

Arduino & Co

Measure, Control, and Hack

Clever Tricks with ATmega328 Pro Mini Boards



Robert Sontheimer

- This is an Elektor Publication. Elektor is the media brand of
Elektor International Media B.V.
PO Box 11, NL-6114-ZG Susteren, The Netherlands
Phone: +31 46 4389444

- All rights reserved. No part of this book may be reproduced in any material form, including photocopying, or storing in any medium by electronic means and whether or not transiently or incidentally to some other use of this publication, without the written permission of the copyright holder except in accordance with the provisions of the Copyright Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency Ltd., 90 Tottenham Court Road, London, England W1P 9HE. Applications for the copyright holder's permission to reproduce any part of the publication should be addressed to the publishers.

○ Declaration

The Author and Publisher have used their best efforts in ensuring the correctness of the information contained in this book. They do not assume, and hereby disclaim, any liability to any party for any loss or damage caused by errors or omissions in this book, whether such errors or omissions result from negligence, accident, or any other cause.

- British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 978-3-89576-515-5 Print

ISBN 978-3-89576-516-2 eBook

- © Copyright 2022: Elektor International Media B.V. (2022-08 / 1st)

Prepress Production: Robert Sontheimer

English translation: Brian Tristram Williams (and the author)

Printed in the Netherlands by Ipskamp Printing, Enschede

Elektor is part of EIM, the world's leading source of essential technical information and electronics products for pro engineers, electronics designers, and the companies seeking to engage them. Each day, our international team develops and delivers high-quality content - via a variety of media channels (including magazines, video, digital media, and social media) in several languages - relating to electronics design and DIY electronics. **www.elektormagazine.com**

Arduino & Co

Measure, Control, and Hack

●

Clever Tricks with ATmega328 **Pro Mini** Boards

●

Robert Sontheimer

Table of Contents

Foreword.....	5
Chapter 1 • ATmega boards.....	14
1.1 The Pro Mini form factor.....	14
A computer for a few euro.....	15
5 V / 16 MHz and 3.3 V / 8 MHz versions.....	16
ATmega328P and ATmega168PA.....	16
Pin layouts.....	17
1.2 Uno versions.....	18
1.3 LilyPads and similar.....	19
16 MHz LilyPads.....	20
1.4 The Nano board.....	20
Chapter 2 • USB adapter with serial interface.....	21
2.1 USB adapters based on the CP2102.....	21
2.1.1 Project: Universal serial adapter cable.....	22
Construction.....	22
Tip: Neat soldering.....	24
Usage.....	26
2.1.2 Serial Micro USB adapter.....	26
Chapter 3 • Buying tips.....	27
3.1 Local suppliers and domestic mail order companies.....	27
3.1.1 Conrad Electronic.....	27
3.1.2 Reichelt Elektronik.....	28
3.1.3 Other online suppliers.....	28
3.2 Big International online stores.....	28
3.2.2 Ebay.....	28
Search settings.....	29
Security on Ebay.....	29
3.2.3 Amazon.....	29
3.2.4 AliExpress.....	30
AliExpress shipping costs.....	30
Buyer Protection on AliExpress.....	30
3.3 PayPal payment service.....	31
3.4 Customs.....	32
3.5 Caution: Pitfalls!.....	32
Fake items.....	32
False information.....	33
False promises.....	33
3.6 Buying basic equipment.....	34
3.6.1 The necessary tools.....	34
Project: The simplest soldering station in the world.....	34

Additional tools.....	36
3.6.2 ATmega boards.....	36
Serial adapters.....	36
3.6.3 Power supply.....	37
Mains power supplies.....	37
The thing about current and voltage.....	37
Disposable or rechargeable battery.....	39
Lithium-ion rechargeables.....	39
Warning: Fake batteries.....	40
Charge controller with protection circuit.....	41
3.6.4 Standard components.....	41
Resistors.....	41
The E12 series.....	41
Capacitors.....	42
LEDs.....	43
Transistors.....	43
Buzzer.....	44
Jumper wires.....	44
3.6.5 Measuring tools.....	45
Multimeter.....	45
Infrared thermometer.....	45
Vernier calipers.....	46
Chapter 4 • Optimal construction.....	47
4.1 Construction on breadboard.....	47
4.2 Point-to-point construction.....	48
4.3 The thumbtack technique.....	49
4.4 Perfboards.....	49
Hole matrix.....	49
Stripboard.....	50
Other grid arrangements.....	50
4.5 Construction on printed circuit board.....	51
4.6 Pin header connectors.....	52
Coded connections.....	52
Chapter 5 Programming.....	53
5.1 The Arduino-platform.....	53
5.2 Our first program.....	54
Syntax: setup() and loop() functions.....	54
Sketch: Our first program.....	55
5.3 Uploading programs.....	56
5.4 Downloading the programs.....	57
Chapter 6 • Board inputs and outputs.....	58

