Pressure and Temperature Measurement Box – Fundamental Sensors for Flow Chemistry

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This project presents the design and construction of a simple, cost-effective data acquisition device for pressure sensors and thermocouples. Built around an Arduino Uno, it utilizes an ADS1115 analog-to-digital converter and an MCP9600-based thermocouple amplifier, providing a reliable and affordable solution for pressure and temperature measurements including real-time data acquisition to PC.

The device was specifically designed for use with the Metallux ME780 piezoresistive pressure sensor (model: ME780R050010000), which operates in the 0–50 bar range. The sensor features integrated electronic signal conditioning, delivering a 0.5–4.5 V proportional output while requiring a 5.0 V DC power supply. However, this system can be adapted for any analog pressure sensor with a 0–5 V output range.

For temperature measurement, the device is compatible with K-type thermocouples. If other thermocouple types are needed, the thermocouple socket and interconnecting wires must be replaced accordingly.

The project utilizes widely available and affordable modules that incorporate integrated circuits with the necessary peripheral components. This approach allows for quick and easy development, even for individuals with minimal knowledge in the field of electronics. The design avoids the need for custom-made complex electronic circuits and printed circuit boards (PCBs), making it relatively simple to replicate. Almost no programming skills are required. Extensive free resources for Arduino programming and troubleshooting are readily available online.

List of materials:

Name	Details	Vendor
Arduino Uno R3 clone	ATmega328-Board	AZ-Delivery
ADS1115 ADC module	16 bit, PGA	AZ-Delivery
Thermocouple Amplifier	MCP9600 based Thermocouple Amplifier, with I2C communication; ref. 101020594	Seeed Studio Grove, available from RS-Online
LCD display 2x16	LCD HD44780 type with I2C-FC113 adapter	AZ-Delivery
Miniature Thermocouple Panel, for K-thermocouple	Panel mount female socket; no. 455-9528	RS PRO; RS-Online
M8 4 pin Circular Connector	Panel mount female socket; no. T4033014041-000	TE Connectivity, available from RS-Online
9V DC Plug-In AC/DC Power Adapter	7W Plug-In AC/DC Adapter, 9V DC, 0.84A; no. 206-4910	RS PRO, RS-Online
Universal PCB matrix board	Single Sided Matrix Board FR4 1mm Holes; no. 457-0755	RS-Online

M8 4-pin Panel Connector	TE Connectivity Circular M8 Connector, 4 Contacts, Front Mount, Female; no. 219-7390	RS-Online
K-type thermocouple wire	Type K Thermocouple Wire, PFA Insulation; no. 185-3019	RS-Online
K Thermocouple Panel Socket	Panel Mount Thermocouple Connector for Type K Thermocouple, Miniature, BS Standard, no. 455-9528	RS-Online

Brief description and hints for the assembly of the electronic circuit

An external analog-to-digital converter (ADC), the ADS1115 board, was used in the place of 10-bit ADC included on the Arduino Uno's Atmega328 microcontroller, allowing much higher resolution. The ADS1115 can provide up to 16-bit resolution, but in this project, only 15 bits are utilized. This allows for a theoretical resolution of approximately 21332 steps from to 0.5-4.5 V range (2.3 mbar step with the pressure sensor used). However, due to sensor inaccuracies and environmental factors, the realistic resolution is limited by the sensor's 1% error margin (500 mbar for 1% accuracy in the case of 50-bar sensor, according to the Metallux ME780 datasheet). The observed sensitivity for pressure changes is around 10 mbar, and despite the error margin, the sensor can provide sufficiently accurate and reproducible results in practice of flow-chemistry experiments.

The pressure sensor outputs a signal proportional to pressure within the range of 0.5-4.5 V, and the power supply required for this sensor is a stable 5.0 V DC. This is provided by the Arduino Uno's internal voltage regulator, which in turn is powered by an external 9V DC adapter. This is crucial because powering the Arduino directly through USB can lead to unstable voltage outputs, affecting sensor accuracy. When testing the device, it was noted that supplying power from a USB source caused less accurate pressure readings, underscoring the importance of using a reliable external power supply.

No additional capacitors were added in the circuit since all used components (pressure sensor, ADS1115, and MCP9600) already include built-in decoupling capacitors.

Connections and soldering

The communication between modules is based on the I^2C protocol, requiring four connections per module: +5V, GND (power), SDA and SCL (I^2C data lines). Most connections were soldered to ensure long-term stability and prevent issues caused by loose contacts during operation.

A universal PCB was used to create a robust I^2C bus for all connected devices, including the ADS1115 ADC module, MCP9600 thermocouple amplifier, LCD display and Arduino board. To enhance reliability, connections were soldered directly to the Arduino board, reducing the risk of intermittent contact issues that may occur with breadboard setups. All analog connections on the ADS1115 were soldered, especially wiring between the M8 socket (for the pressure sensor) and the ADC module. For these connections, thin (26 AWG) multiconductor copper wires were used, sourced from good-quality Ethernet cables (UTP or FTP).

