HeatShield

A low-cost didactic device for control education simulating 3D printer heater blocks

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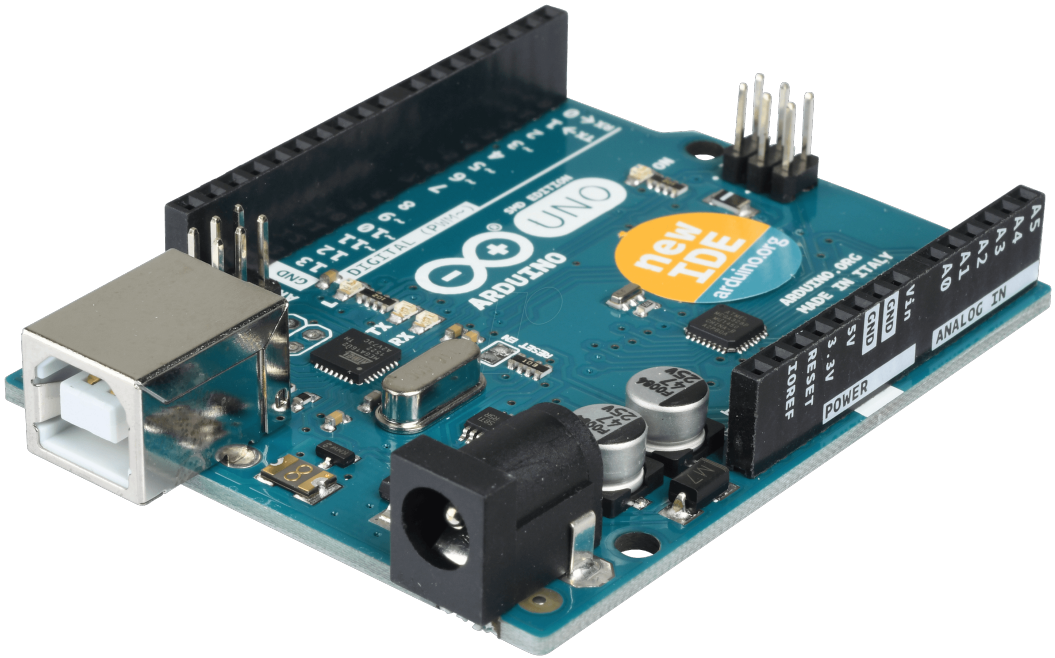
Motivation: Current tools for control education

- Feedback control engineering needs lab tools
- Tools are expensive, large, complicated and cannot be taken home
- Many require closed source tools (e.g. MATLAB, LabView)
- Implementation on microcontroller units (MCU) is under-represented

Motivation: A platform to build on

- Cheap
- Open source
- Standardized
- Free integrated development environment (IDE)
- Great community and abundance of materials
- Hardware expansion through “Shields”



Create novel tools for control engineering education, implementing a lab experiment on a single Arduino expansion Shield — a "live" control laboratory in the palm of your hand.

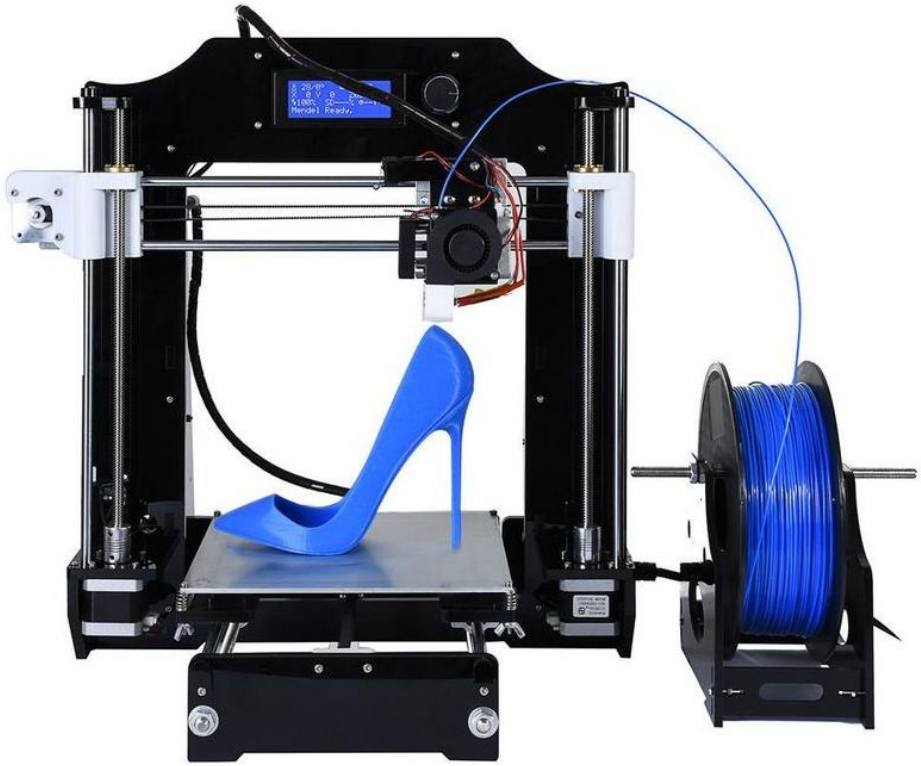
- Cheap
- Open source
- Standardized
- Free software library compatible with the Arduino IDE

