POLITECNICO
DI TORINO

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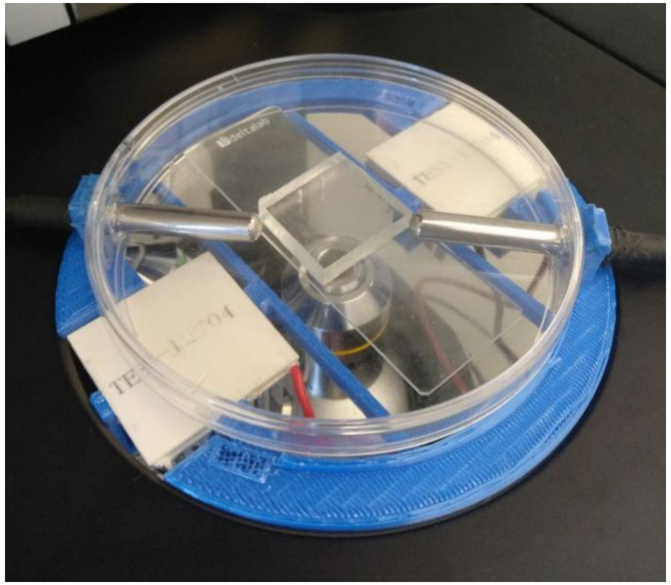
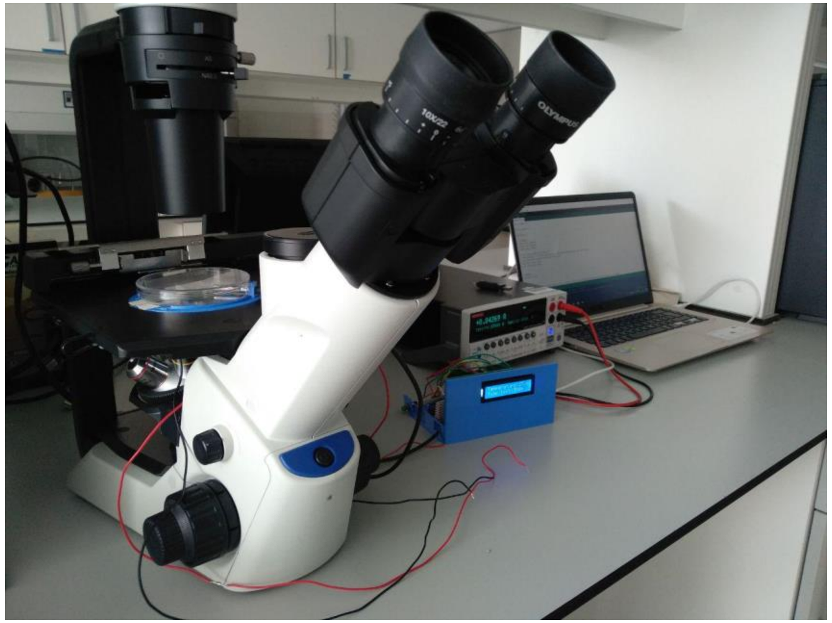
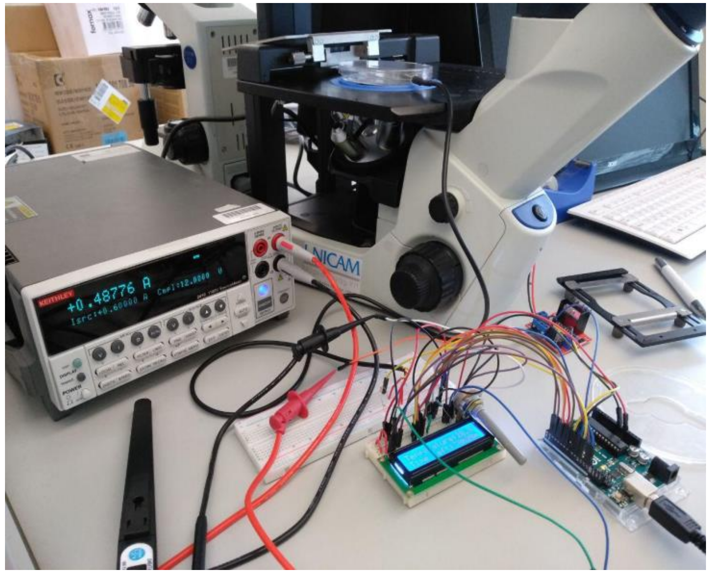
Temperature control system development in microfluidic environment for biological purposes







INTRODUCTION

MATHEMATICAL MODEL

HARDWARE

SOFTWARE

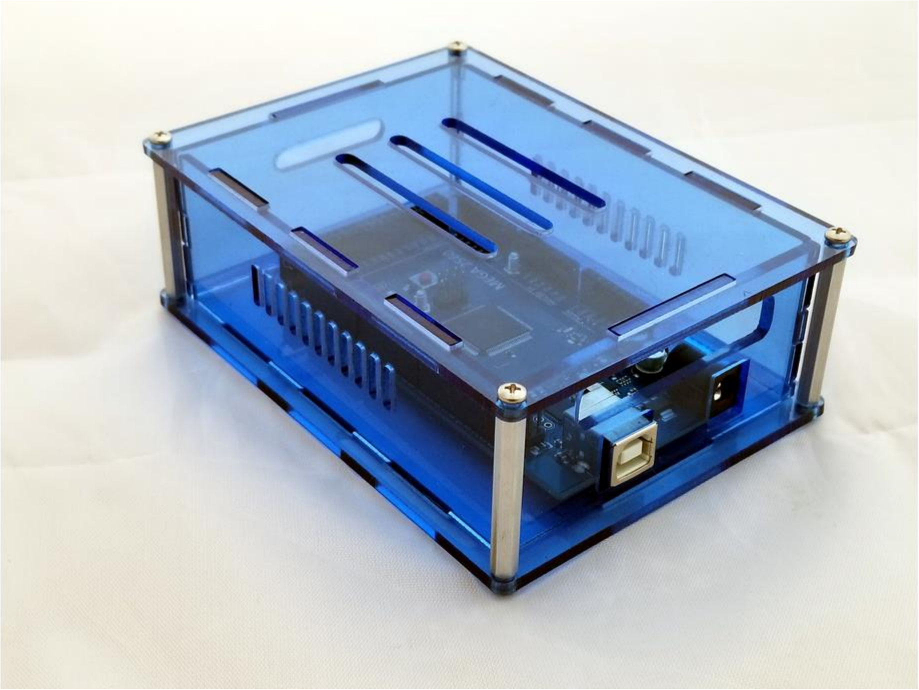
3D PRINTING

TESTING AND RESULTS

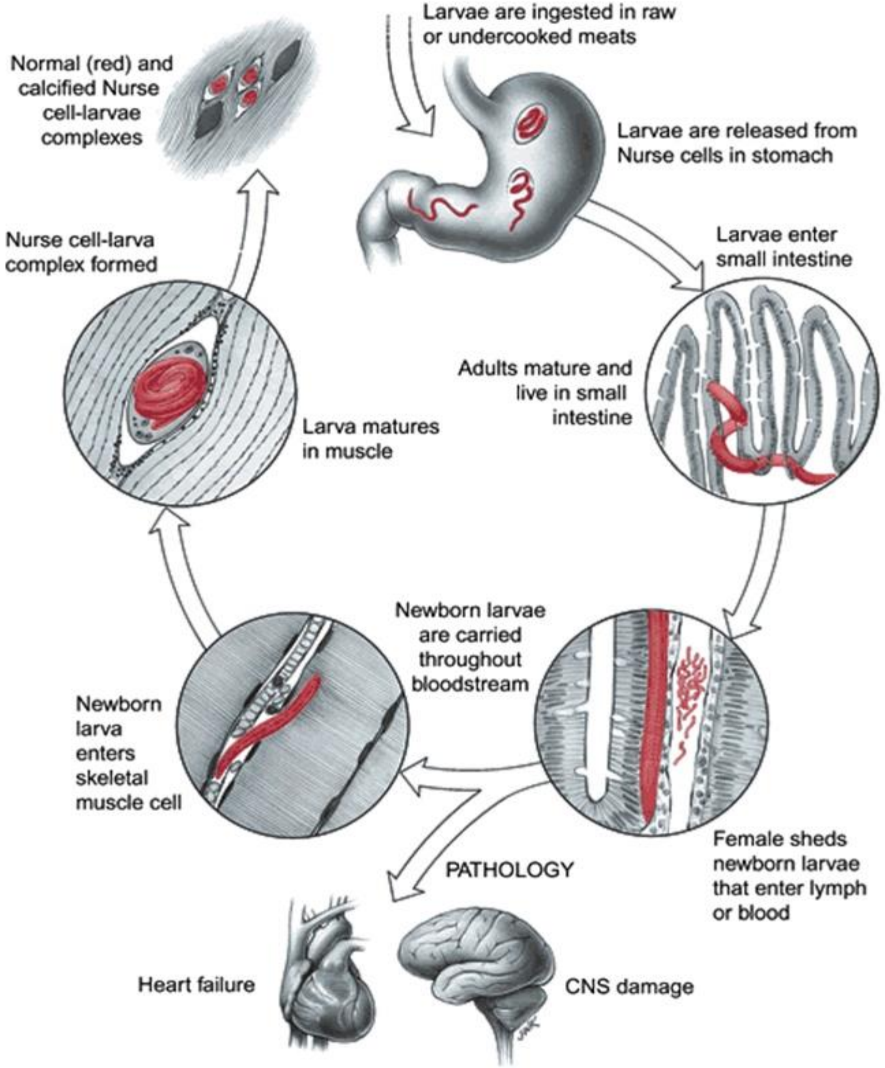
QUESTIONS

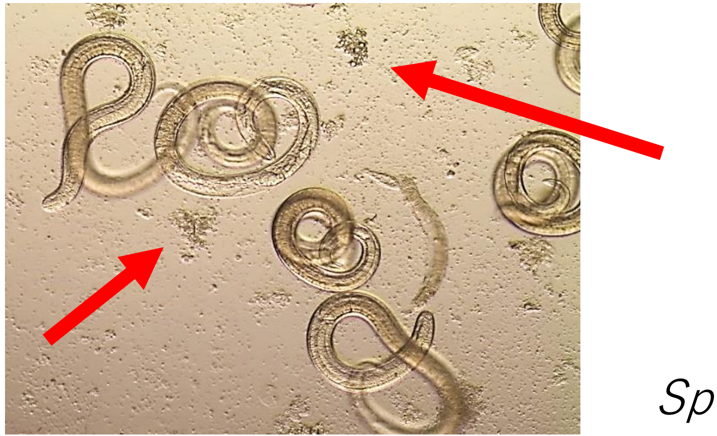
AIM

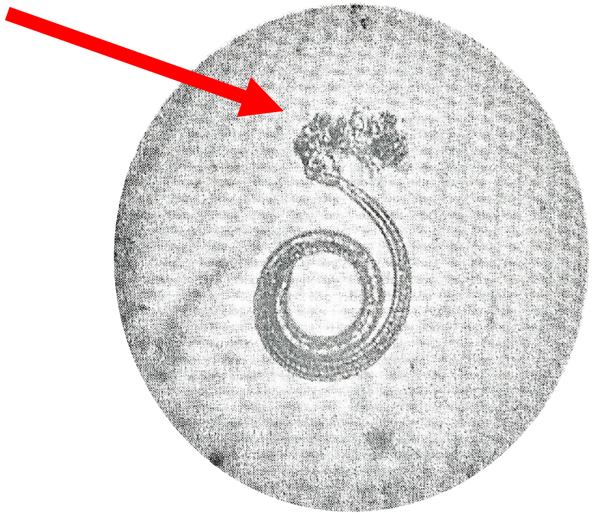
Design of a temperature controller for microfluidic devices which can be perfectly integrated on a reverse microscope , with some user-friendly features .