A K-type thermocouple socket was implemented, using an appropriate K-type thermocouple cable ensuring correct polarity. This is crucial, as thermocouples operate based on the Seebeck effect, where dissimilar metals generate a voltage proportional to temperature differences. Incorrect polarity can introduce unwanted thermoelectric junctions, potentially leading to incorrect readings. The MCP9600 thermocouple amplifier compensates for unavoidable additional junctions by measuring the ambient temperature and providing compensation, ensuring accurate temperature readings.

LCD display

The I^2C LCD display used in this project may require assembly before use. Specifically, the I^2C adapter board must be soldered to the main LCD display board using the provided gold pin connectors. Once assembled, the display contrast will likely need manual adjustment. To achieve this, the display should first be connected to the programmed Arduino, which should be sending data for display. The contrast can then be adjusted by rotating the potentiometer on the I^2C adapter board using a small screwdriver until the text appears clearly. Care should be taken to rotate the potentiometer gently to avoid damaging the component. Photographs of the assembled device and LCD setup are included for reference.

Final notes

This project is designed to be accessible and easy to replicate by using off-the-shelf modules and widely available components. Even those with minimal experience in electronics or programming should be able to assemble and operate the device without difficulty. The Arduino Uno can be programmed using a simple and widely supported programming environment, and the necessary software libraries for the ADS1115, MCP9600, and LCD display can be easily installed via the Arduino IDE's library manager. By avoiding custom circuit designs and printed circuit boards, this project remains affordable while providing reliable pressure and temperature measurements.

Conversion of ADC output to pressure and temperature

To convert the raw ADC output into a pressure value, the code follows a straightforward process. The ADS1115 ADC, with the programmable gain amplifier (PGA) set to "0" (ADS_0.setGain(0) or ADS_0.setGain(GAIN_TWOTHIRDS)), has a full-scale input range of ±6.144 V. Since the ADC operates at 15-bit resolution, it provides 32,767 discrete steps. This results in a voltage resolution of approximately 0.00018751 V per step.

The pressure sensor used in this project outputs a voltage range from 0.5 V to 4.5 V, corresponding to a pressure range of 0 to 50 bar. The relationship between voltage and pressure is linear and can be expressed using the equation $y = ax + b$, where y is the pressure (in bar) and x is the measured voltage. Given the two known calibration points (0.5 V = 0 bar and 4.5 V = 50 bar), the slope a is calculated as *12.5*, and the intercept b as *-6.25*. Using this equation, the code directly converts the sensor's voltage output into a pressure reading (see figure 1).

```
int16_t raw_0 = 0;
float d = 0.00018751;
float voltage_0 = 0;
float a = 12.5;
float b = -6.25;
```

```
void loop() {
  raw_0 = ADS_0.readADC_Differential_0_1();
  voltage_0 = raw_0 * d;
  pressure = (voltage_0 * a + b);
```

Figure 1. Parts of the Arduino code responsible for converting the voltage output from the pressure sensor for the pressure value. Voltage was left in calculations to allow checking the correct operation of ADC. Pre-calculated values "a" and "b" for linear equation are saved in the code.

Reading the temperature from the MCP9600 is straightforward. Using the command *mcp.readThermocouple()*, the temperature value is directly retrieved from the MCP9600 chip and returned in degrees Celsius (°C).

Assembly process and visual documentation

Additional details on the physical assembly, including photos taken during the assembly process, are provided in the following figures. Each figure is accompanied by a detailed description, offering further insights into the assembly steps and important considerations. Please refer to these descriptions for a clearer understanding of the assembly procedure. See figures 2 – 15.

3D-printed case and additional information

A custom 3D-printed case was designed to house all the electronic components. The case features 3D-printed M3 threads to accommodate screws, as frequent disassembly and reassembly are not expected. The base of the case includes threaded supports designed to hold the Arduino board, MCP9600 thermocouple amplifier board, and ADS1115 analog-to-digital converter board.

The universal PCB, which connects all I^2C communication and power lines, is positioned above the MCP9600 board using M3 brass spacers. These spacers also serve to secure the MCP9600 board in place. This additional PCB was carefully cut from a universal matrix board, with drilled holes to fit M3 screws. A rectangular cutout was also made to ensure the PCB fits without interfering with the MCP9600 board's thermocouple terminal.

After completing the soldering, the Arduino board is mounted with small 3D-printed plastic washers placed on the M3 screws to prevent any potential short-circuits caused by the heads of the M3 screws. The shorter side walls of the case feature openings for the Arduino's USB and power input ports, as well as for the pressure sensor's M8 socket and the thermocouple socket. The longer wall of the case include mounting brackets, which allow the device to be attached securely to a horizontal rod installed on a standard laboratory stand.

The LCD display is mounted on the front panel of the case using short (4-5 mm) M3 screws. The display is recessed into the case, leaving space for the optional installation of a thin glass shield (approximately 1 mm thick), which serves to protect the display from solvent splashes during operation. The glass shield can be attached to the case with a small amount of silicone, epoxy, or another adhesive applied along the edges of the recess.