AutomationShield

Control Systems Engineering Education

www.automationshield.com

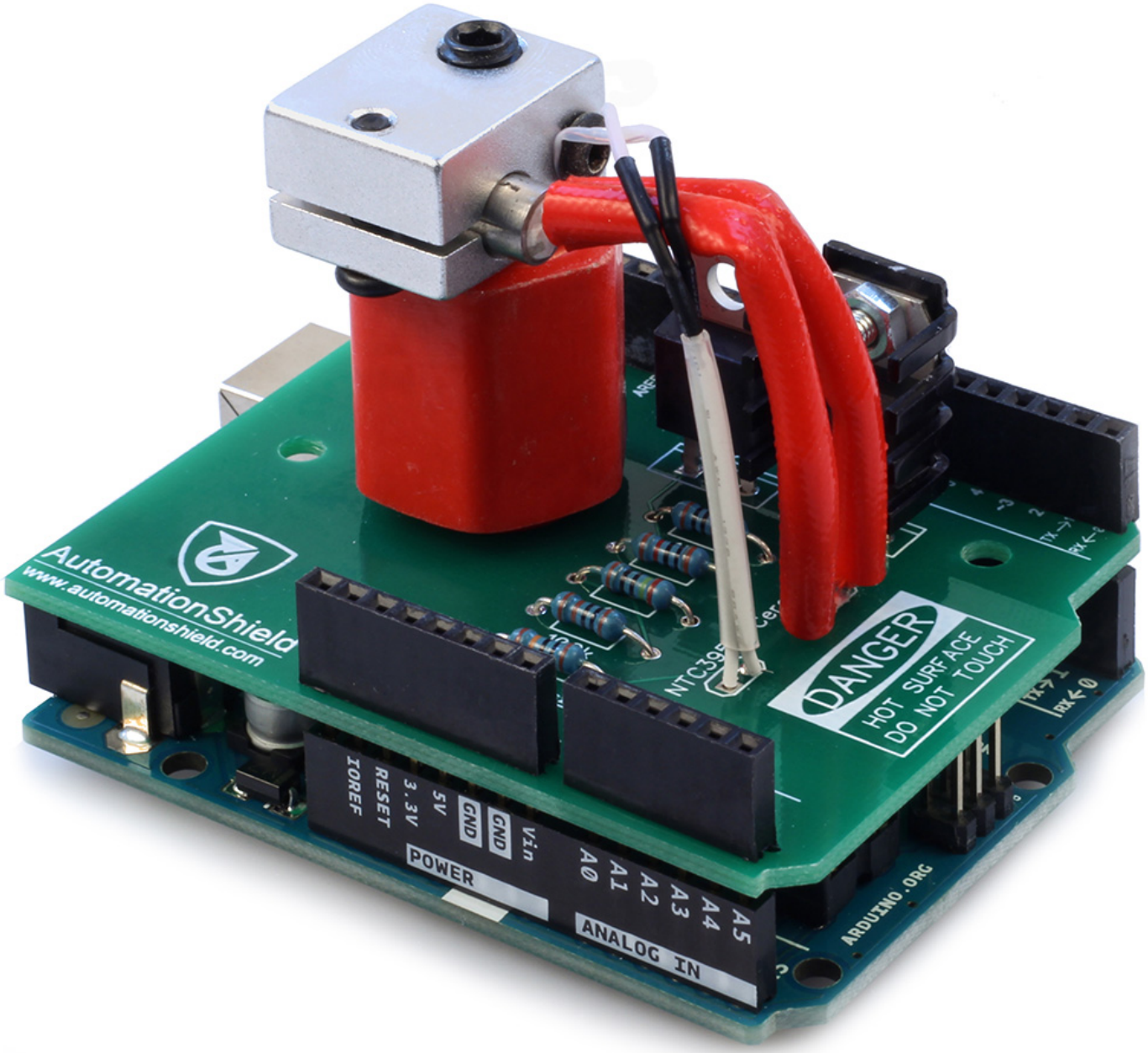
Teach thermal feedback control concepts by controlling the temperature of the so-called “hotend” of a 3D printer.