APPLICATION: Trichinella Spiralis

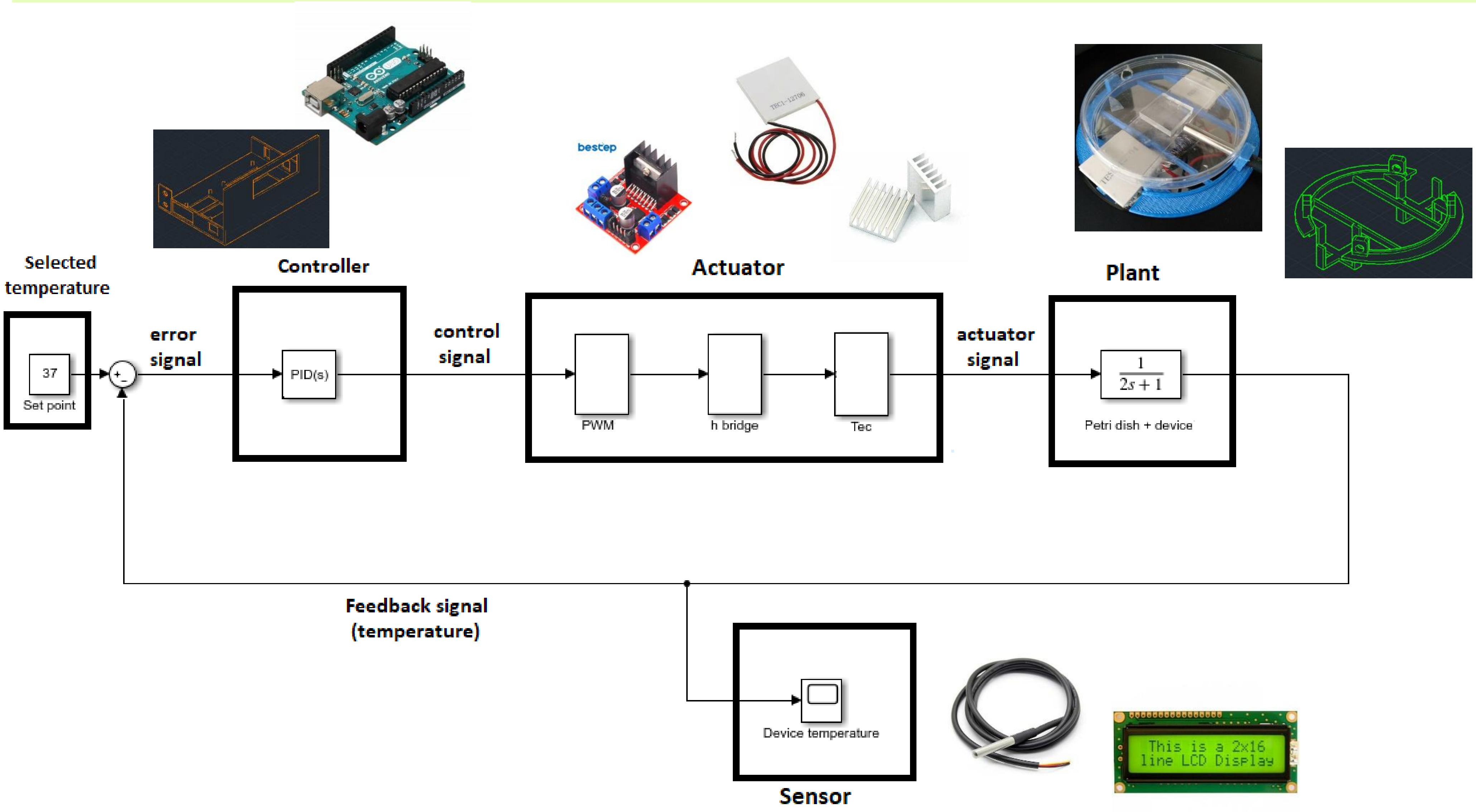

Larvae are ingested in raw or undercooked meats
Larvae are released from Nurse cells in stomach
Larvae enter small intestine
Adults mature and live in small intestine
Female sheds newborn larvae that enter lymph or blood
Newborn larvae are carried throughout bloodstream
Newborn larva enters skeletal muscle cell
Larva matures in muscle
Nurse cell-larva complex formed
Normal (red) and calcified Nurse cell-larvae complexes
PATHOLOGY
Heart failure
CNS damage





Larvae of *Trichinella Spiralis* must be kept alive for several hours (24 h-48 h) in order to produce microprecipitate and be detected

SYSTEM



Selected temperature

Controller

Actuator

Plant

error signal

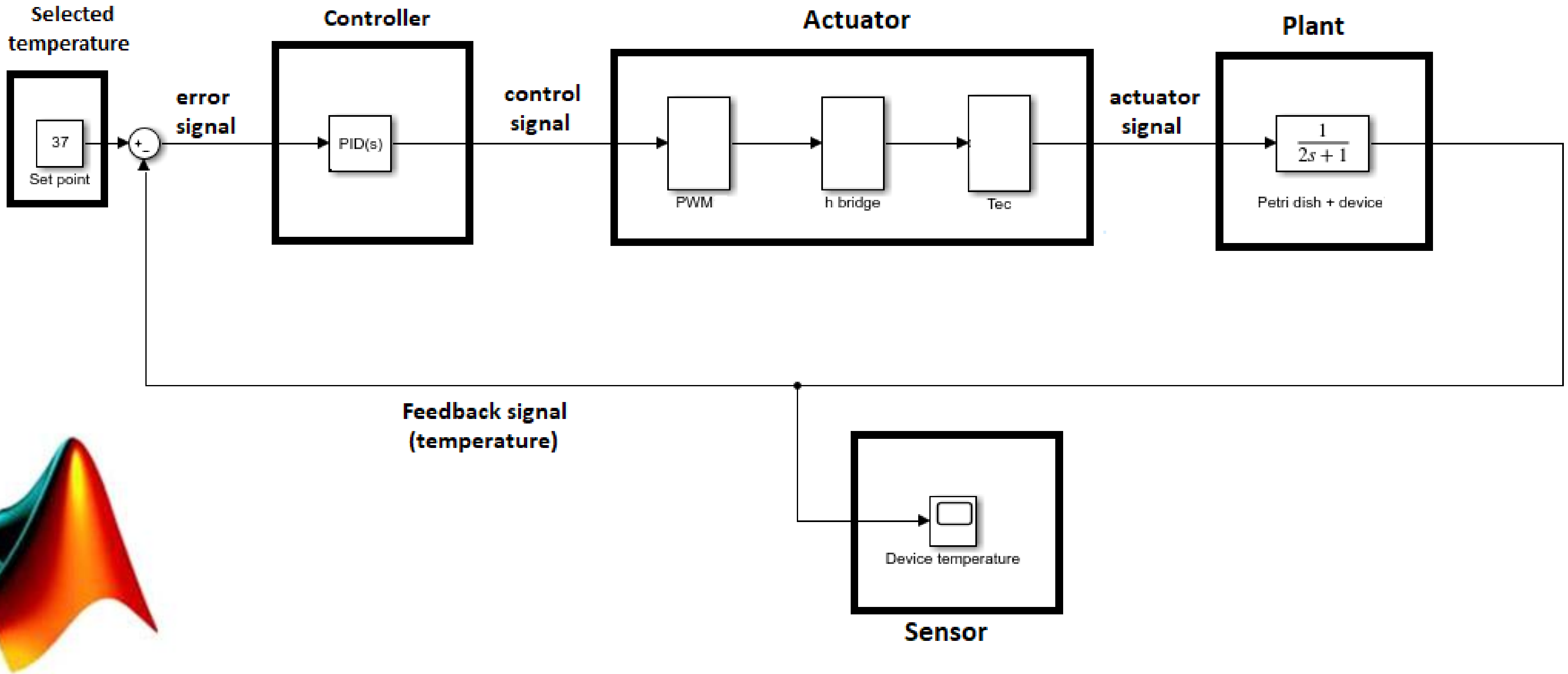
control signal

actuator signal

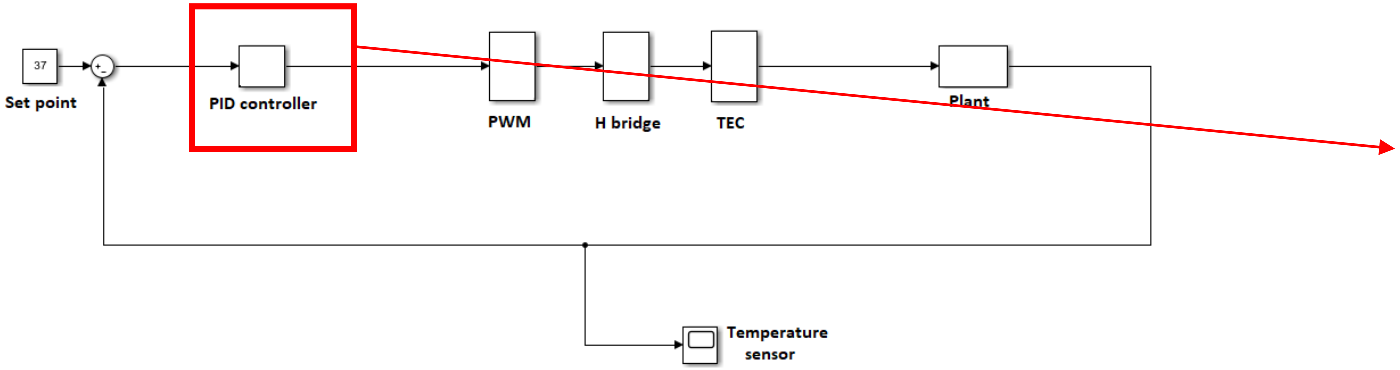
Feedback signal (temperature)

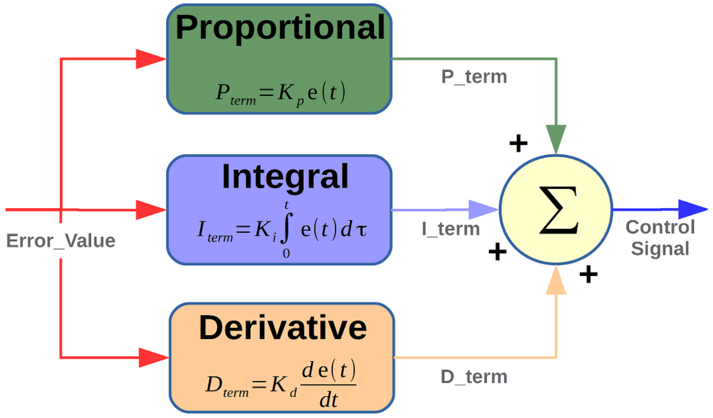
Sensor

MATHEMATICAL MODEL



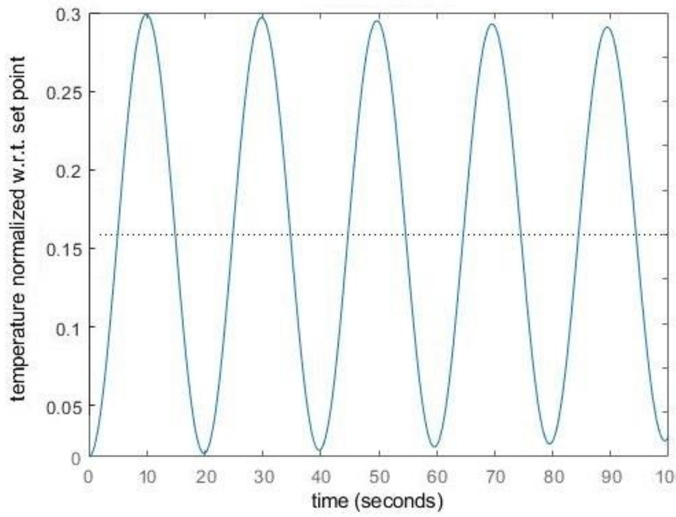
PID CONTROLLER



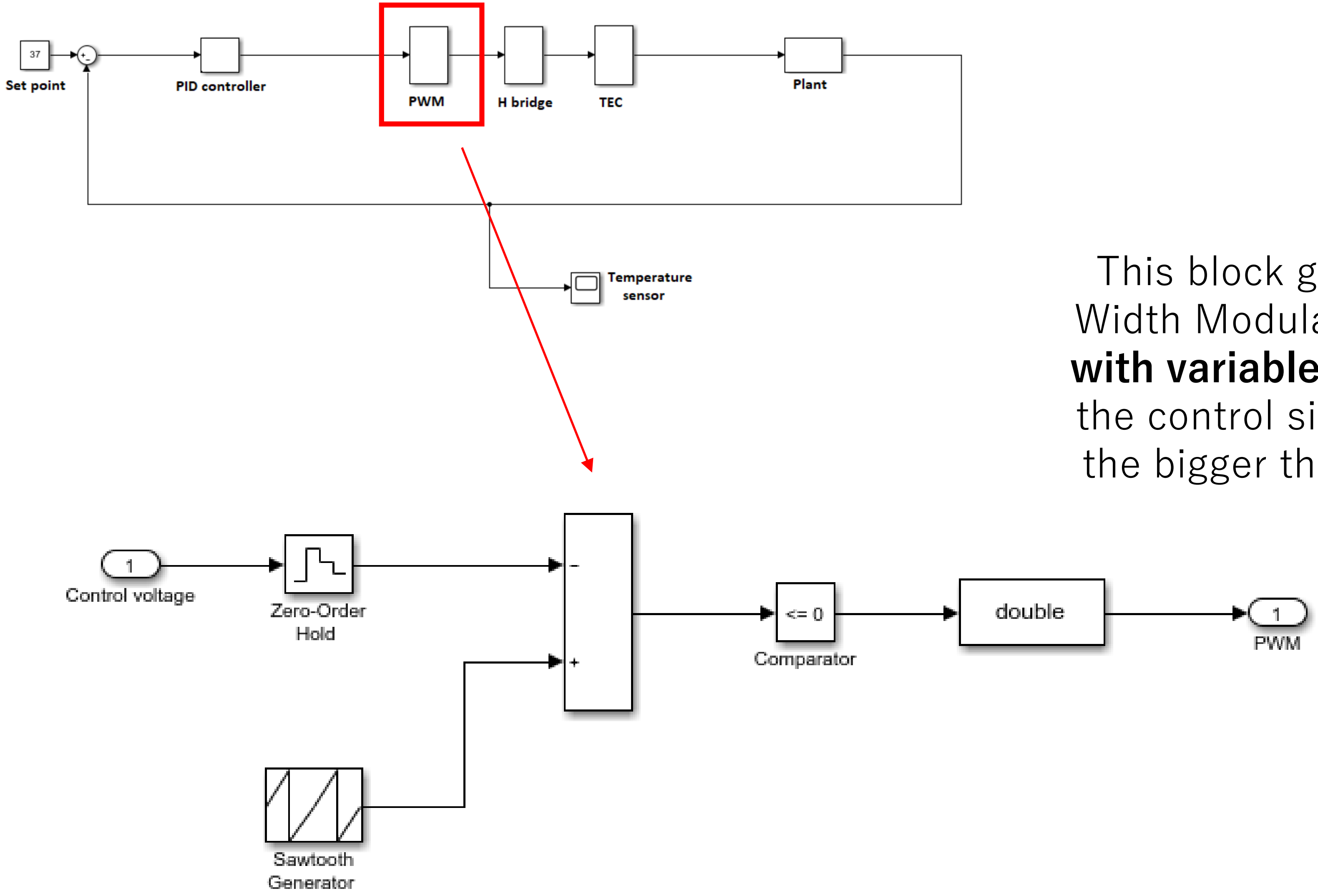


The three constants **Kp, Ki** and **Kd** where tuned using the Ziegler-Nichols method,

Control type	K_p	T_i	T_d	K_i	K_d
classic PID	$0{,}6\ K_u$	$T_u/2$	$T_u/8$	$1{,}2\ K_u/T_u$	$3\ K_u T_u/40$
some overshoot	$K_u/3$	$T_u/2$	$T_u/3$	$0{,}666\ K_u/T_u$	$K_u T_u/9$
minimize overshoot	$K_u/5$	$T_u/2$	$T_u/3$	$0{,}4\ K_u/T_u$	$K_u T_u/15$



