .		235
Freetronics Eleven . . . . .		235
The Adafruit Pro Trinket . . . . .		236
The Arduino Nano . . . . .		236
The LilyPad . . . . .		237
The Arduino Mega 2560 . . . . .		237
The Freetronics EtherMega . . . . .		238
The Arduino Due . . . . .		238
Looking Ahead . . . . .		240
<b>14</b>		
<b>MOTORS AND MOVEMENT</b>		<b>241</b>
Making Small Motions with Servos . . . . .		241
Selecting a Servo . . . . .		242
Connecting a Servo . . . . .		243
Putting a Servo to Work . . . . .		243
<b>Project #37: Building an Analog Thermometer</b>		<b>244</b>
The Hardware . . . . .		244
The Schematic . . . . .		245
The Sketch . . . . .		245
Using Electric Motors . . . . .		247
Selecting a Motor . . . . .		247
The TIP120 Darlington Transistor . . . . .		247
<b>Project #38: Controlling the Motor</b>		<b>248</b>
The Hardware . . . . .		248
The Schematic . . . . .		249
The Sketch . . . . .		250
Using Small Stepper Motors . . . . .		251
<b>Project #39: Building and Controlling a Robot Vehicle</b>		<b>254</b>
The Hardware . . . . .		255
The Schematic . . . . .		256
Connecting the Motor Shield . . . . .		257
The Sketch . . . . .		259
Connecting Extra Hardware to the Robot . . . . .		262
Sensing Collisions . . . . .		262
<b>Project #40: Detecting Robot Vehicle Collisions with a Microswitch</b>		<b>262</b>
The Schematic . . . . .		263
The Sketch . . . . .		264
Infrared Distance Sensors . . . . .		266
Wiring It Up . . . . .		266
Testing the IR Distance Sensor . . . . .		267

<b>Project #41: Detecting Robot Vehicle Collisions with an IR Distance Sensor</b>	<b>269</b>
The Sketch . . . . .	269
Modifying the Sketch: Adding More Sensors . . . . .	271
Ultrasonic Distance Sensors . . . . .	271
Connecting the Ultrasonic Sensor . . . . .	272
Testing the Ultrasonic Sensor . . . . .	272
<b>Project #42: Detecting Collisions with an Ultrasonic Distance Sensor</b>	<b>273</b>
The Sketch . . . . .	273
Looking Ahead . . . . .	275
<b>15</b>	
<b>USING GPS WITH YOUR ARDUINO</b>	<b>277</b>
What Is GPS? . . . . .	278
Testing the GPS Shield . . . . .	280
<b>Project #43: Creating a Simple GPS Receiver</b>	<b>281</b>
The Hardware . . . . .	282
The Sketch . . . . .	282
Running the Sketch . . . . .	283
<b>Project #44: Creating an Accurate GPS-Based Clock</b>	<b>284</b>
The Hardware . . . . .	284
The Sketch . . . . .	284
<b>Project #45: Recording the Position of a Moving Object over Time</b>	<b>286</b>
The Hardware . . . . .	286
The Sketch . . . . .	286
Running the Sketch . . . . .	289
Looking Ahead . . . . .	290
<b>16</b>	
<b>WIRELESS DATA</b>	<b>291</b>
Using Low-Cost Wireless Modules . . . . .	291
<b>Project #46: Creating a Wireless Remote Control</b>	<b>293</b>
The Transmitter Circuit Hardware . . . . .	293
The Transmitter Schematic . . . . .	293
The Receiver Circuit Hardware . . . . .	294
The Receiver Schematic . . . . .	294
The Transmitter Sketch . . . . .	296
The Receiver Sketch . . . . .	297
Using LoRa Wireless Data Modules for Greater Range and Faster Speed . . . . .	298
<b>Project #47: Remote Control over LoRa Wireless</b>	<b>299</b>
The Transmitter Circuit Hardware . . . . .	299
The Transmitter Schematic . . . . .	299
The Receiver Circuit Hardware . . . . .	301
The Receiver Schematic . . . . .	301
The Transmitter Sketch . . . . .	302
The Receiver Sketch . . . . .	303
<b>Project #48: Remote Control over LoRa Wireless with Confirmation</b>	<b>304</b>
The Transmitter Circuit Hardware . . . . .	304
The Transmitter Schematic . . . . .	305
The Transmitter Sketch . . . . .	306
The Receiver Sketch . . . . .	307