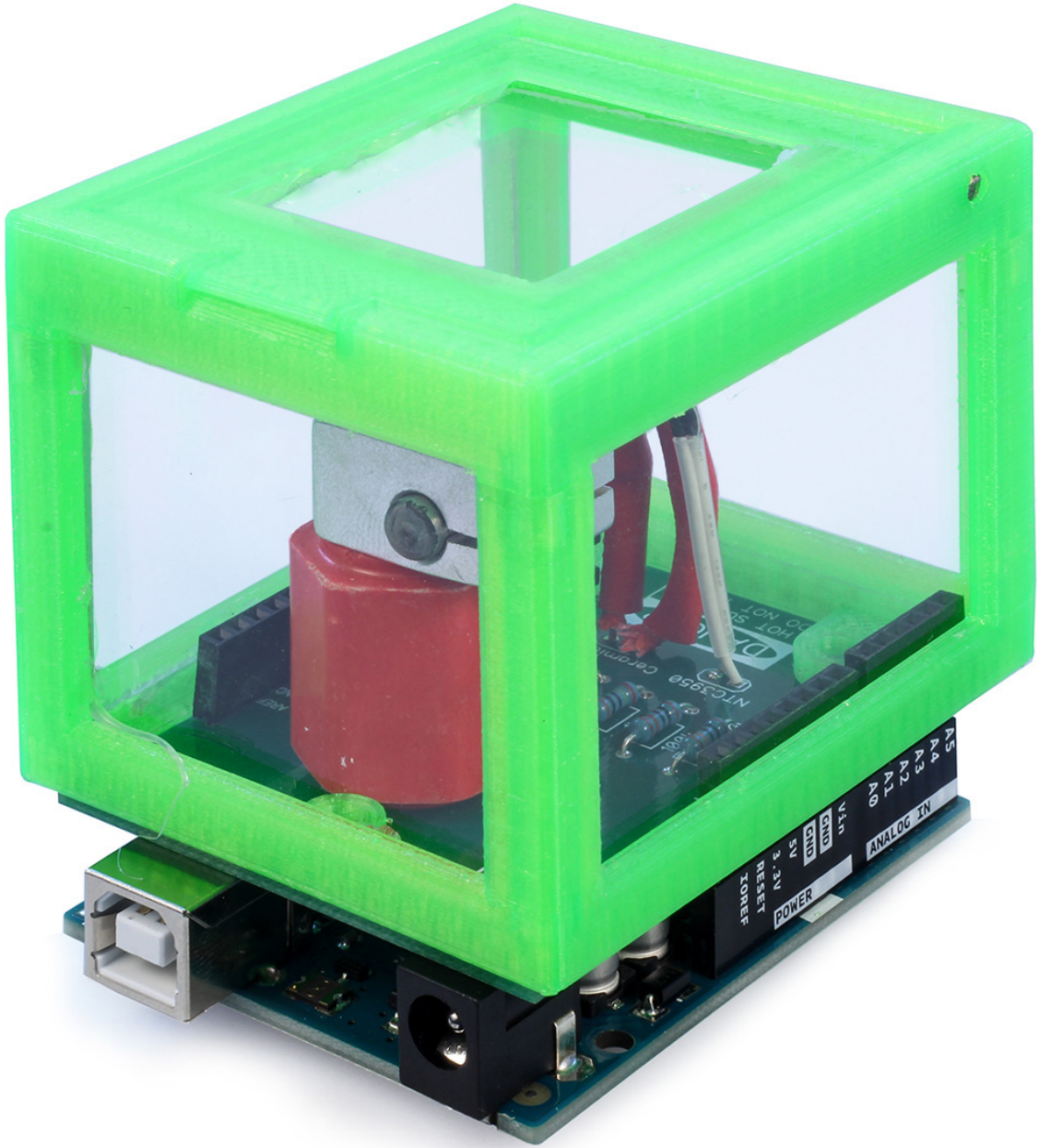
3D printer

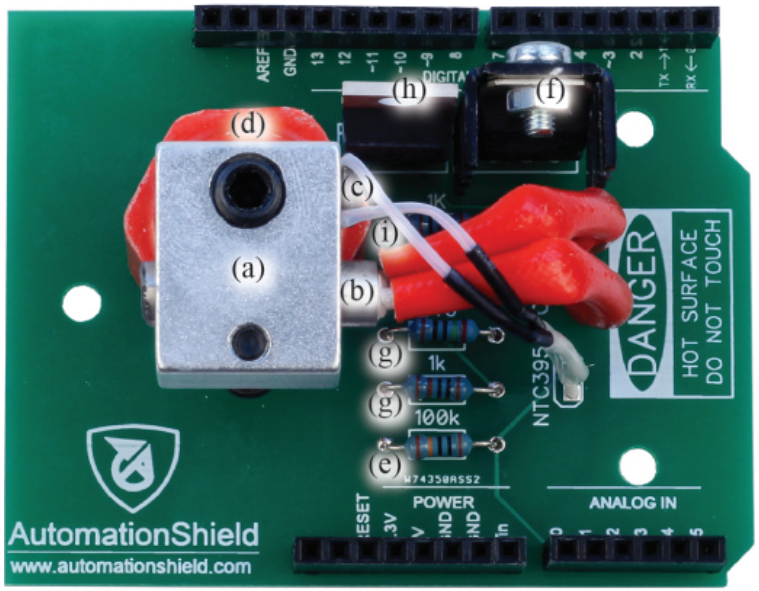
“Hotend”

Meet the "HeatShield"