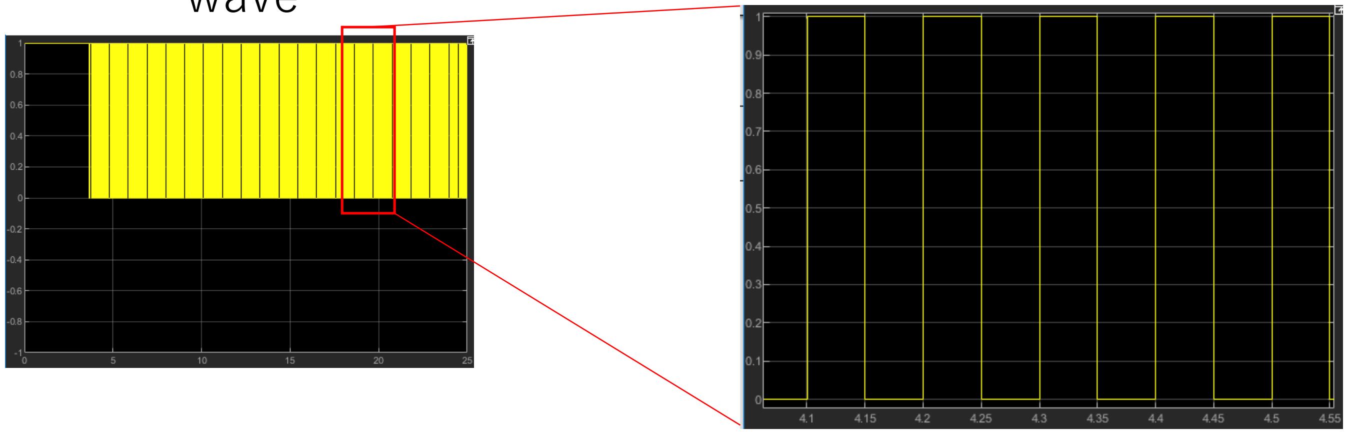
PWM GENERATOR

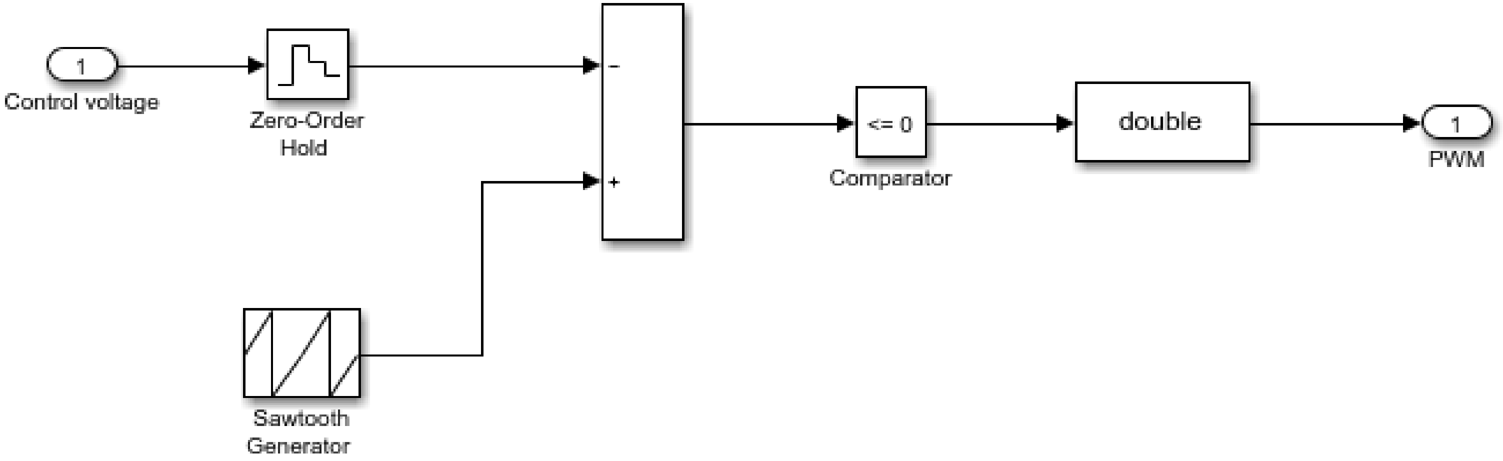


This block generates a PWM wave (Pulse Width Modulated) signal, i.e. a **square wave with variable duty cycle** , which depends on the control signal. The bigger the duty cycle, the bigger the flow of current in the heating elements

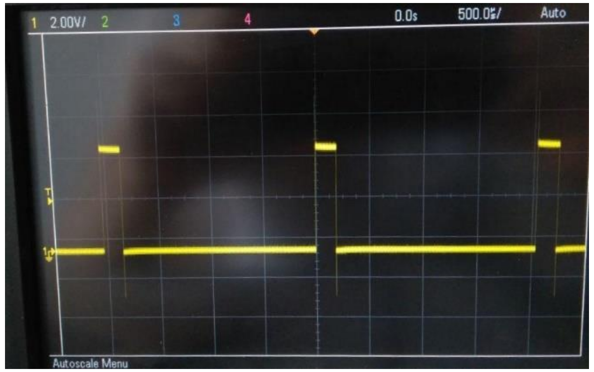
PWM GENERATOR

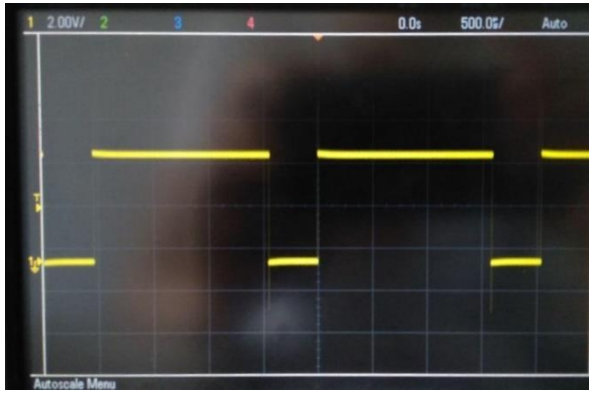
Output: PWM square wave



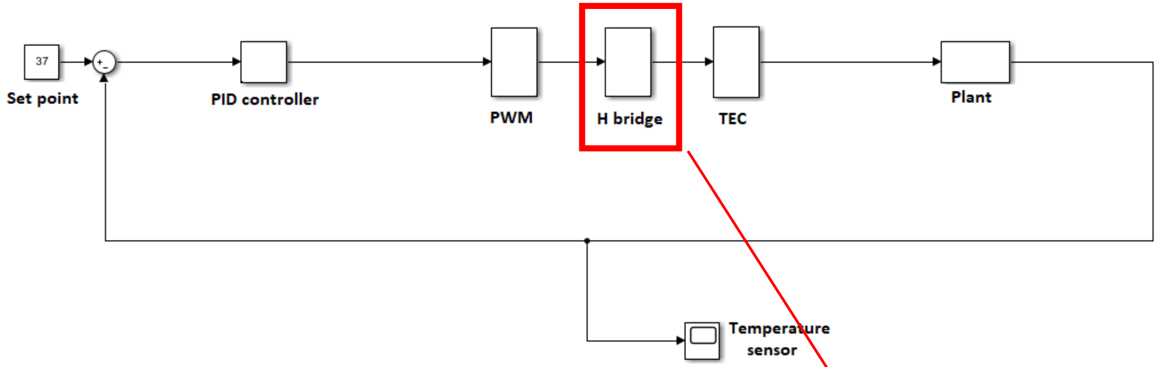


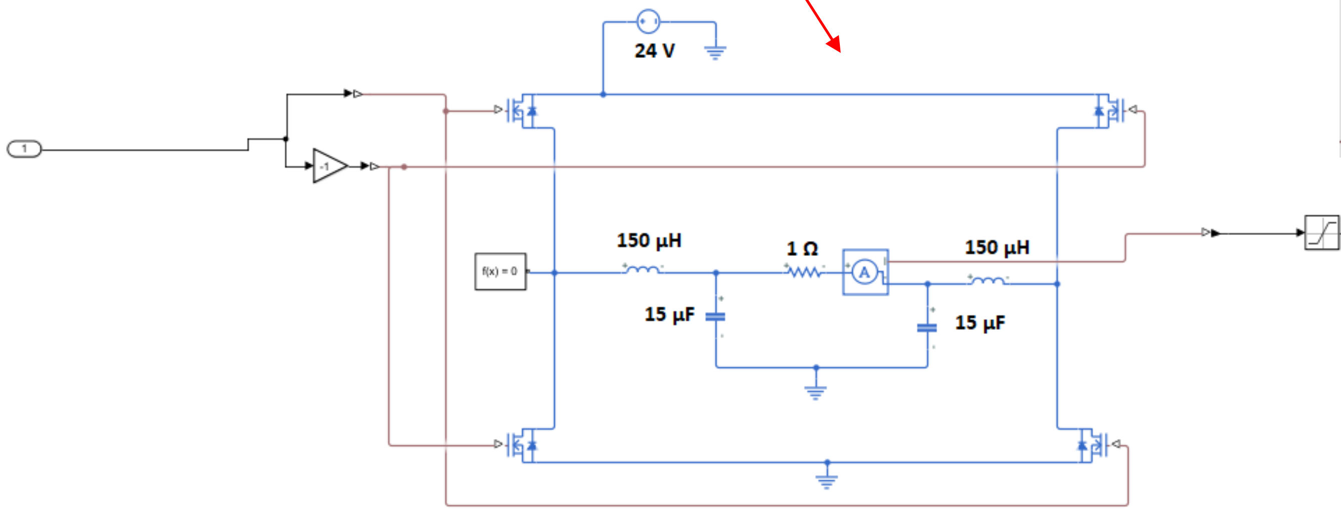
The PWM square wave changes duty cycle over time depending on the control signal



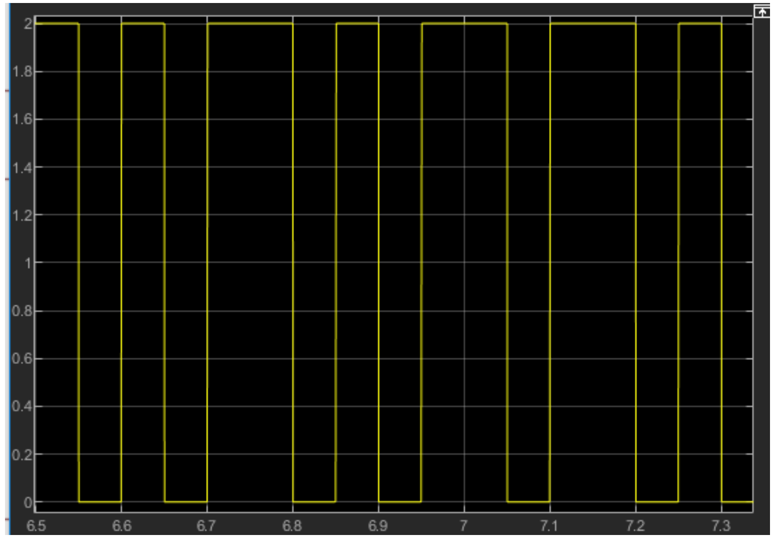


H-BRIDGE



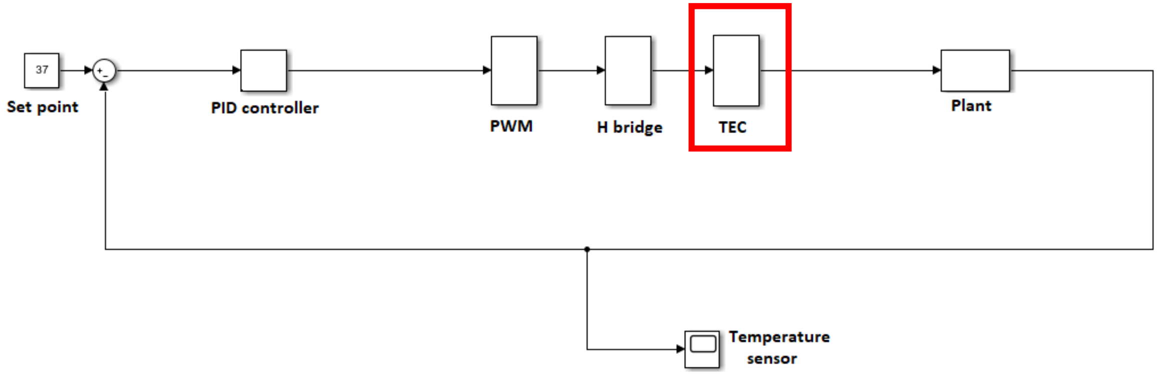


Output current
(to Peltier)



The H bridge receives in input the PWM signal and returns in output **the same PWM signal**, with the same duty cycle as the input, **but with a greater amount of power**. In this way, the thermoelectric heaters can be driven

THERMOELECTRIC COOLER / HEATER



In the TEC mathematical model, the equations that model the heat flux between the two plates of the Peltier cell are implemented . The result is **that the heat gets pumped into** the plant (**the petri dish**)