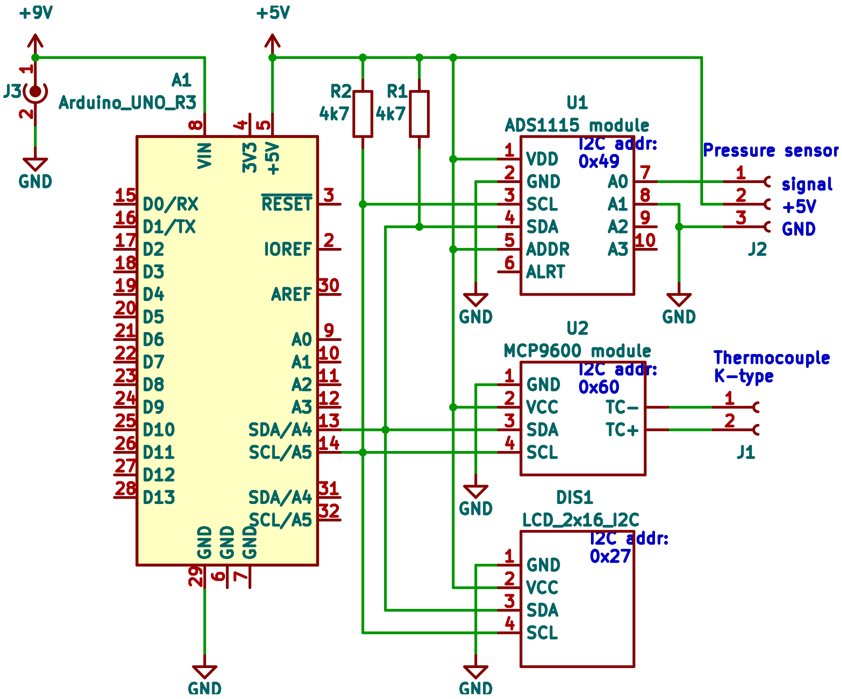

Figure 2. A schematic diagram showing the connections between the Arduino Uno board and the additional modules: the ADS1115 analog-to-digital converter for pressure sensor readings, the MCP9600 module for K-type thermocouple readings, and the 16x2 LCD display. Communication between the Arduino and these modules is facilitated through the I²C protocol. The I²C address of the ADS1115 can be modified by adjusting the "ADDR" pin. In this configuration, the "ADDR" pin is connected to the +5V line, which sets the I²C address of the ADS1115 to 0x49, as specified in the Arduino code provided in the repository. If necessary, this address can be changed by wiring the "ADDR" pin to different pins, following the instructions in the ADS1115 datasheet.

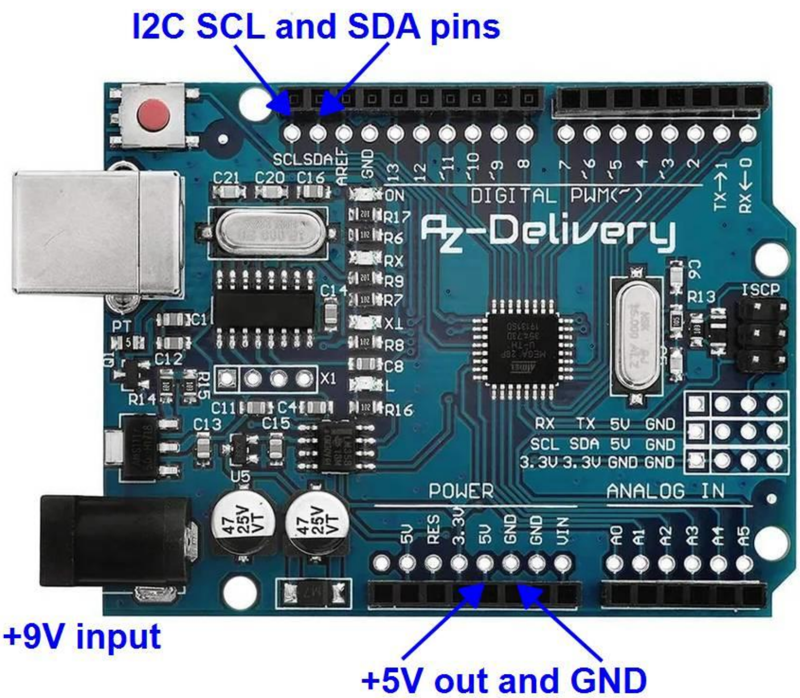

Figure 3. A simple diagram illustrating which Arduino pins are used for the connections. Both "gold-pin" connectors and soldered connections can be utilized, with soldering being the preferred method for long-term stability and reliability.