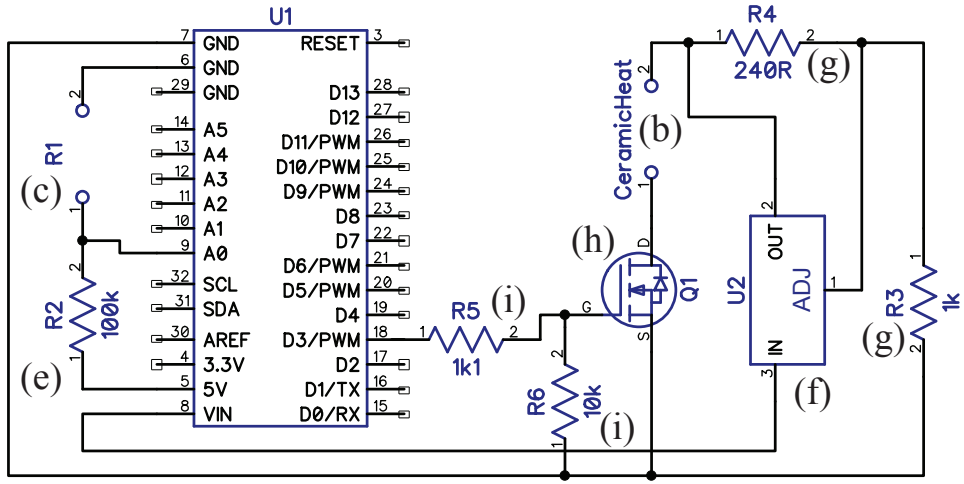


Safety cage: 3D printing and Plexiglas





Top view of the HeatShield



Electrical schematics of the HeatShield

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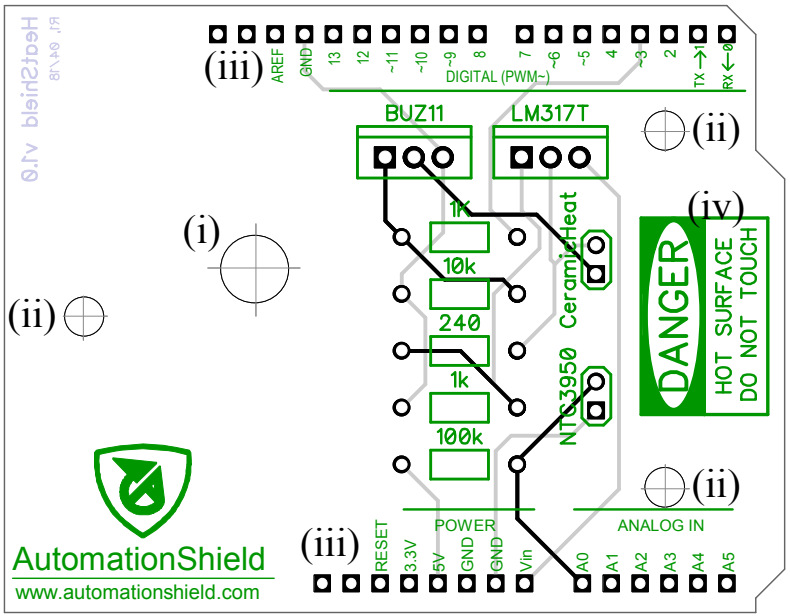
Cheap!

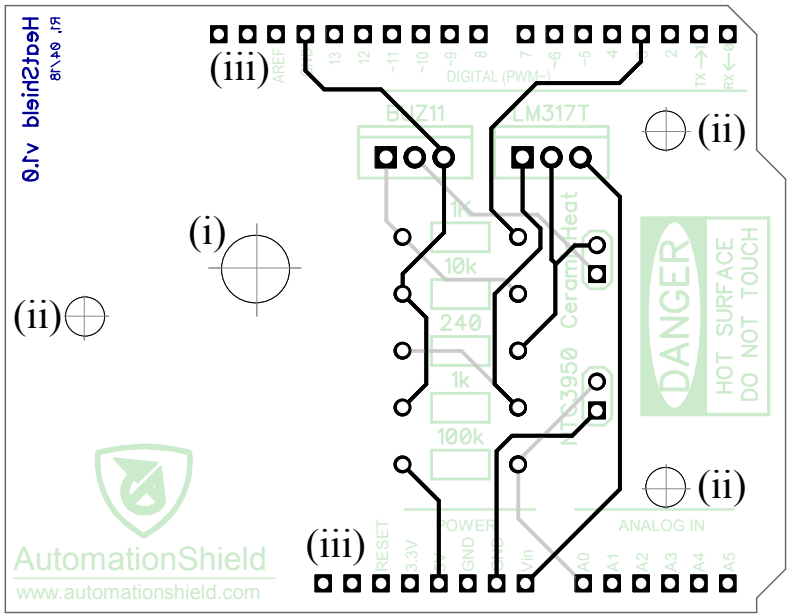
Hardware cost is less than $5 per unit, incl. PCB fabrication.