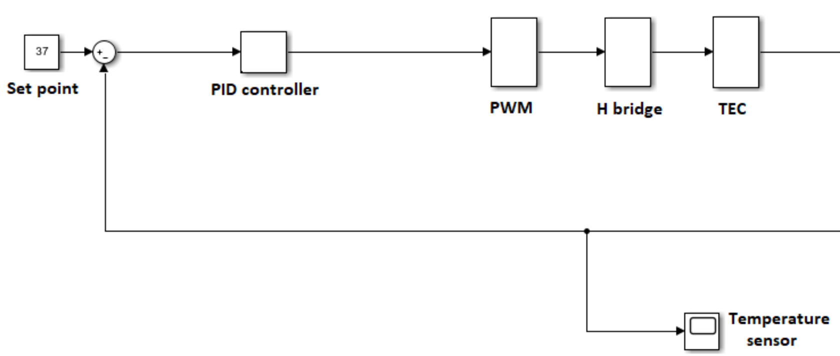
$$R = \frac{V_{\max}(T_{\mathrm{h}} - \Delta T_{\max})}{I_{\max} T_{\mathrm{h}}} \qquad Q_{\mathrm{c}} = S I T_{\mathrm{c}} - \frac{I^2 R}{2} - K_{\mathrm{th}} \Delta T$$

$$K_{\mathrm{th}} = \frac{V_{\max} I_{\max}(T_{\mathrm{h}} - \Delta T_{\max})}{2 T_{\mathrm{h}} \Delta T_{\max}} \qquad Q_{\mathrm{h}} = S I T_{\mathrm{h}} + \frac{I^2 R}{2} - K_{\mathrm{th}} \Delta T$$

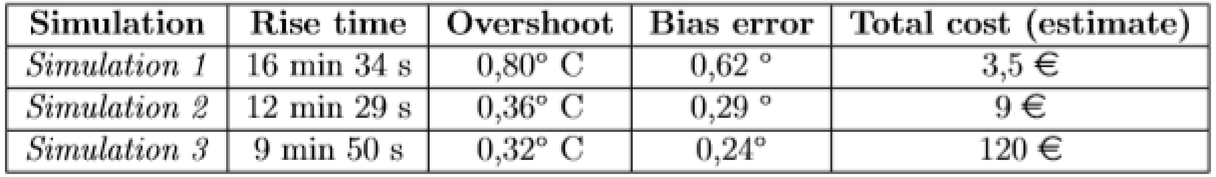
$$S = \frac{V_{\max}}{T_{\mathrm{h}}}$$

$$T_c = \frac{0.5 I^2 R + K_{th} T_h + Q_c}{S I + K_{th}}$$

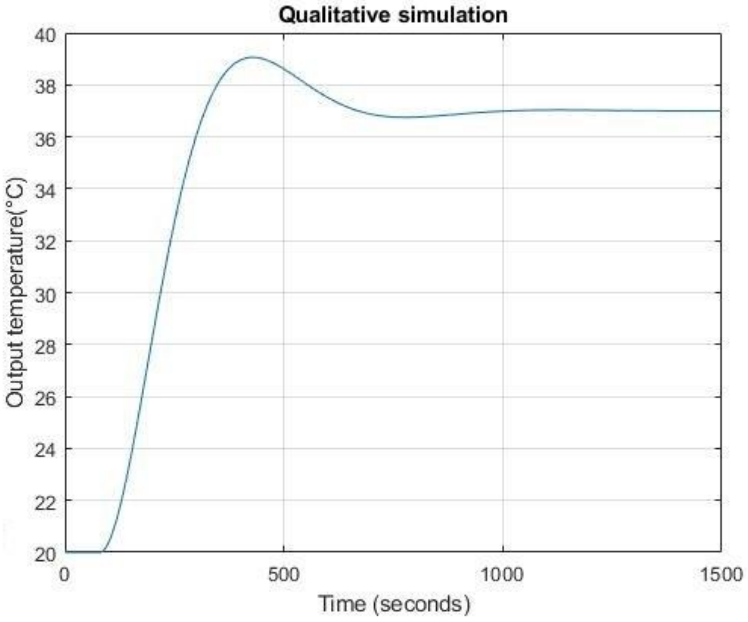
PLANT & OUTPUT

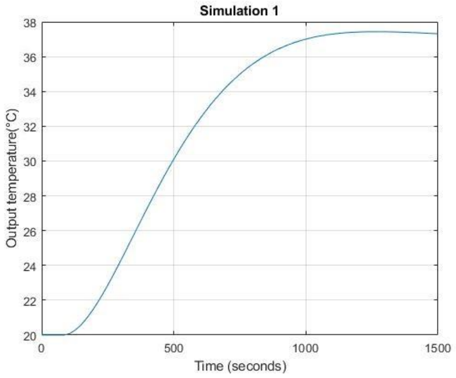


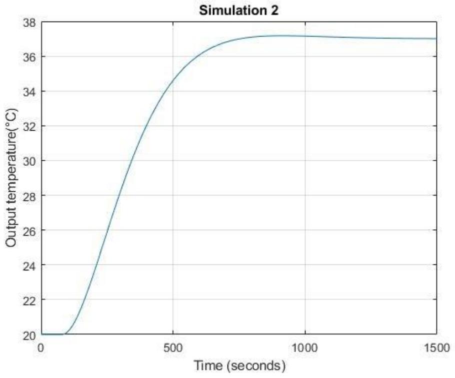
The plant transfer function is approximated as a first order transfer function

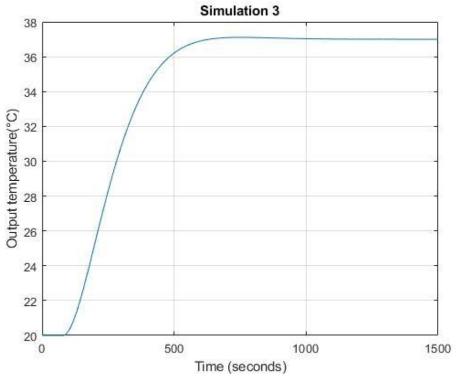


Simulation	Rise time	Overshoot	Bias error	Total cost (estimate)
Simulation 1	16 min 34 s	0,80° C	0,62 °	3,5 €
Simulation 2	12 min 29 s	0,36° C	0,29 °	9 €
Simulation 3	9 min 50 s	0,32° C	0,24°	120 €

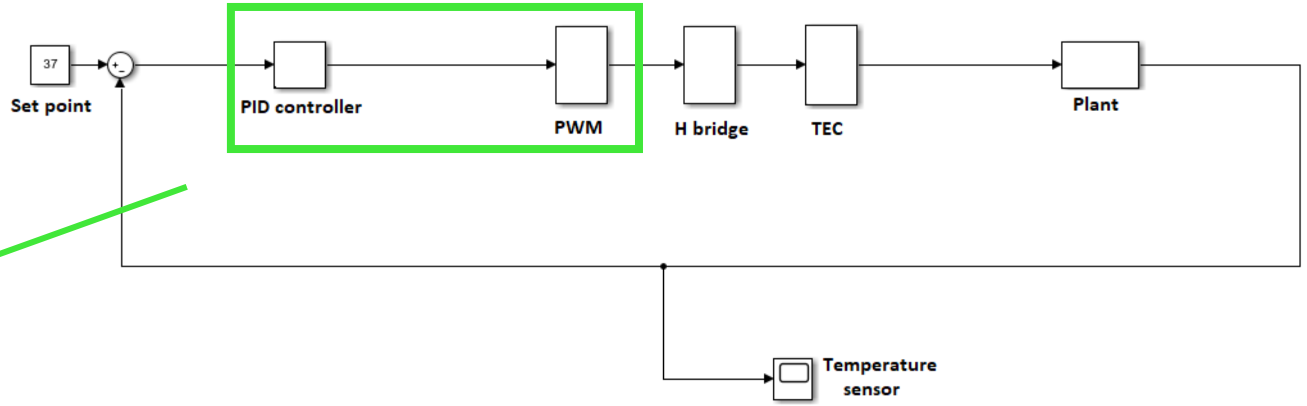








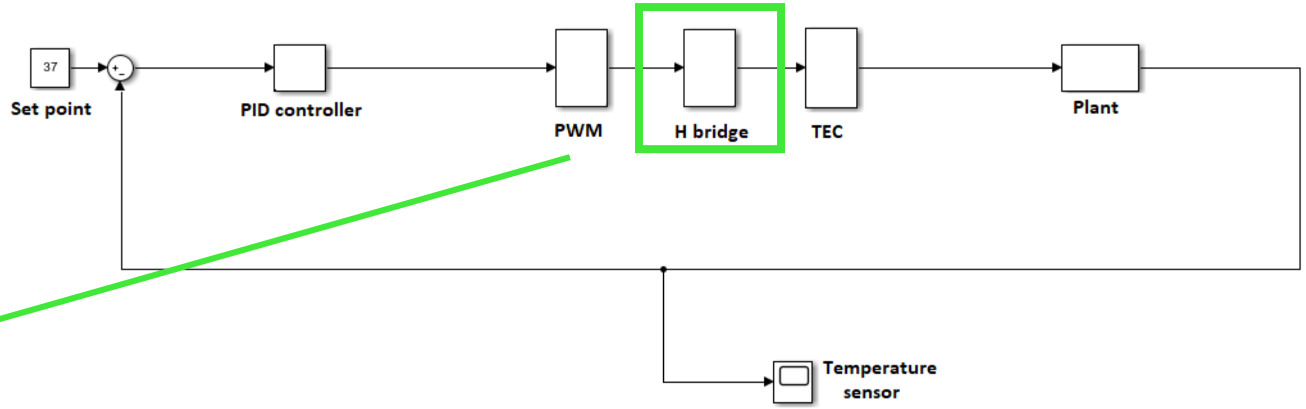
ARDUINO UNO

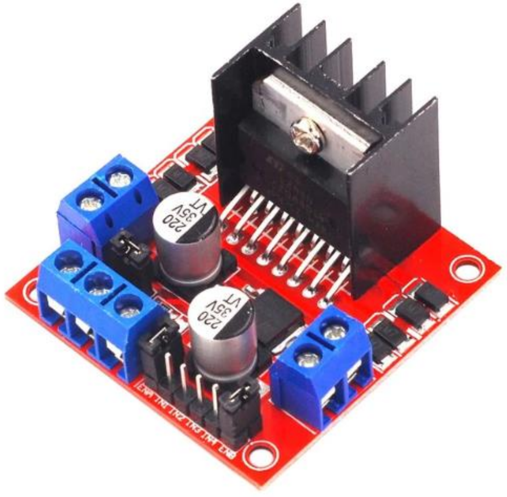


ARDUINO UNO BOARD

- Microcontroller unit
- Support C / C++ code
- Capable of **PID control** and **PWM** generation via Software
- Manages the user interface

H - BRIDGE

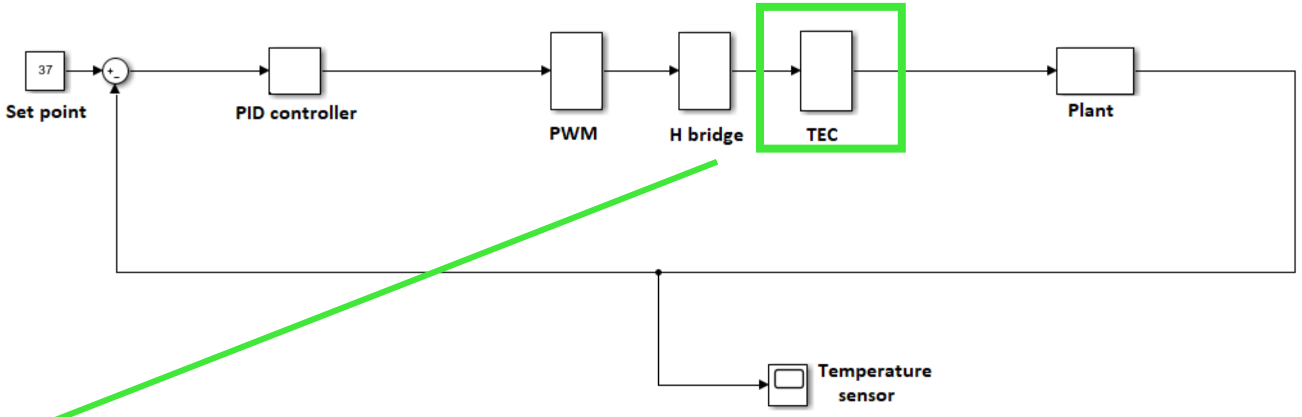


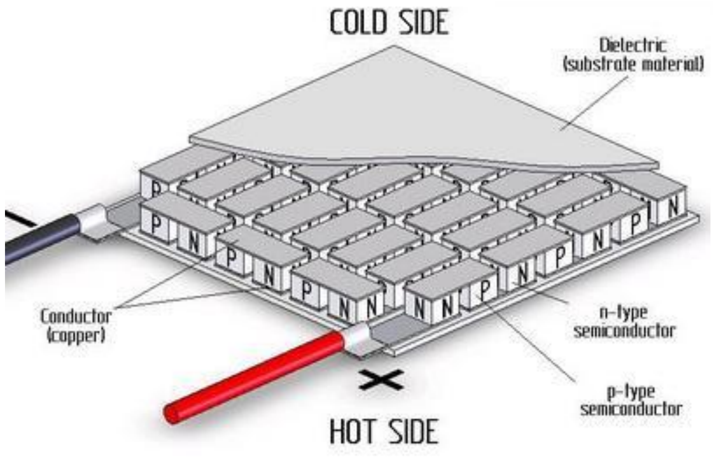


H-Bridge

- Driven by the Arduino trough PWM control signal
- Powered by the power supply
- Allows the current to go backward or forward
- Can drive two Peltier cells simultaneously