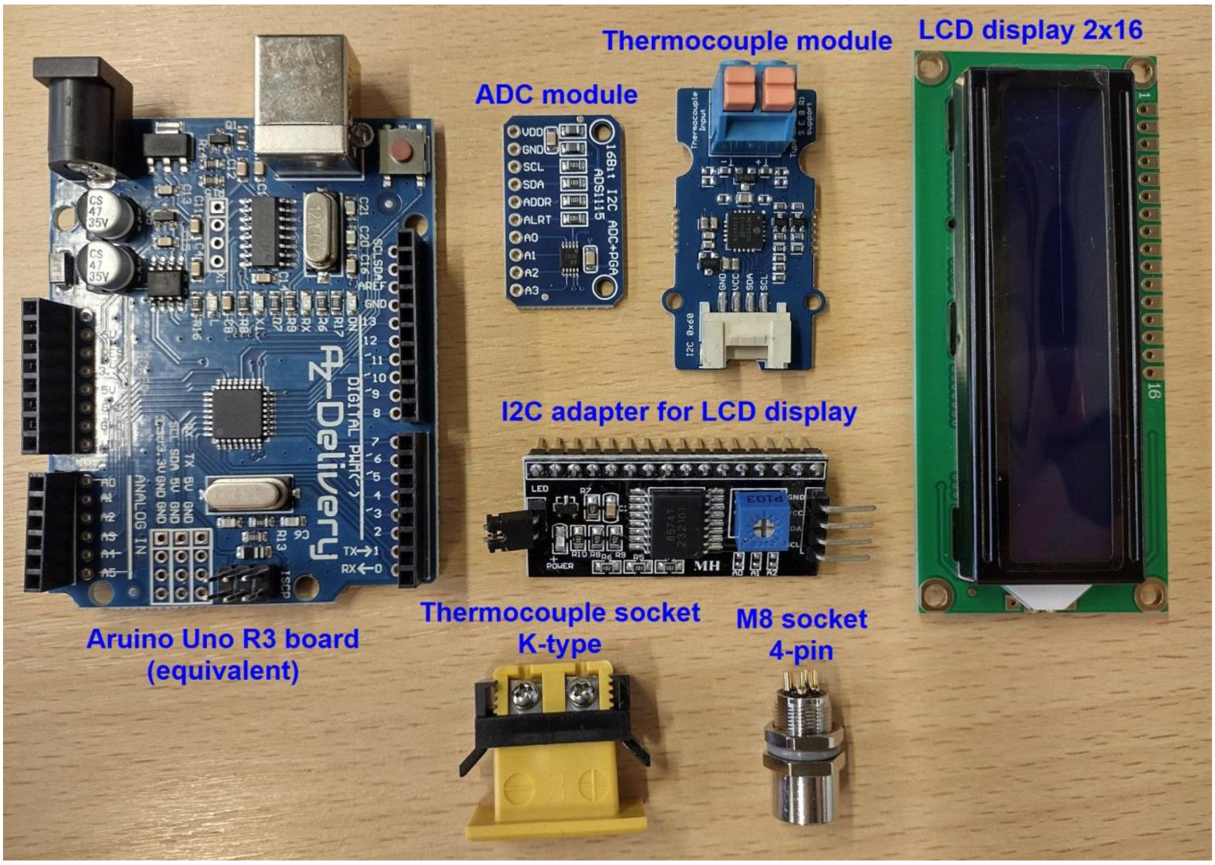

Figure 4. Elements consisting in the described system.

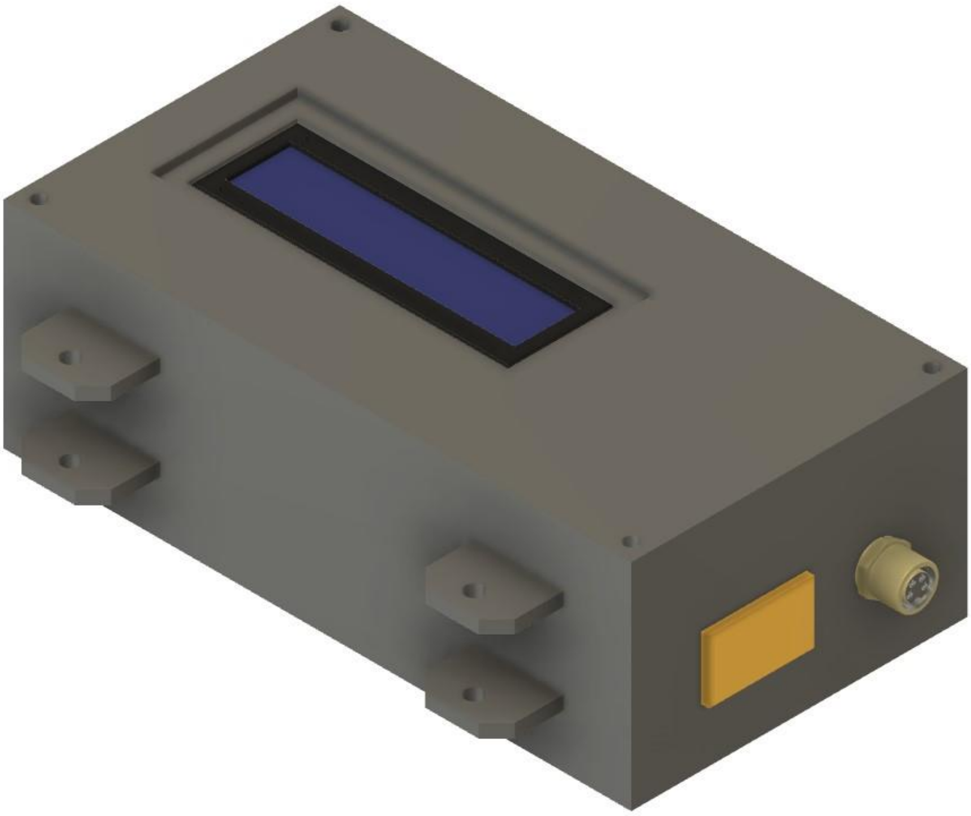
Figure 5. Overview of the 3D-designed case.