Description	Designator	Value	Quantity	Unit Price[a]	Price
Transistor	Q1	BUZ11, N-channel power MOSFET, 50V, TO-220 THT	1	$0.262	$0.262
Voltage regulator	U2	LM317T, Adjustable positive linear voltage regulator, 1.2–37 V, TO-220, THT	1	$0.116	$0.116
Heat sink	—	Heatsink for the voltage regulator, TO-220 package	1	$0.053	$0.053
Thermistor	R1	NTC 3950, 100 kΩ ± 1%, rated 300 °C with wiring	1	$0.445	$0.445
Resistor	R2	100 kΩ, 1/4 W, THT	1	$0.016	$0.016
Resistor	R3, R5	1 kΩ, 1/4 W, THT	2	$0.016	$0.032
Resistor	R4	240 kΩ, 1/4 W, THT	1	$0.016	$0.016
Heating cartridge	—	24V, 30W, 20×6 mm	1	$0.98	$0.98
Heater block	—	Aluminum, 20×16×12 mm	1	$0.99	$0.99
Bolt		M6×20 mm, headless, block to insulator	1	0.0526	0.0526
Thermal insulator	—	Hexagonal glass-filled polyester insulator M6 IS20HH625, 25×20 mm	1	$0.89	$0.89
Bolt	—	M6×10 mm, rounded 3.3 mm flat head, insulator to PCB	1	$0.10	$0.10
Header	—	6x1, female, 2.54 mm pitch	1	$0.070	$0.070
Header	—	8x1, female, 2.54 mm pitch	2	$0.099	$0.198
Header	—	8x1, female, 2.54 mm pitch	1	$0.099	$0.099
PCB	—	FR4, 2 layer, 1.6 mm thick	1	$0.50	$0.50
Total:					**$4.83**[b]

[a] For low quantity orders.
[b] Excluding labor and postage.

The HeatShield is Open Source. Editable schematic plans and the PCB layout available:





An open-source library for the Arduino IDE handles I/O

Initialize:

```
1 HeatShield.begin();
```

Temperature y_k in degrees Celsius:

```
1 y = HeatShield.sensorRead();
```

Power u_k to heater in percents:

```
1 HeatShield.actuatorWrite(u);
```

Many more functions in the AutomationShield library e.g. for hard real-time sampling, PID control, etc.

. . . but the same works in the MATLAB scripting environment:

Initialize:

```
1 HeatShield.begin();
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Temperature y_k in degrees Celsius:

```
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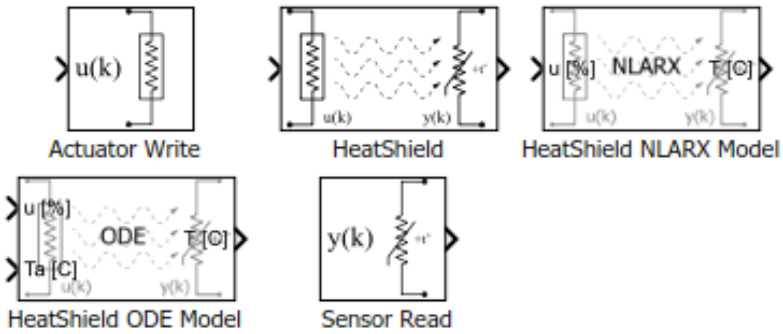
```

Power u_k to heater in percents:

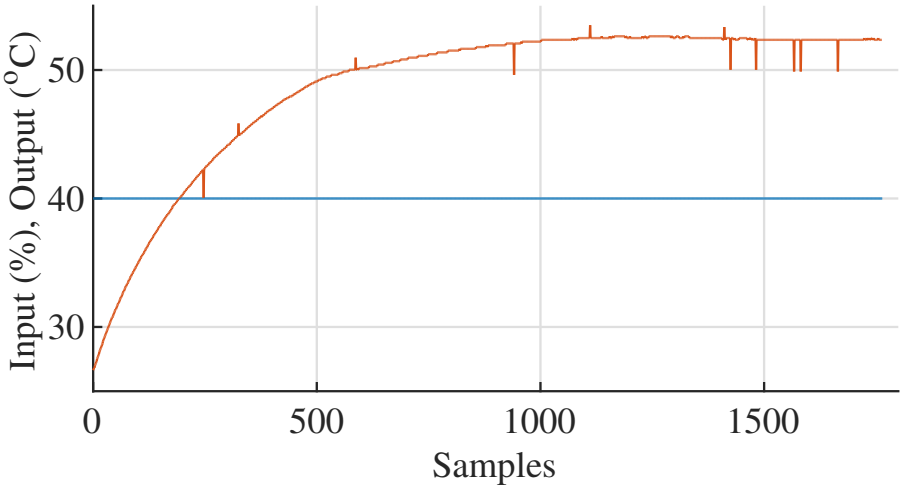
```
1 HeatShield.actuatorWrite(u);
```

. . . and in Simulink as well:

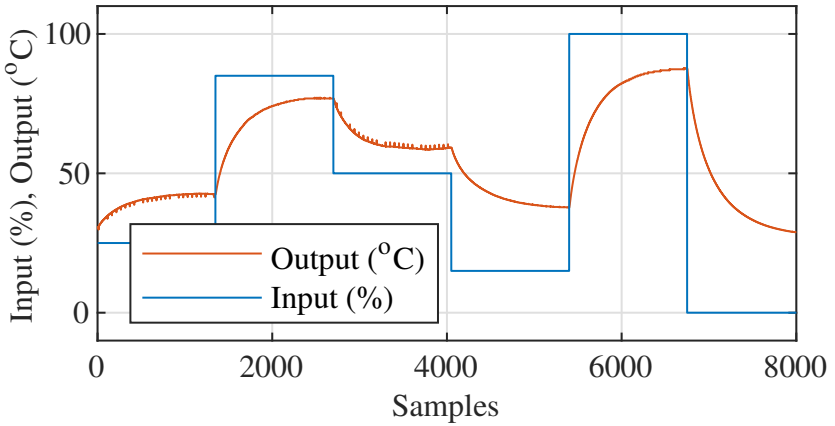


System Identification Experiments

- Experiments to gather input-output data for post-processing, system identification and model validation.
- Available in C/C++, MATLAB and Simulink.



Step: Live system identification experiment by an open-loop step response implemented through the MATLAB API.



PR(B)S: System identification experiment by a sequence of open-loop step responses implemented through the C/C++ API.

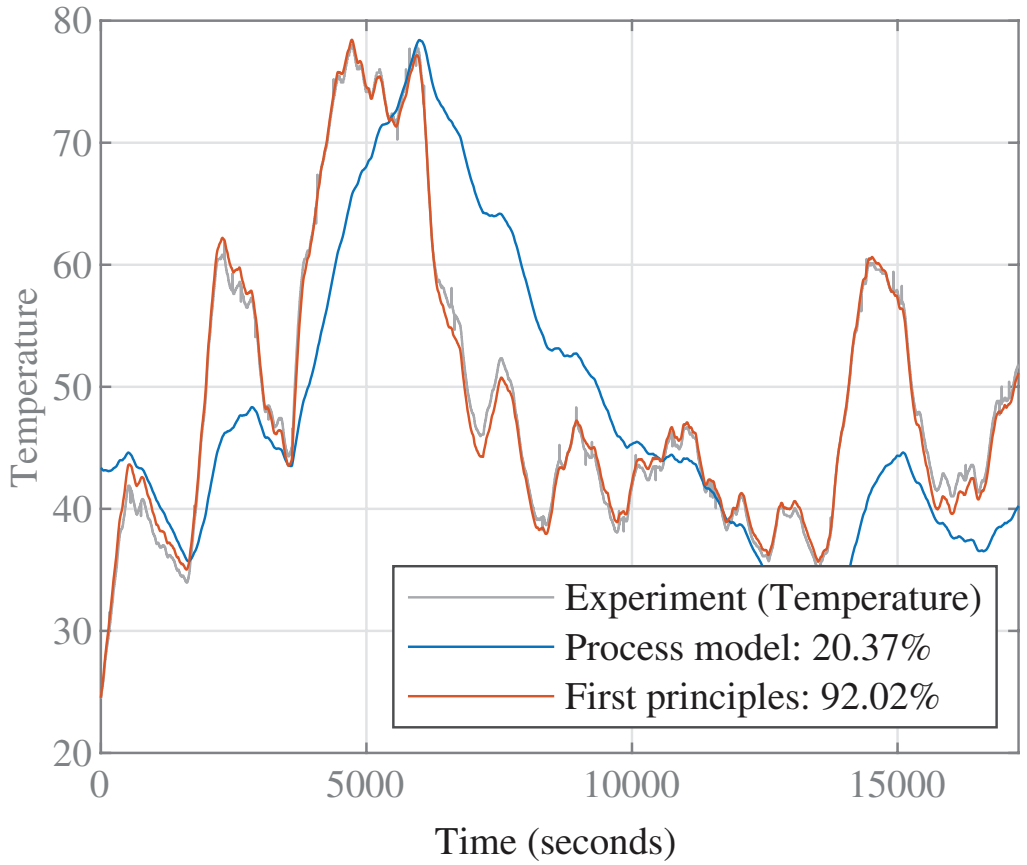
$$\dot{Q}_{\mathrm{C}}(t) = \dot{Q}_{\mathrm{J}}(t) - \dot{Q}_{\mathrm{R}}(t),$$