THERMOELECTRIC COOLER / HEATER





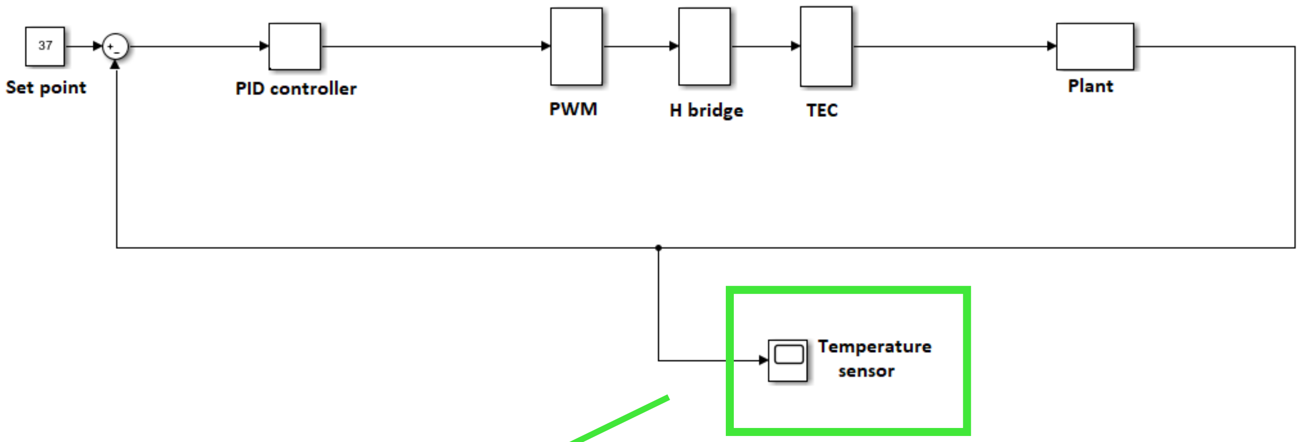
Thermoelectric heater: Peltier cell + aluminium heatsink

- Active heat pump which transfers heat from one side of the device to the other,
- Driven by the H-bridge trough PWM control signal
- Allows the current to go backward or forward
- Can drive two Peltier cells simultaneously
- Heatsink is needed to dissipate the heat

TEMPERATURE SENSOR, LCD DISPLAY, PUSHBUTTONS

16x02 LCD display and pushbuttons

- Used to select display real-time temperature and time
- Employ I2C communication



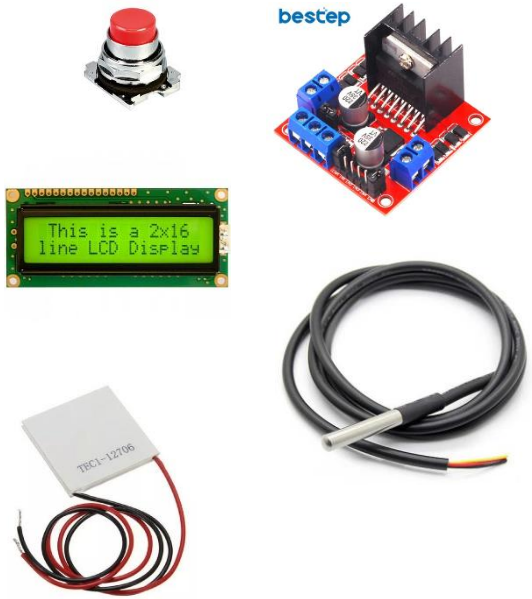
DS18B20 temperature sensor

- 1-wire digital temperature sensor
- Measures temperatures from -55° C to +125° C
- Accuracy of ± 0.15 ° C
- Powered by the Arduino +5V pin
- Waterproof

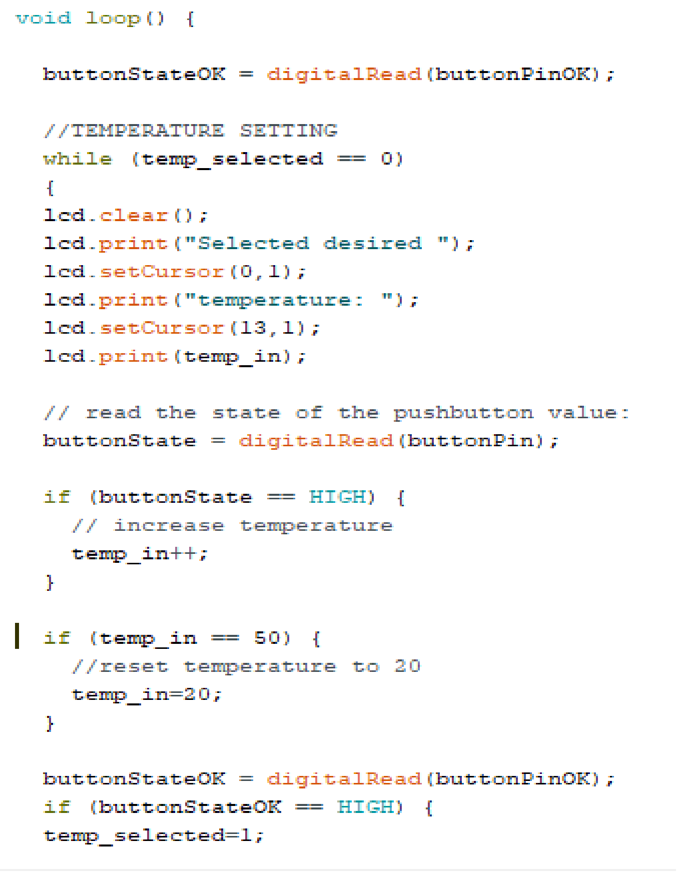
SOFTWARE

Code (C++ language) is uploaded on the Arduino board from a notebook through an USB cable

Arduino drives the hardware according to the instructions in the code and the inputs received from the user



SOFTWARE



```
void loop() {

  buttonStateOK = digitalRead(buttonPinOK);

  //TEMPERATURE SETTING
  while (temp_selected == 0)
  {
  lcd.clear();
  lcd.print("Selected desired ");
  lcd.setCursor(0,1);
  lcd.print("temperature: ");
  lcd.setCursor(13,1);
  lcd.print(temp_in);

  // read the state of the pushbutton value:
  buttonState = digitalRead(buttonPin);

  if (buttonState == HIGH) {
    // increase temperature
    temp_in++;
  }

  if (temp_in == 50) {
    //reset temperature to 20
    temp_in=20;
  }

  buttonStateOK = digitalRead(buttonPinOK);
  if (buttonStateOK == HIGH) {
  temp_selected=1;
```

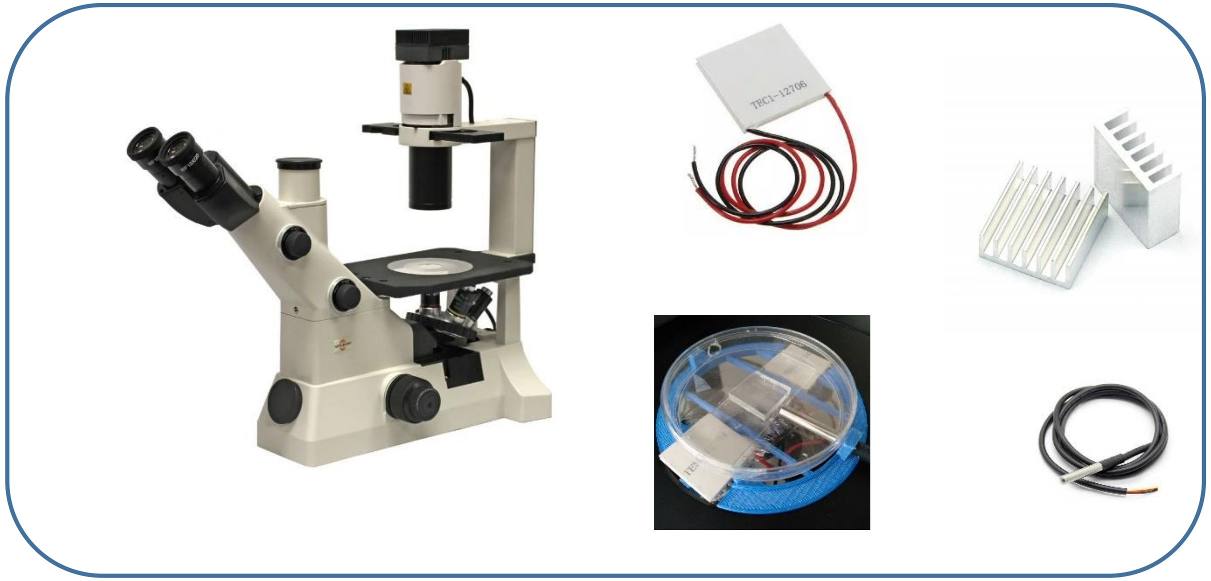
A portion of code is displayed here as an example

Aims of the software:

- Implement the PID controller;
- Read and manage the temperature from the ds18b20 sensor;
- Generate PWM to properly drive the H-bridge;
- Ensure communication between Arduino, the LCD display and the pushbuttons;

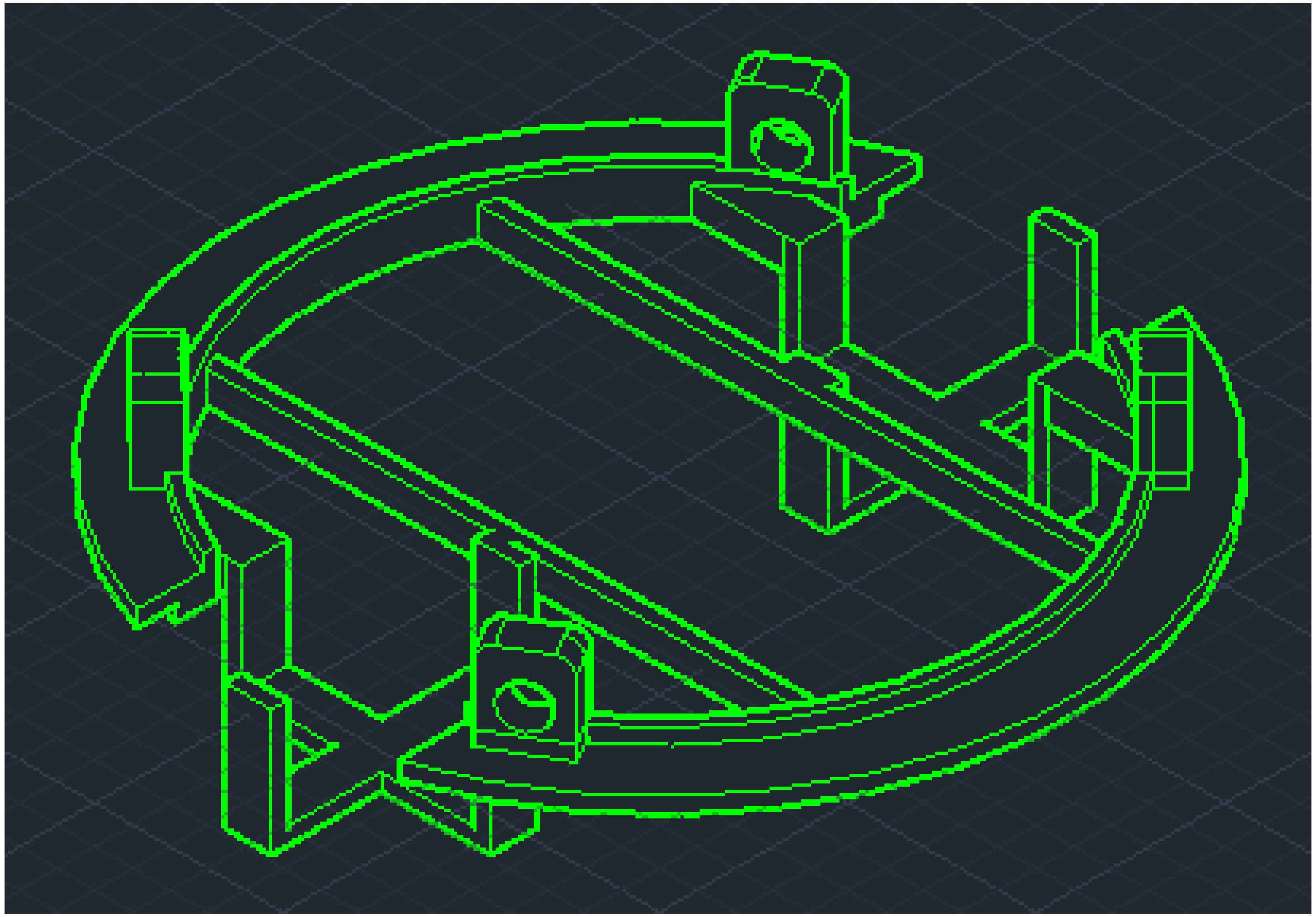
3D PRINTING

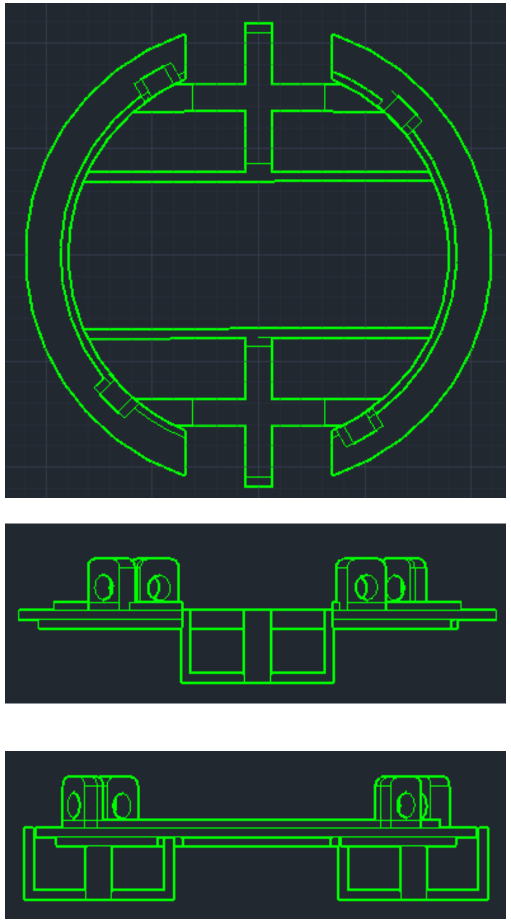
First structure :
heating chamber on the inverse microscope