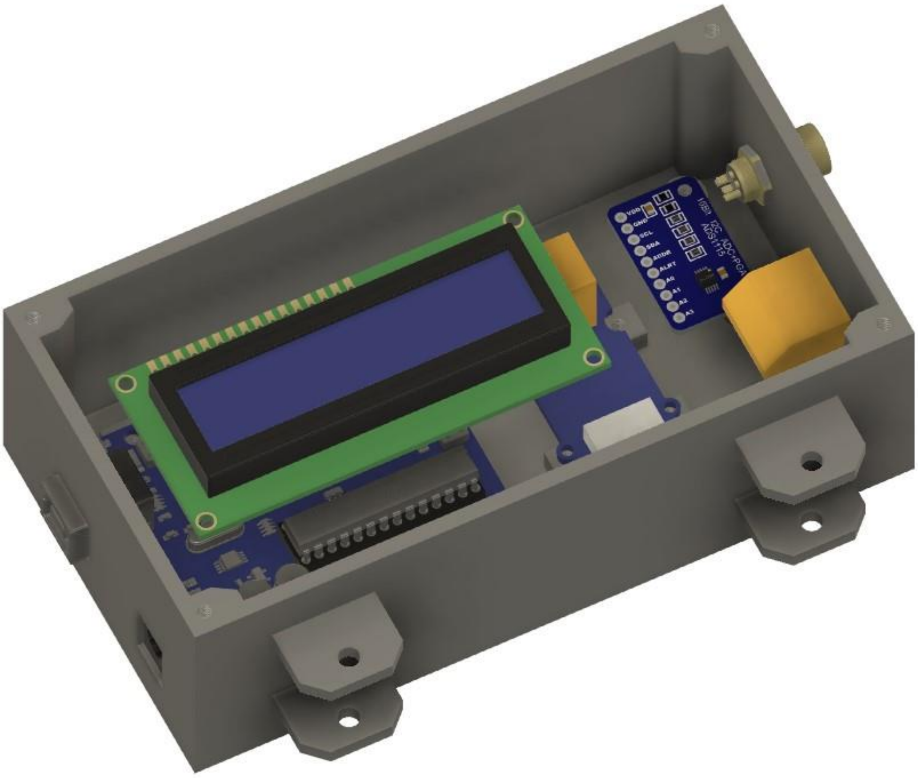

Figure 6. Internal view of the 3D-designed case.

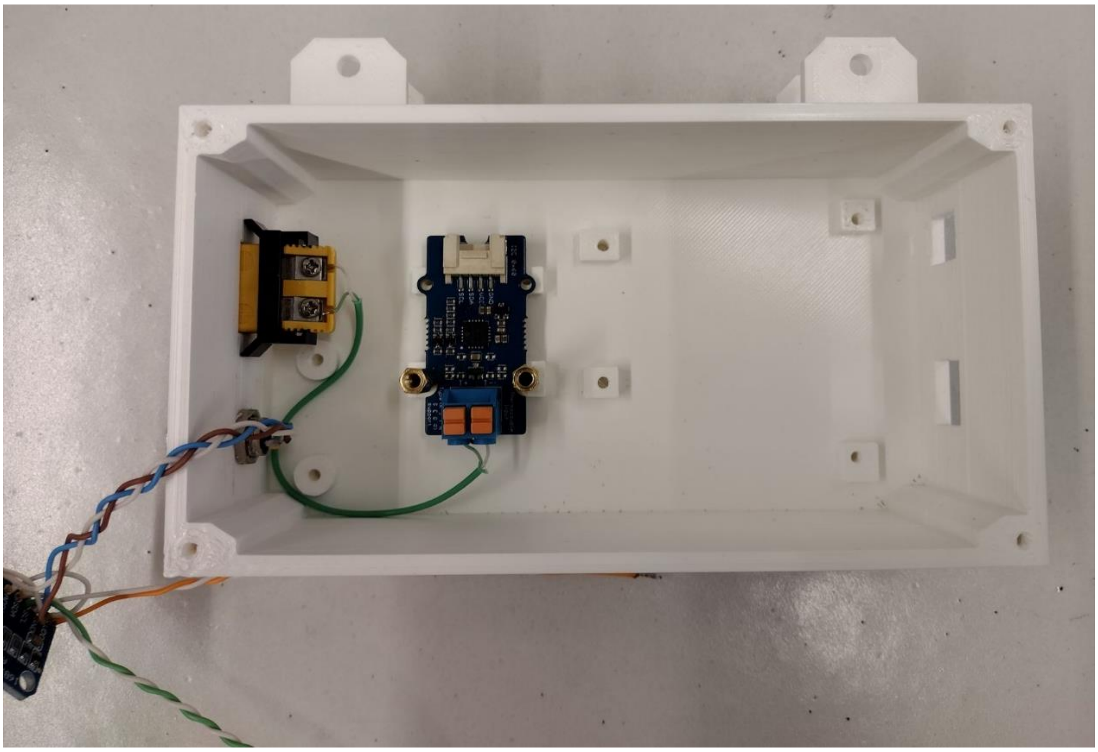

Figure 7. The assembly begins with the installation of the thermocouple socket and the MCP9600 board, followed by connecting them using a special thermocouple cable. It is important to ensure correct polarity, so attention should be paid to the color coding of the thermocouple wires (thermocouple wire color coding can be found in Internet). Afterward, the M8 connector for the pressure sensor is installed, with three wires (GND, +5V, and signal) pre-soldered to the connector. The next step involves soldering the necessary wires to the Arduino board (+5V, GND, SDA, SCL). At the same time, the universal PCB is prepared to facilitate the I^{2}C connections. All interconnecting wires are prepared with a length longer than strictly required, which provides flexibility during the assembly process and allows for easier handling of the components.