where

$$\dot{Q}_{\mathrm{C}}(t) = mc\dot{T}(t),$$
$$\dot{Q}_{\mathrm{J}}(t) = \frac{V^2}{R}\left(\frac{1}{100}u(t)\right),$$
$$\dot{Q}_{\mathrm{R}}(t) = hA(T(t) - T_{\mathrm{a}}(t)),$$

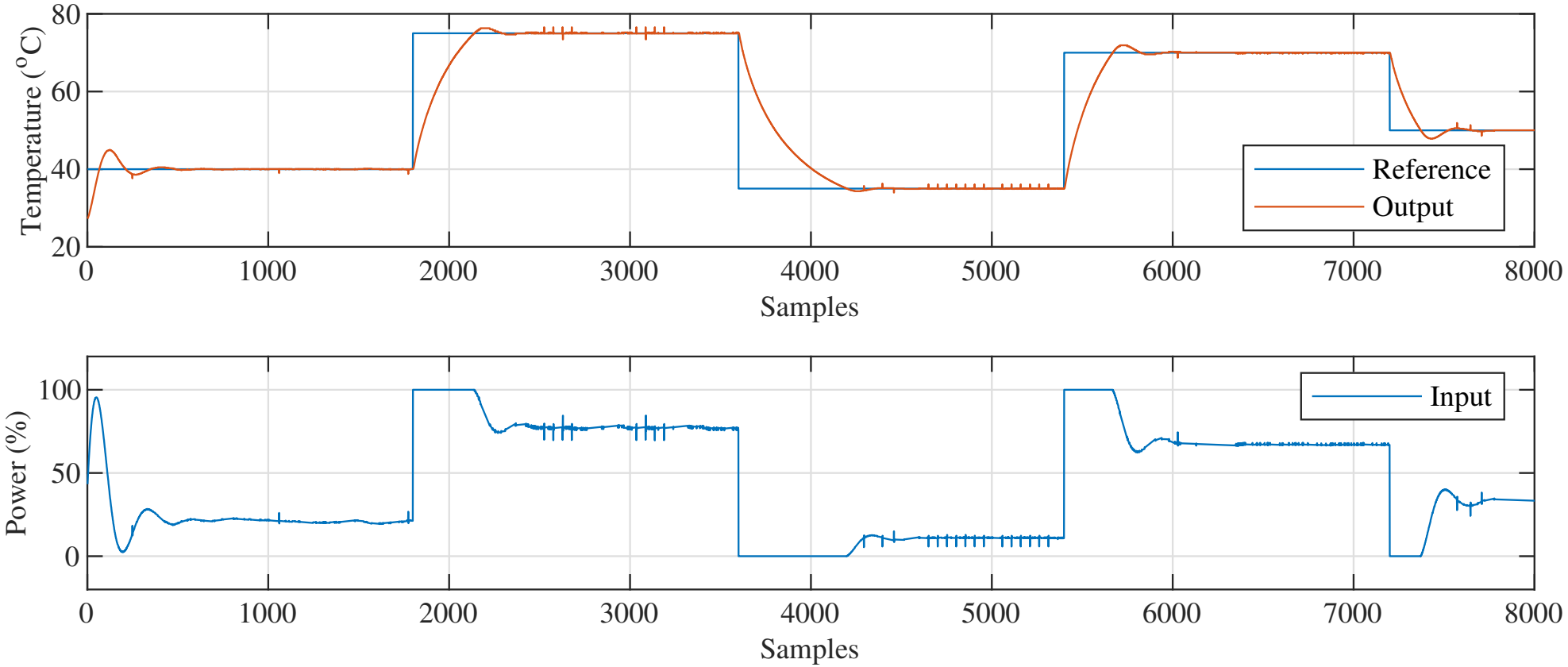
and thus

$$\dot{T}(t) = -\frac{hA}{mc}T(t) + \frac{V^2}{mcR}\left(\frac{1}{100}u(t)\right) + \frac{hA}{mc}T_{\mathrm{a}}(t)$$



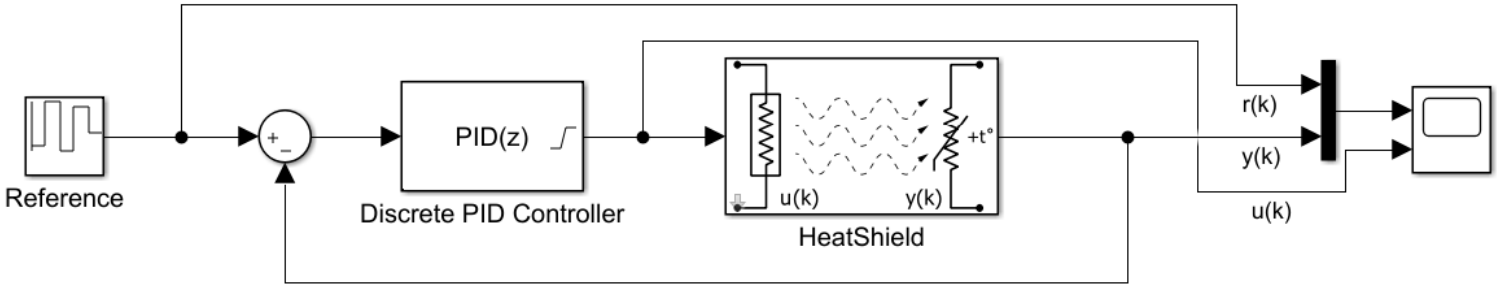
Measured vs. simulated response for the HeatShield device

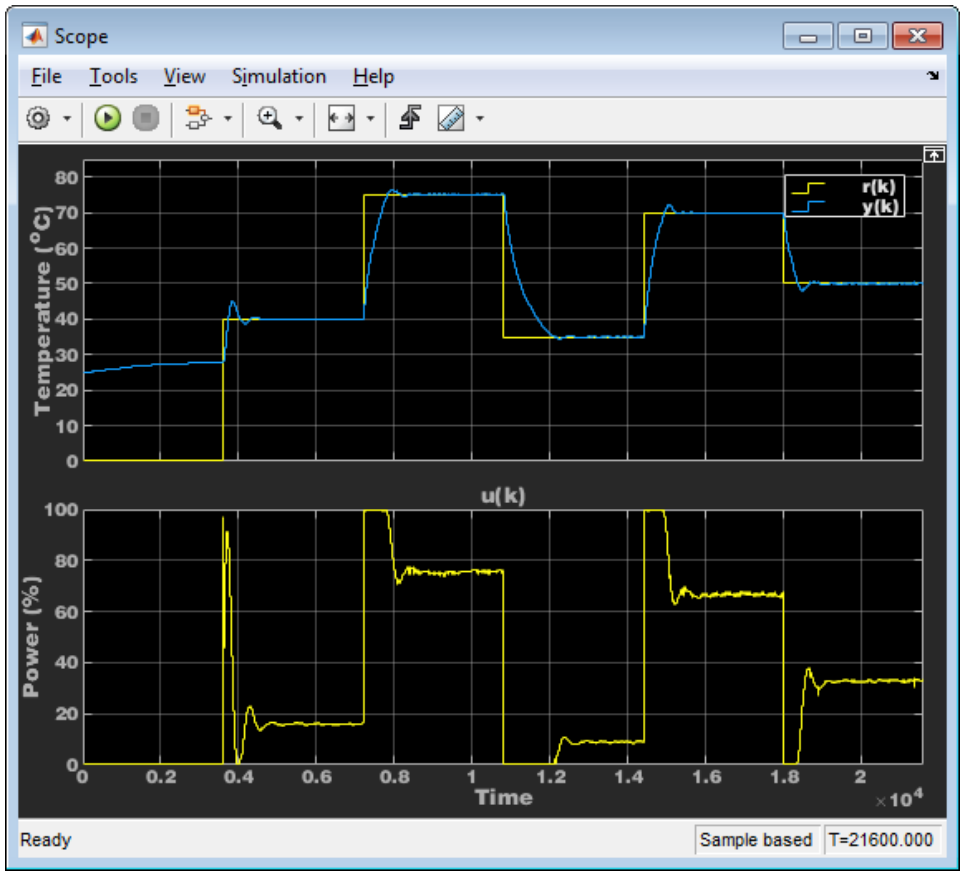
PID control experiments with simplified built-in sampling and PID functionality



Closed-loop response of the printer head temperature in the C/C++ API implementation of the PID example, logged in the MATLAB API.

Example: PID Control (Simulink)





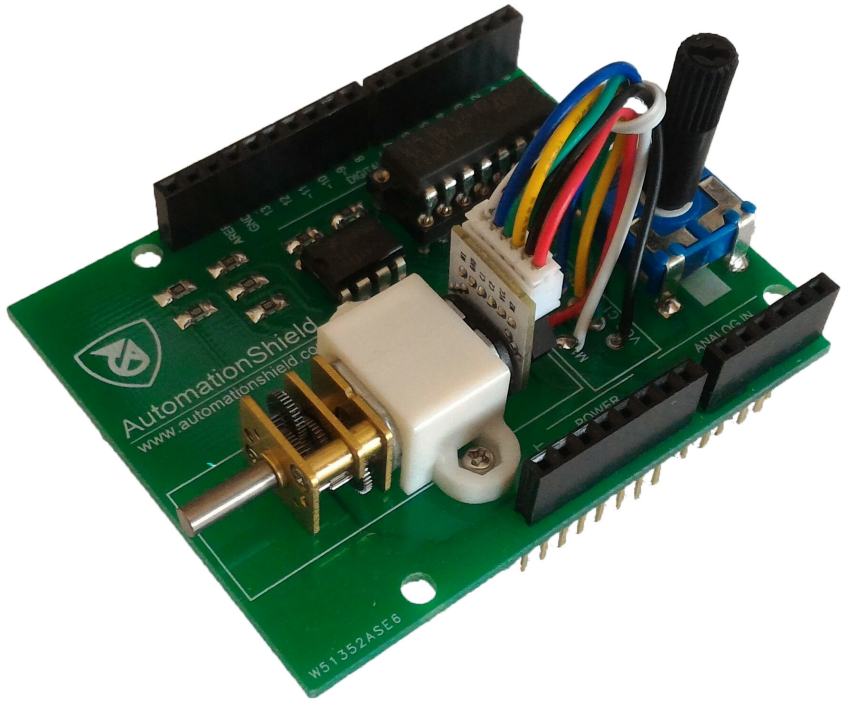
The future: More shields to come

- AutomationShield: a non-commercial project for control engineering education
- Full feedback control experiments can be fitted to Arduino expansion modules (lab-on-a-shield)
- HeatShield: thermal feedback control experiment for 3D printer hotends
- Manufacturing cost is <$5
- Students can take the "laboratory" home
- Open-source hardware
- Open-source software and examples for Arduino IDE (C/C++), MATLAB and Simulink

The future: More shields to come

More open-source Arduino Shields for control to come:

Upcoming: "MagnetoShield" A magnetic levitation experiment



Upcoming: "MotoShield" A motor control experiment

Thank you for your attention!

Make sure to visit `www.automationshield.com` for more information.

Please feel free to contact me any time at
`gergelytakacs@gergelytakacs.com`