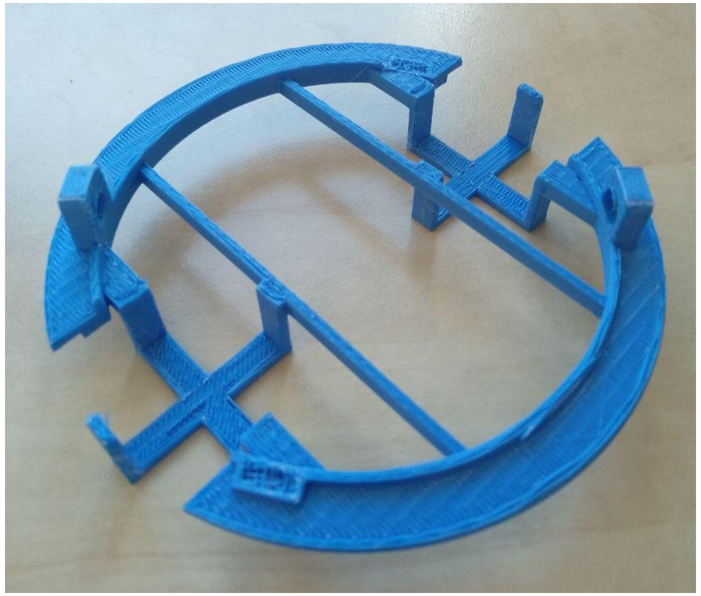
Second structure :
case for Arduino, H-bridge , LCD and pushbuttons