6.1 Reading inputs digitally	58
Syntax: Variables	60
Syntax: pinMode(), digitalRead() and digitalWrite()	61
Syntax: Comparisons and conditions	62
Syntax: while and do-while loops	63
Pushbutton switch	63
Sketch: Pushbutton switch	64
6.2 Reading analog inputs	65
Reference voltage	65
VCC as reference	65
Internal reference	66
External reference	66
Syntax: analogRead() and analogReference()	66
6.2.1 Measuring voltages directly	67
Syntax: Defining constants	67
Syntax: Serial transmission	68
Syntax: Calculations and assignments	68
Calculation pitfalls	69
Syntax: Rounding up and down	69
Sketch: Measuring voltages up to VCC	70
Calibration	71
6.2.2 Measuring using internal ref. & voltage divider	71
Possible ranges	72
Sketch: Measuring using internal ref. & voltage divider	72
Calibration	74
6.2.3 Measuring directly using the internal reference	74
Tip: Commenting out lines	75
Calibration	75
6.2.4 Measuring current	76
Sketch: Measuring current	76
Possible ranges	78
Calibration	79
6.2.5 Resistor measurement	80
Sketch: Resistance measurement	81
Swapping resistors	82
Calibration	82
6.3 Switching outputs digitally	82
Chapter 7 • How do you switch something?	83
7.1 LEDs	83
7.1.1 Calculating the series resistance	84
7.1.2 LEDs in battery operation	84
7.1.3 Switching direction to ground or positive	85
7.1.4 Project: LED effect board	86

Determining resistor values.....	87
LilyPad construction template.....	88
Pro Mini construction template.....	89
Syntax: Arrays.....	90
Syntax: for loop.....	90
Syntax: delay() and system time.....	91
Simple LED effect.....	92
Sketch: LED rotation effect.....	92
Syntax: Random values with random().....	94
LED running light effects.....	94
Sketch: LED running light effects.....	95
Other Blink applications.....	97
7.1.5 Battery protection for effect flasher.....	97
7.1.6 LEDs with integrated series resistor.....	98
7.1.7 Power LEDs.....	98
7.2 Switching using a transistor.....	99
7.2.1 BC547 transistor.....	100
7.2.2 BC337-40 transistor.....	101
7.2.3 BD435 transistor.....	101
Tip: Heat test.....	102
7.2.4 Switching using MOSFETs.....	102
The NTD4906N and IRLR8726PbF.....	103
Tip: Thermally conductive adhesive.....	104
7.2.5 ULN2003A transistor array.....	104
7.2.6 ULN2803A transistor array.....	105
7.3 Switching using a relay.....	106
7.3.1 Solid-State relay.....	107
Chapter 8 • Controlling, regulating, and dimming.....	108
8.1 Pulse-width modulation (PWM).....	108
Syntax: analogWrite().....	109
8.1.1 Project: Dimming LEDs in all colors.....	109
8.1.2 Quick color theory.....	110
8.1.3 Flowing color changes.....	111
Syntax: sin() and cos().....	111
Sketch: Flowing color changes.....	112
Tip: Small test with LED effect board.....	113
8.2 Low-pass demodulation.....	114
Time constant τ	114
Calculation.....	115
Ripple.....	115
Two-stage filter.....	116
8.3 Regulation with a feedback loop.....	116
8.4 Project: Adjustable constant current source.....	116

Customization.....	118
Syntax: Bitwise operators.....	119
Sketch: Adjustable constant-current source.....	120
Calibration.....	125
8.5 Project: Lithium-ion battery testing and charging station.....	127
Construction on a PCB.....	128
Construction using thumbtacks.....	129
Supplying power via USB.....	132
Separate power supply.....	132
Cooling.....	133
Sketch: Lithium-ion testing and charging station.....	134
Current and voltage specifications.....	149
Serial output.....	151
Internal resistance.....	152
Calibration.....	153
8.6 Project: Adjustable current source with limits.....	155
Time vs charge amount.....	155
Sketch: Adjustable current source with limits.....	157
Power supply.....	158
Serial output.....	158
Cooling.....	159
Default values, limits.....	160
Calibration.....	161
Chapter 9 • Controlling motors.....	163
9.1 DC motors.....	163
9.1.1 Transistor control.....	163
9.1.2 Speed control using PWM.....	164
9.1.3 Forward and reverse with an H-bridge.....	165
The L9110S.....	165
The L298N.....	166
9.1.4 Full control using H-bridge and PWM.....	167
Syntax: min() and max() functions.....	168
Sketch: Full motor control.....	168
9.2 Stepper motors.....	170
9.2.1 How it works.....	170
Bipolar and unipolar versions.....	171
Full- and half-step operation.....	172
Actual stepper motors.....	173
9.2.2 The 28BYJ-48.....	174
Control using a ULN2003 driver board.....	175
Control using 4 transistors.....	176
Tip: Stepper motor under battery operation.....	177
Sketch: 28BYJ-48 stepper motor control.....	177