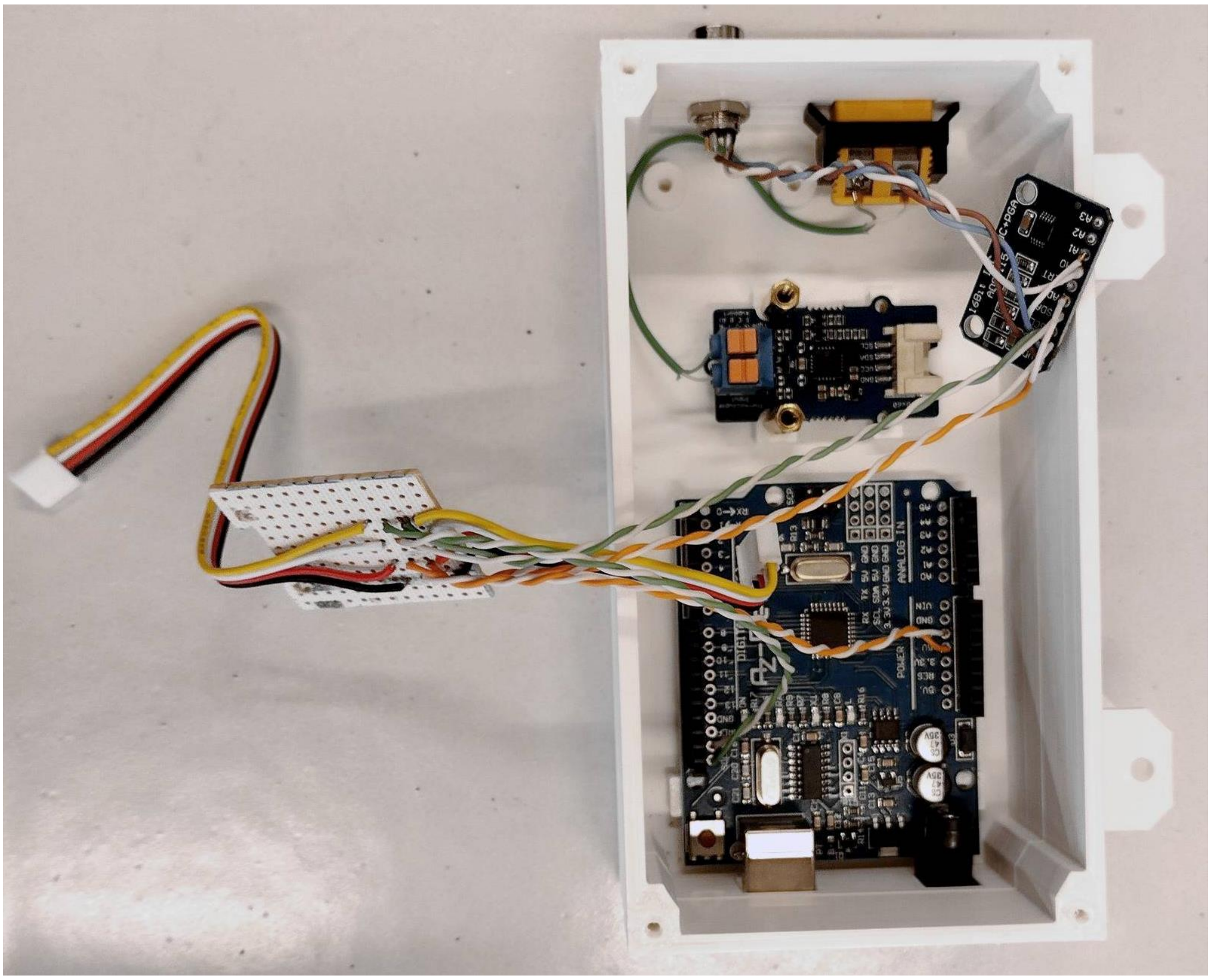

Figure 8. The wires are soldered to the ADS1115 board. Power can be delivered to the sensor socket by soldering both the supply wires for ADS1115 and the wires leading to the socket into the same holes (+5 V, GND) on the ADS1115 board. Proper connections are also made to the A1 input (connected to GND) and the ADDR pin (connected to +5V) in a similar manner. While these connections could also be made on the universal PCB, this approach minimizes the length of the analog signal connections which reduces potential noise in signal. The brass spacers holding the MCP9600 board are visible in the figure. The 4-wire cable, originally supplied with the MCP9600 board and terminated with 4-pin connectors, was cut in half. Both halves were then soldered to the universal PCB, providing a connection to the MCP9600 board and a detachable connection to the LCD display. Note that the connectors on the LCD I^2C adapter may need to be slightly bent to allow proper connection with this 4-wire cable connector. After assembling the components, double-check all connections before performing a power-up test. For the test, it is recommended to use a regulated power supply with a current limit set to 50 mA or lower. The "VIN" pin can be used to supply the circuit with 5V, as well as the round power socket.