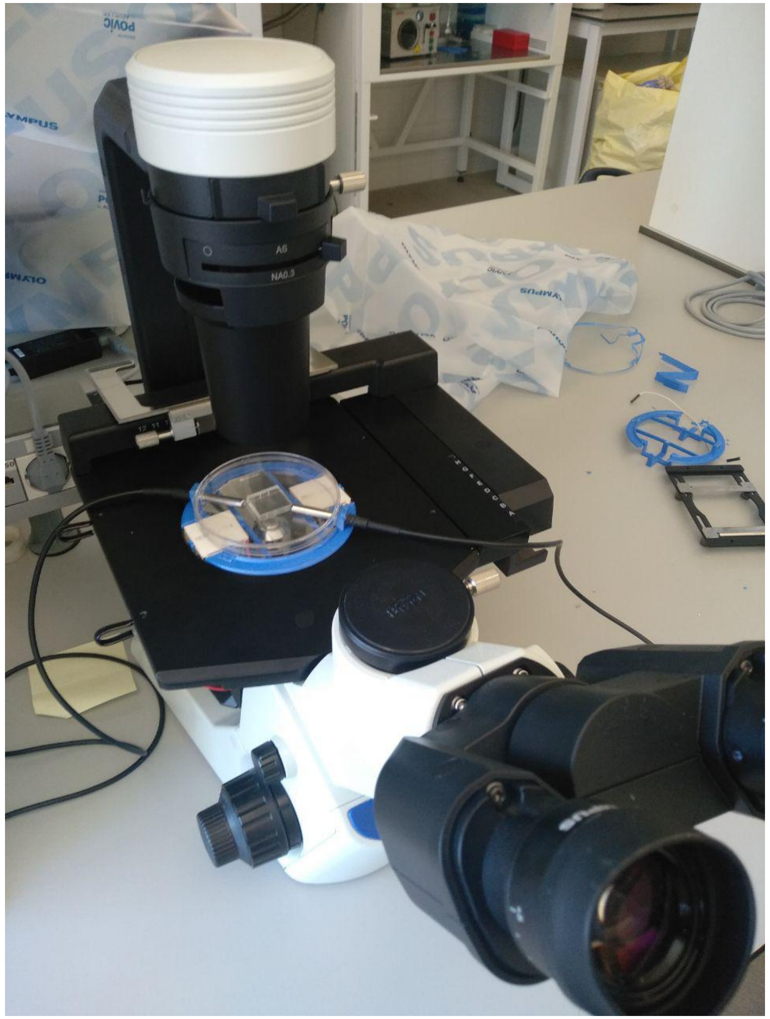
HEATING CHAMBER

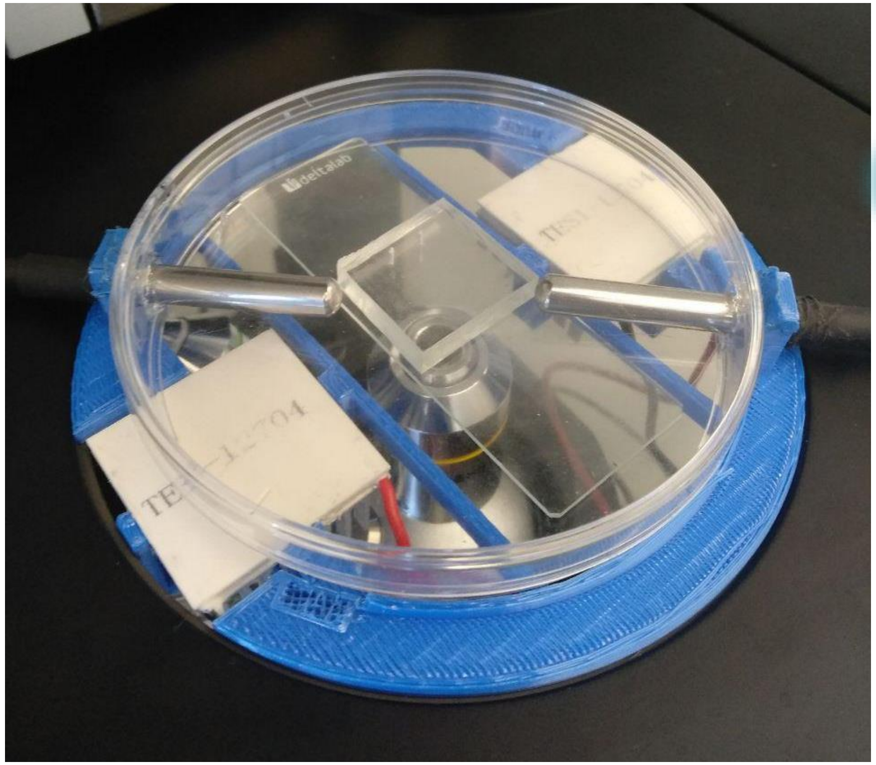




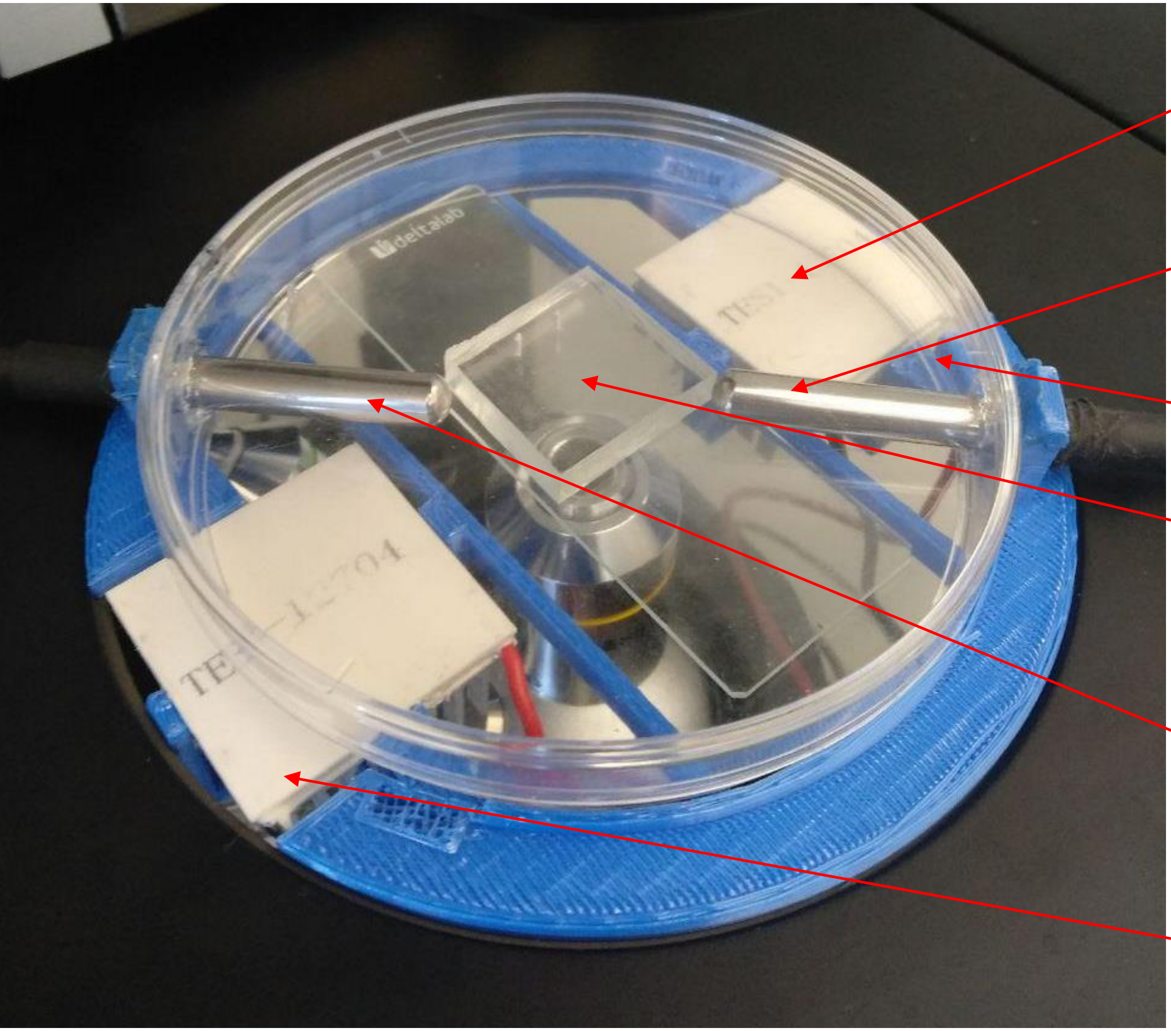
HEATING CHAMBER







HEATING CHAMBER



Peltier cell 1
+
heatsink

Temperature
sensor 1

Petri dish

Microfluidic Chip

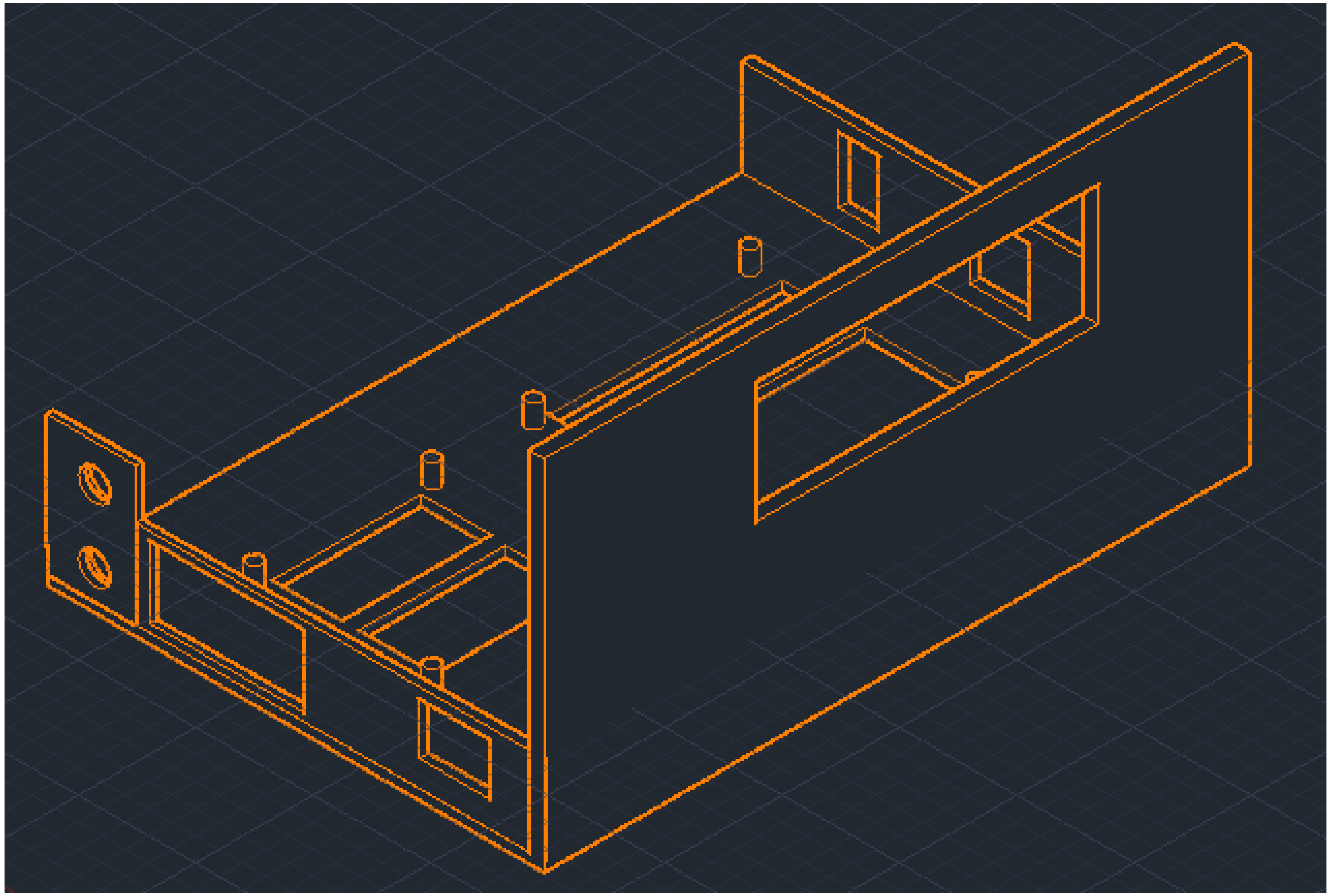
Temperature
sensor 2

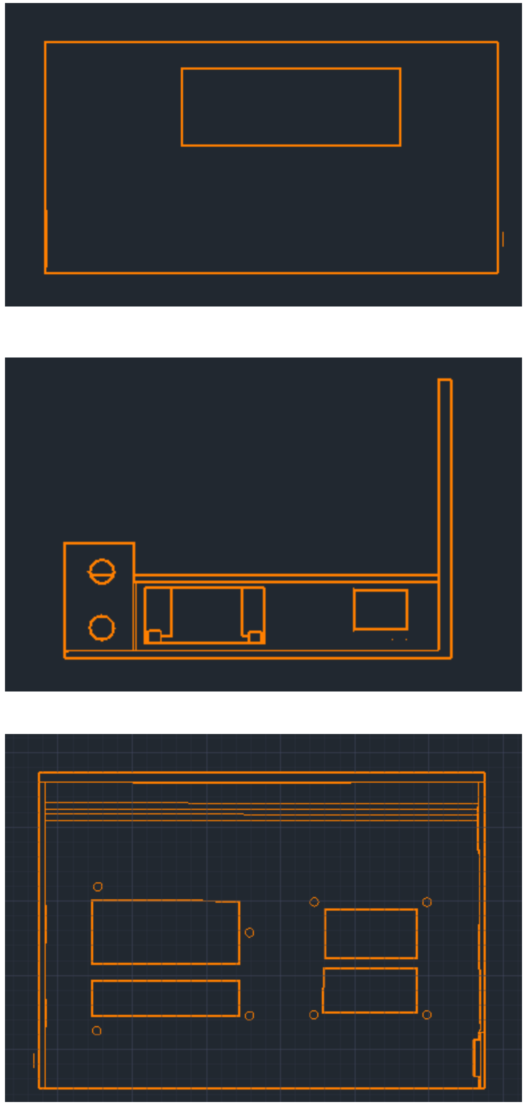
Peltier cell 2
+
heatsink

Features of the heating chamber

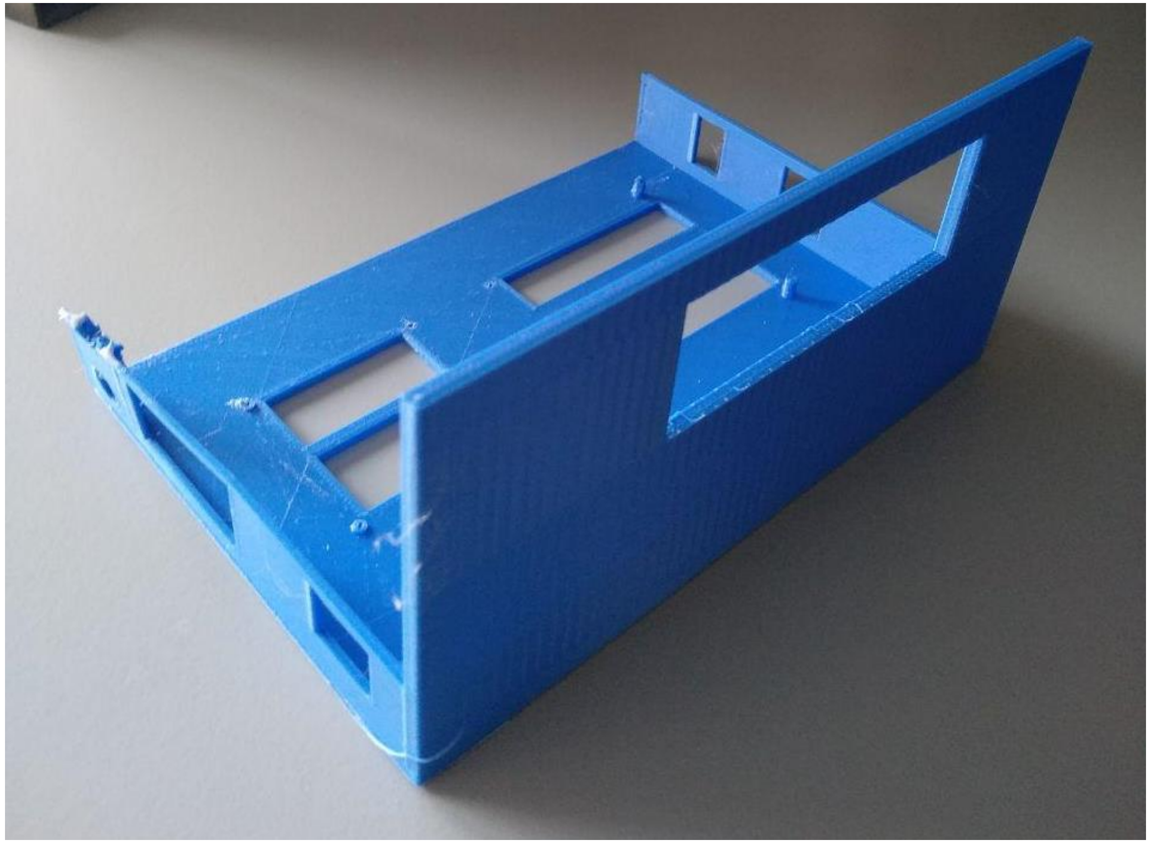
- Designed to perfectly fit in the inverse microscopes of the microfluidic laboratory (Olympus CKX53);
- Hold the petri dish in position , with the thermoelectric heaters below it;
- Hold in the optimal position the temperature sensor , to achieve the maximum precision ;
- Allow the user to switch the different lenses of the microscope by rotating them without touching the structure;