9.2.3 Control using the A4988.....	183
Pinout.....	184
Adjusting the current.....	185
9.2.4 Control using the DRV8825.....	186
Pinout.....	186
Adjusting the current.....	187
9.2.5 Version A4988 vs. DRV8825.....	188
9.3 Brushless motors.....	188
9.3.1 Control using ESC.....	189
Power supply.....	189
Control signal.....	190
Sketch: ESC-control using potentiometer.....	190
9.4 Servos.....	192
Control.....	192
Chapter 10 • Sensors.....	193
10.1 Analog sensors.....	193
10.1.1 Brightness sensor using LDR.....	193
10.1.2 NTC temperature measurement.....	194
Sketch: Temperature measurement using NTC.....	195
10.1.3 Analog joystick.....	198
10.1.4 Measuring light with a photodiode.....	199
10.2 Digital measurements.....	199
10.2.1 TL1838 or VS1838B infrared receiver.....	199
10.2.2 HC-SR04 ultrasonic distance sensor.....	201
Syntax: pulseIn() function.....	202
Sketch: Ultrasonic distance measurement.....	202
10.2.3 HC-SR501 motion sensor.....	205
Supplying power to the HC-SR501.....	207
10.2.4 The I²C interface.....	207
SCL and SDA.....	207
I ² C on the ATmega328 and 168.....	209
Syntax: Including libraries.....	209
Syntax: I ² C functions with Wire.h.....	210
I ² C sensors.....	211
Breakout boards.....	211
10.2.5 BMP180 air pressure sensor.....	211
Project: Pressure and altitude sensing with the BMP180.....	212
Syntax: Function definitions.....	213
Sketch: Air-pressure sensor and altimeter.....	214
Accuracy from double-oversampling.....	219
10.2.6 MPU-6050 accelerometer.....	219
Sketch: Rotation and acceleration measurement.....	220
Output window.....	222

10.2.7 HMC5883L magnetic field sensor	223
Project: 3D compass	223
Sketch: 3D compass	224
Output window	227
10.2.8 GY-87 multi-sensor	227
Chapter 11 • Other components	228
11.1 RF remote control	228
Coding	229
Antenna	229
11.2 Seven-segment displays	230
Multiplexing	230
11.2.1 Basic program for 1 to 6 digits	232
Sketch: 7-segment display with several digits	233
int, float, hex, and degree displays	239
Syntax: modulo operator	239
Sketch: 7-segment display functions	239
11.2.2 Project: Voltmeter	244
Sketch: Voltmeter with 7-segment display	245
11.2.3 Project: Thermometer	246
Sketch: Thermometer with 7-segment display	247
Thermostat	249
11.3 Text displays with back-lighting	250
Pinouts and functions	251
Syntax: Controlling text displays	252
Sketch: Example with user-defined characters	253
Text display with I ² C interface	254
11.4 Mini lasers	254
Laser application examples	255
11.5 SD card module	256
Connection to the Arduino	256
Syntax: SD.h file functions	257
Sketch: Reading and writing files	257
Chapter 12 • Rechargeable batteries and accessories	260
Tip: Soldering round cells	261
12.1 Functionality and handling	262
12.2 Protection circuit	262
12.3 Connecting rechargeables in series	263
12.4 Balancers	263
12.5 USB charging regulators	264
Chapter 13 • Clever hacks and tricks	265
13.1 Measuring battery level without components	265

A weird measurement method.....	266
Sketch: Measuring battery voltage without components.....	266
Calibration.....	268
13.2 Arduino in deep sleep.....	268
Sketch: Sleep mode (bare template).....	269
A pin to wake up.....	269
Sketch: Sleep mode (with wake-up pin).....	270
13.3 Low-battery switch-off.....	271
Sketch: Low-battery switch-off.....	272
Integrating low-battery switch-off into projects.....	273
13.4 Pro Mini battery operation.....	274
Reducing current consumption.....	274
13.5 Project: Electronic die.....	275
Syntax: EEPROM functions.....	277
Sketch: Electronic die.....	278
Tip: LED effect board as a die.....	285
Dice for cheaters.....	285
13.6 Analog measurement without waiting.....	285
Sketch: Continuous analog measurement.....	286
Usage.....	289
13.7 Project: Universal remote control receiver.....	291
Turning the principle on its head.....	291
Sketch: 10-channel universal remote receiver.....	294
Teaching the receiver.....	302
Tip: Exact clocking of the loop with one byte.....	304
Tip: Exact clocking of the loop using an integer.....	305
Tip: Clocking of the loop with lateness options.....	306
Tip: Clocking of the loop using only system time.....	307
13.8 Project: Extreme altimeter.....	308
Sketch: Extreme altimeter.....	308
Settings and possibilities.....	312
Measuring small altitude changes.....	312
Weather trend barometer.....	313
13.9 Project: Infrasound recorder.....	315
Sketch: Infrasound recorder.....	318
Weather recorder.....	325
Index.....	327