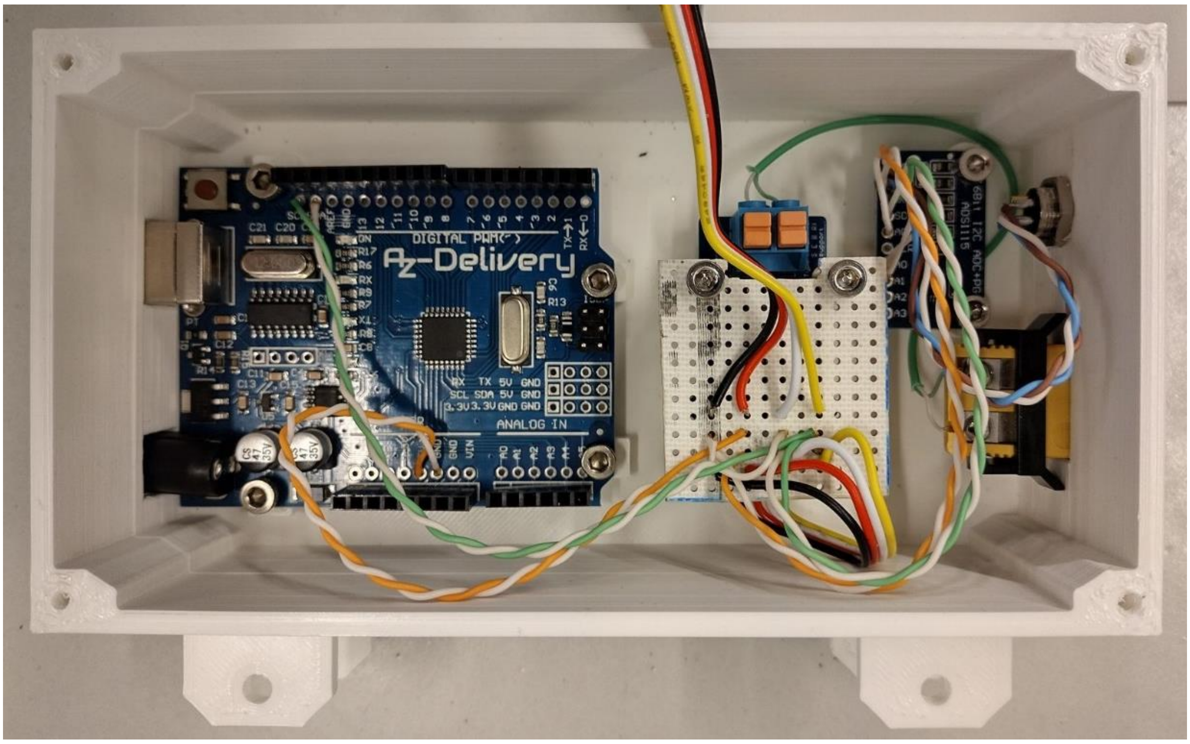

Figure 9. The additional cut made on the universal PCB (before soldering) is visible, which allows for avoiding any collision with the thermocouple connector on the MCP9600 board. After successfully powering up and testing the circuit, all the boards are securely installed in their designated positions within the 3D-printed case.