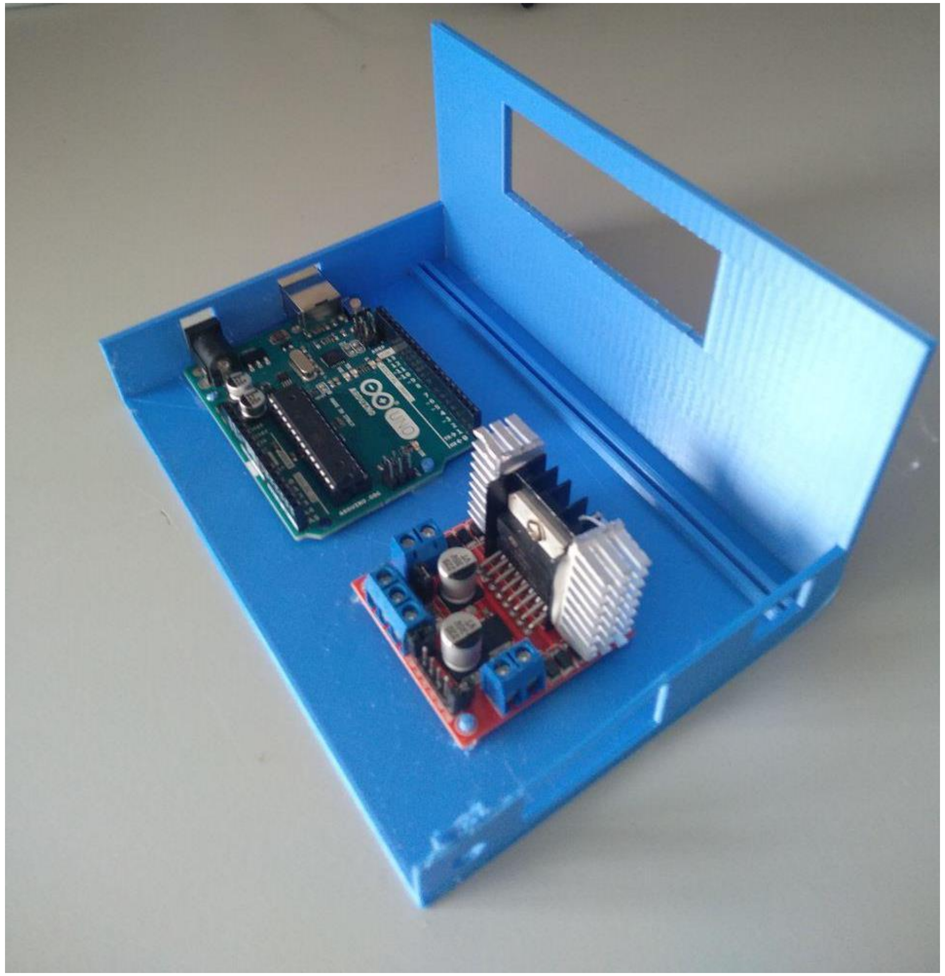
CASE



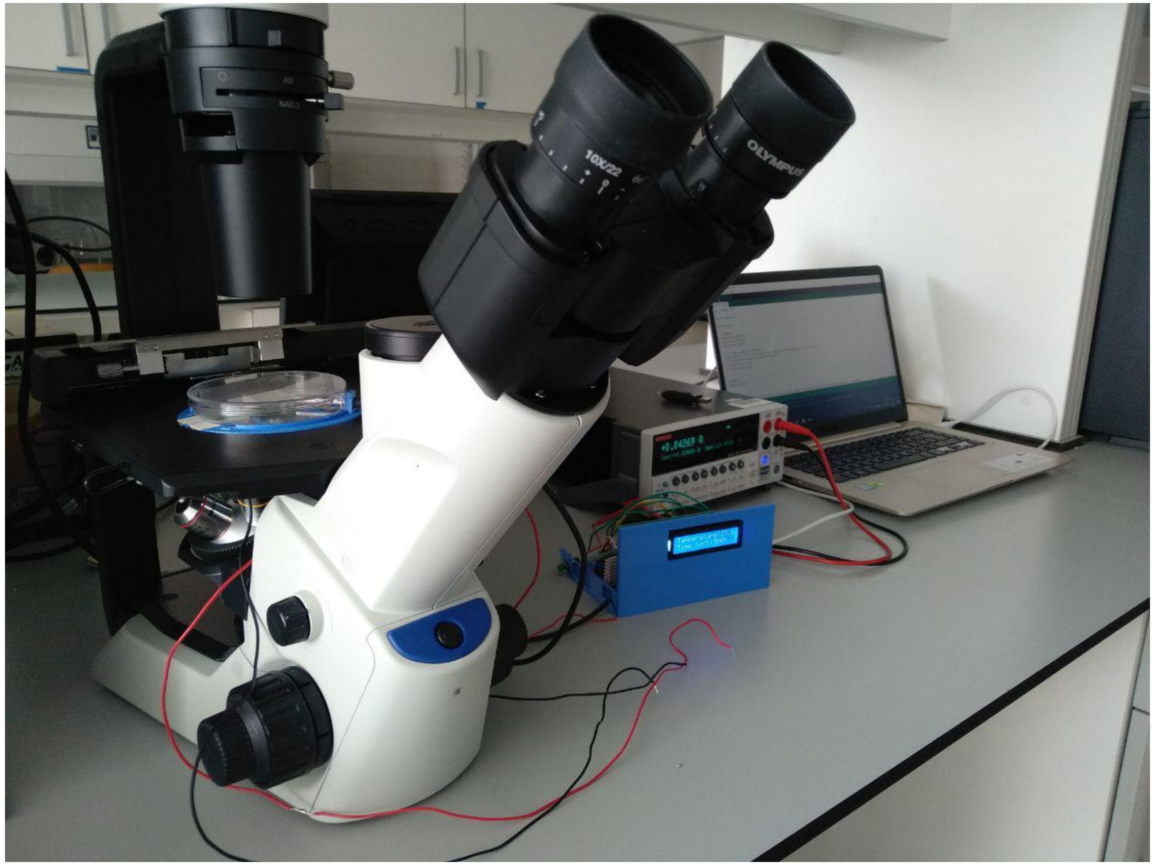


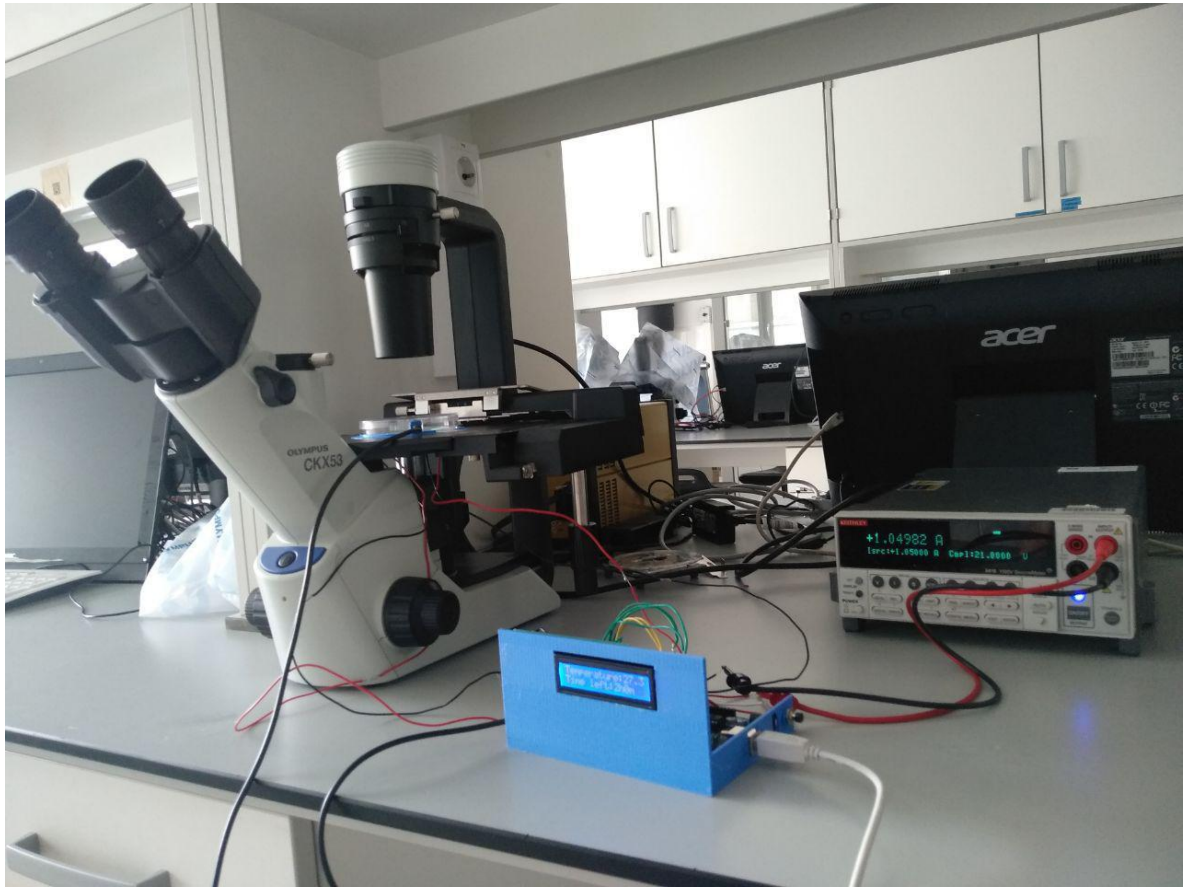
CASE





CASE

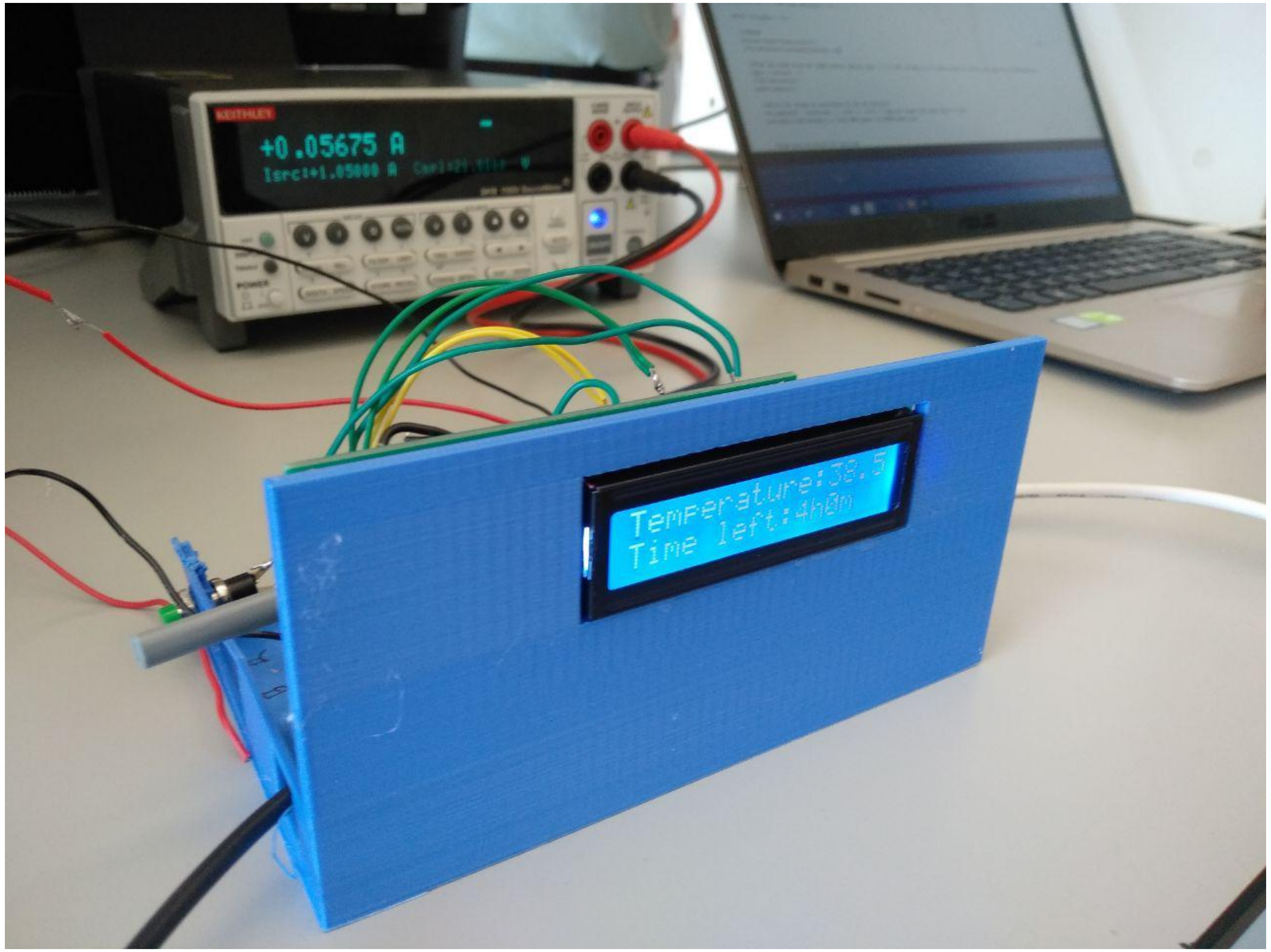




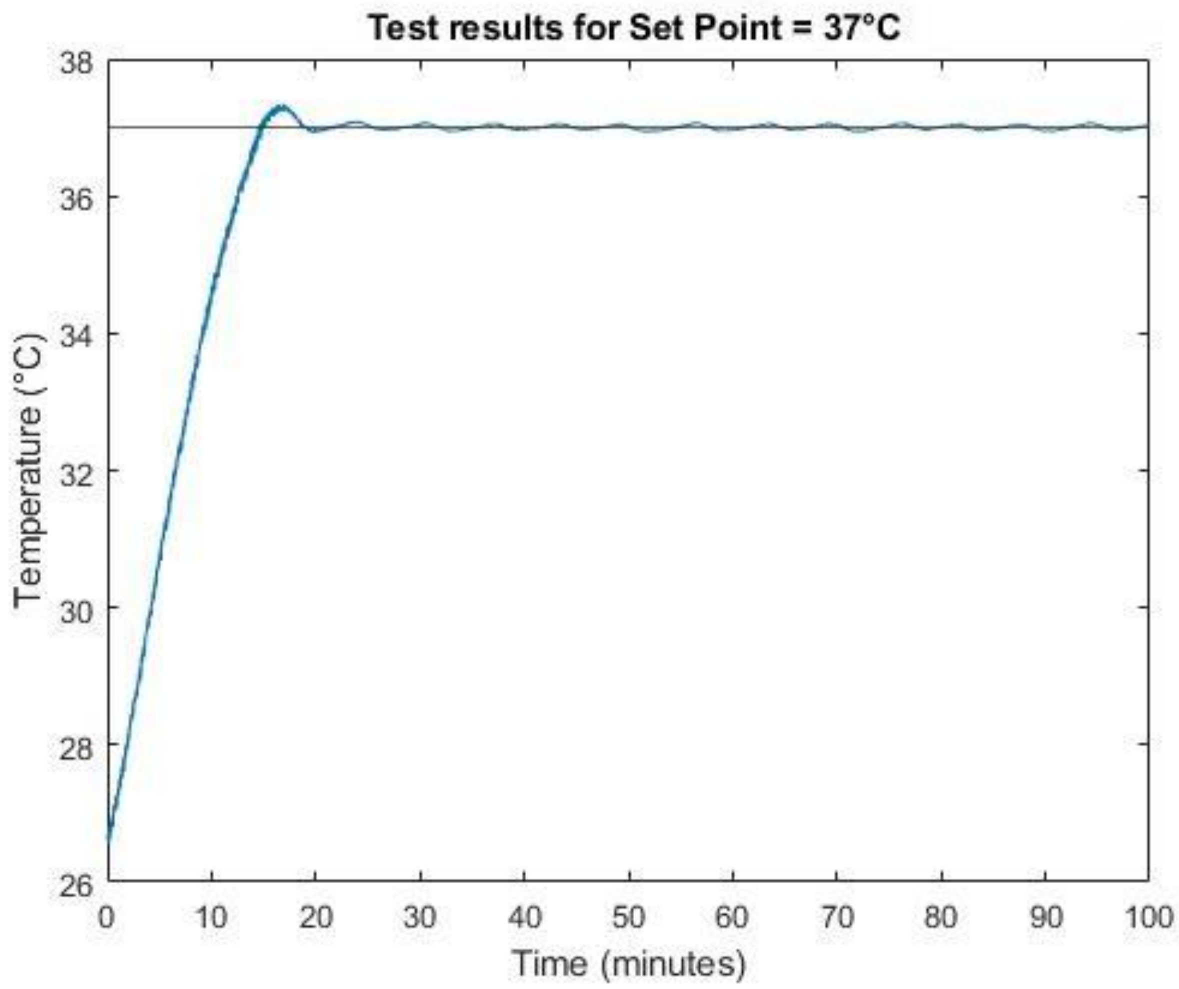
CASE

Features of the case

- Contain and protect the main hardware: Arduino, H bridge, stripboard with electrical circuitry, ;
- Allow the user, trough LCD and pushbuttons, to select the desired temperature and time;
- Optimized to waste as little as possible of thermoplastic necessary for the 3D printing.



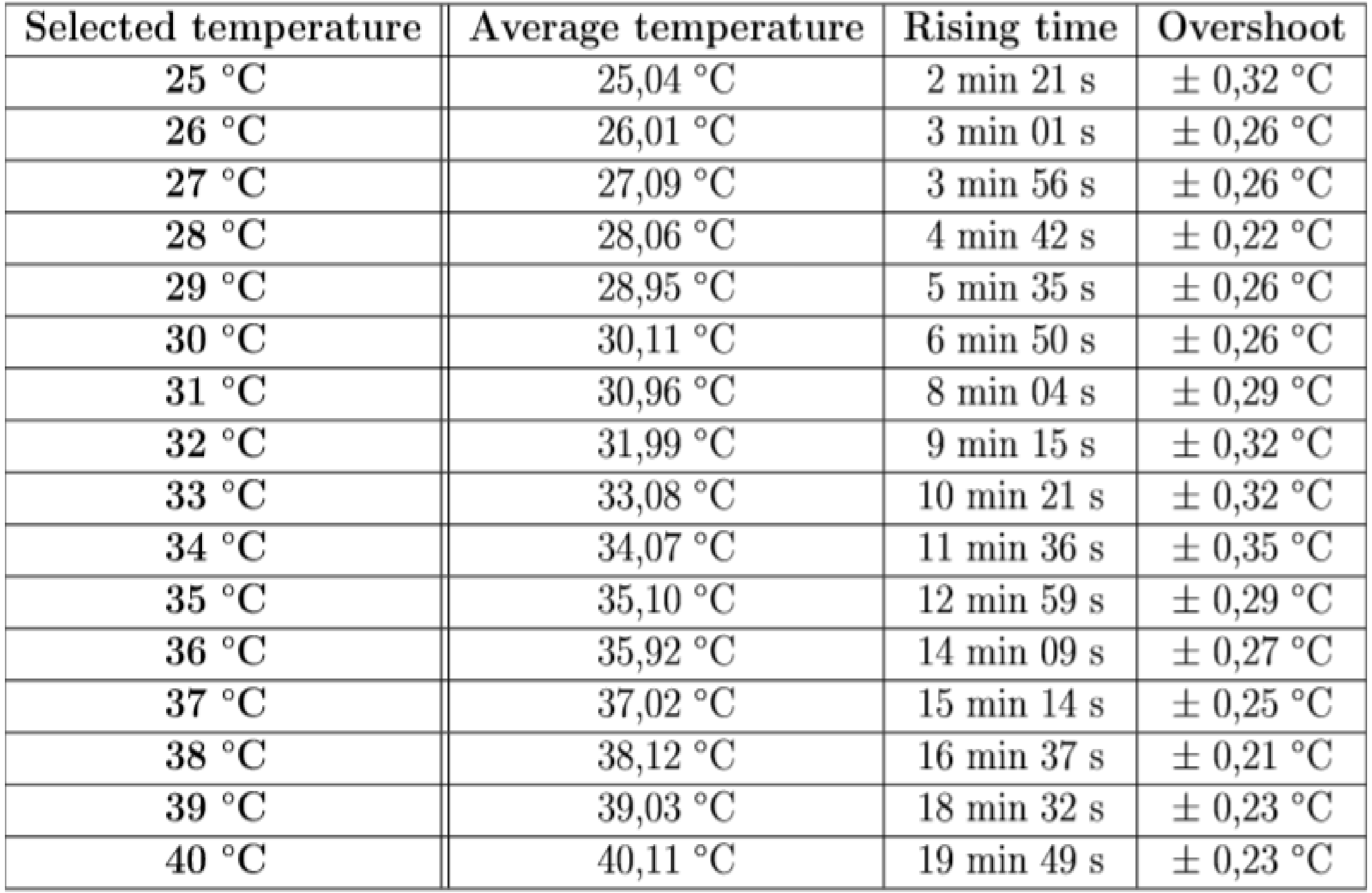
TESTING & RESULTS



Plot of the measured temperature of the microfluidic chip under test (in ° C versus minutes); the Set Point chosen for this test, 37 ◦ C, is the temperature needed for the main application of the system, the study of *T. Spiralis*.

TESTING & RESULTS

Test results for different temperatures



Selected temperature	Average temperature	Rising time	Overshoot
25 °C	25,04 °C	2 min 21 s	± 0,32 °C
26 °C	26,01 °C	3 min 01 s	± 0,26 °C
27 °C	27,09 °C	3 min 56 s	± 0,26 °C
28 °C	28,06 °C	4 min 42 s	± 0,22 °C
29 °C	28,95 °C	5 min 35 s	± 0,26 °C
30 °C	30,11 °C	6 min 50 s	± 0,26 °C
31 °C	30,96 °C	8 min 04 s	± 0,29 °C
32 °C	31,99 °C	9 min 15 s	± 0,32 °C
33 °C	33,08 °C	10 min 21 s	± 0,32 °C
34 °C	34,07 °C	11 min 36 s	± 0,35 °C
35 °C	35,10 °C	12 min 59 s	± 0,29 °C
36 °C	35,92 °C	14 min 09 s	± 0,27 °C
37 °C	37,02 °C	15 min 14 s	± 0,25 °C
38 °C	38,12 °C	16 min 37 s	± 0,21 °C
39 °C	39,03 °C	18 min 32 s	± 0,23 °C
40 °C	40,11 °C	19 min 49 s	± 0,23 °C

QUESTIONS

Thank you for your attention.

Now, I would be pleased to answer any question you might have.