<b>Project #49: Sending Remote Sensor Data Using LoRa Wireless</b>	<b>309</b>
The Transmitter Circuit Hardware . . . . .	309
The Receiver Circuit Hardware . . . . .	309
The Receiver Schematic . . . . .	309
The Transmitter Sketch . . . . .	310
The Receiver Sketch . . . . .	312
Looking Ahead . . . . .	314
<b>17</b>	
<b>INFRARED REMOTE CONTROL</b>	<b>315</b>
What Is Infrared? . . . . .	315
Setting Up for Infrared . . . . .	316
The IR Receiver . . . . .	316
The Remote Control . . . . .	316
A Test Sketch . . . . .	317
Testing the Setup . . . . .	317
<b>Project #50: Creating an IR Remote Control Arduino</b>	<b>318</b>
The Hardware . . . . .	319
The Schematic . . . . .	319
The Sketch . . . . .	320
Modifying the Sketch . . . . .	321
<b>Project #51: Creating an IR Remote Control Robot Vehicle</b>	<b>321</b>
The Hardware . . . . .	321
The Sketch . . . . .	321
Looking Ahead . . . . .	324
<b>18</b>	
<b>READING RFID TAGS</b>	<b>325</b>
Inside RFID Devices . . . . .	326
Testing the Hardware . . . . .	327
The Schematic . . . . .	327
Testing the Schematic . . . . .	327
The Test Sketch . . . . .	327
Displaying the RFID Tag ID Number . . . . .	328
<b>Project #52: Creating a Simple RFID Control System</b>	<b>328</b>
The Sketch . . . . .	329
Understanding the Sketch . . . . .	330
Storing Data in the Arduino's Built-in EEPROM . . . . .	331
Reading and Writing to the EEPROM . . . . .	332
<b>Project #53: Creating an RFID Control with "Last Action" Memory</b>	<b>333</b>
The Sketch . . . . .	333
Understanding the Sketch . . . . .	336
Looking Ahead . . . . .	336
<b>19</b>	
<b>DATA BUSES</b>	<b>337</b>
The I <sup>2</sup> C Bus . . . . .	338
<b>Project #54: Using an External EEPROM</b>	<b>339</b>
The Hardware . . . . .	340
The Schematic . . . . .	340

The Sketch . . . . .	341
Running the Sketch . . . . .	342
<b>Project #55: Using a Port Expander IC</b>	<b>343</b>
The Hardware . . . . .	343
The Schematic . . . . .	343
The Sketch . . . . .	345
The SPI Bus . . . . .	346
Pin Connections . . . . .	346
Implementing the SPI . . . . .	346
Sending Data to an SPI Device . . . . .	347
<b>Project #56: Using a Digital Rheostat</b>	<b>348</b>
The Hardware . . . . .	348
The Schematic . . . . .	348
The Sketch . . . . .	349
Looking Ahead . . . . .	350

## 20

### REAL-TIME CLOCKS 351

Connecting the RTC Module . . . . .	352
<b>Project #57: Adding and Displaying Time and Date with an RTC</b>	<b>352</b>
The Hardware . . . . .	352
The Sketch . . . . .	353
Understanding and Running the Sketch . . . . .	355
<b>Project #58: Creating a Simple Digital Clock</b>	<b>356</b>
The Hardware . . . . .	356
The Sketch . . . . .	357
Understanding and Running the Sketch . . . . .	359
<b>Project #59: Creating an RFID Time-Clock System</b>	<b>360</b>
The Hardware . . . . .	360
The Sketch . . . . .	361
Understanding the Sketch . . . . .	364
Looking Ahead . . . . .	365

## 21

### THE INTERNET 367

What You'll Need . . . . .	367
<b>Project #60: Building a Remote Monitoring Station</b>	<b>369</b>
The Hardware . . . . .	369
The Sketch . . . . .	369
Troubleshooting . . . . .	372
Understanding the Sketch . . . . .	372
<b>Project #61: Creating an Arduino Tweeter</b>	<b>373</b>
The Hardware . . . . .	373
The Sketch . . . . .	373
Controlling Your Arduino from the Web . . . . .	375
<b>Project #62: Setting Up a Remote Control for Your Arduino</b>	<b>375</b>
The Hardware . . . . .	376
The Sketch . . . . .	377
Controlling Your Arduino Remotely . . . . .	377
Looking Ahead . . . . .	379

<b>22</b>		
<b>CELLULAR COMMUNICATIONS</b>		<b>381</b>
The Hardware . . . . .		382
Hardware Configuration and Testing . . . . .		383
<b>Project #63: Building an Arduino Dialer</b>		<b>385</b>
The Hardware . . . . .		386
The Schematic . . . . .		386
The Sketch . . . . .		387
Understanding the Sketch. . . . .		387
<b>Project #64: Building an Arduino Texter</b>		<b>388</b>
The Sketch . . . . .		388
Understanding the Sketch. . . . .		389
<b>Project #65: Setting Up an SMS Remote Control</b>		<b>390</b>
The Hardware . . . . .		390
The Schematic . . . . .		390
The Sketch . . . . .		391
Understanding the Sketch. . . . .		393
Looking Ahead . . . . .		393
<b>INDEX</b>		<b>395</b>