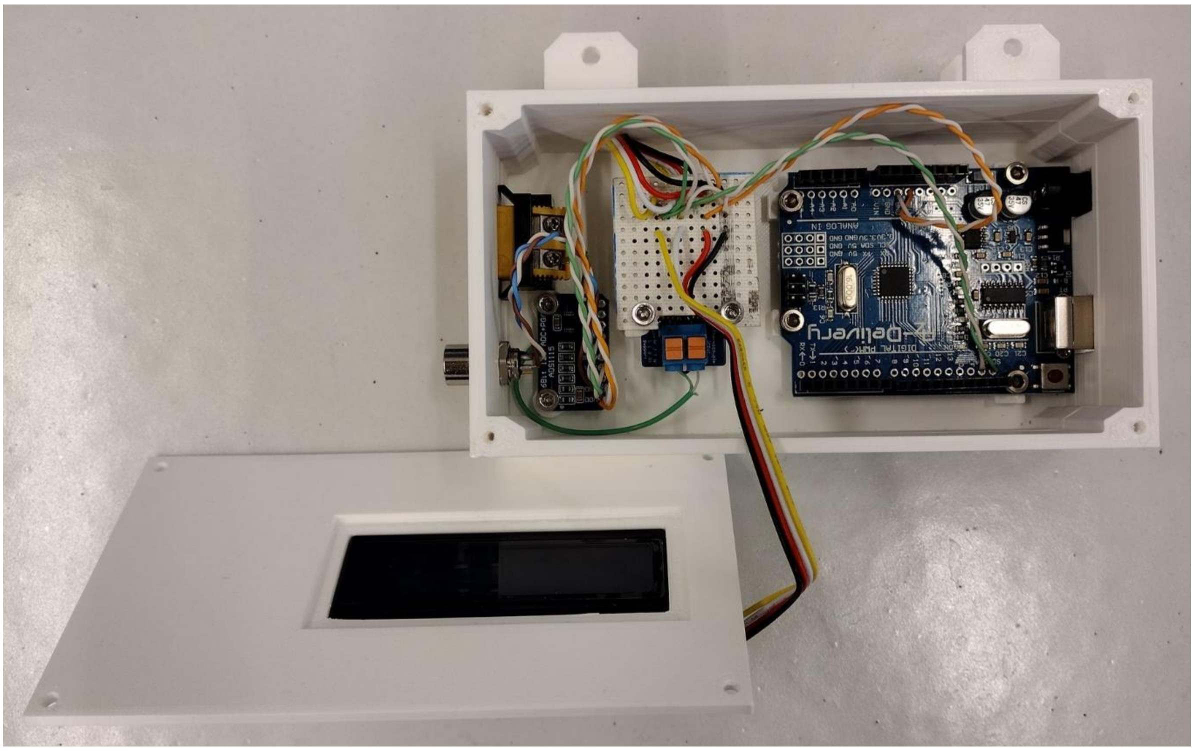

Figure 10. All cables inside the case are organized to ensure that the case can be closed properly. Special attention is given to the pre-bending of the 4-wire cable leading to the LCD, as it has a certain stiffness and requires attention to avoid difficulties while closing the 3D-printed case.

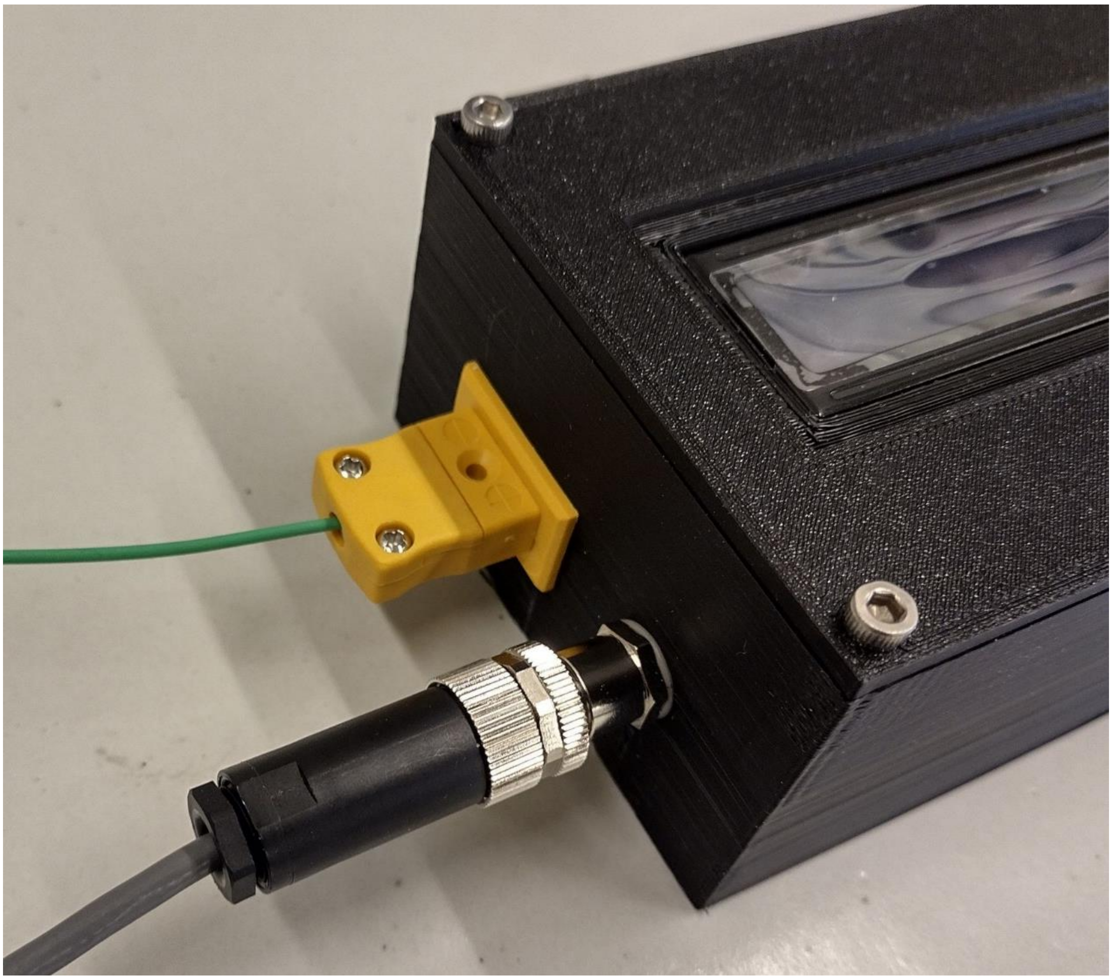

Figure 11. The connectors for the K-type thermocouple and the pressure sensor are shown in this image. The M8 plug provides a secure and reliable connection, utilizing a screw-in attachment method.

Figure 12. The fully assembled device is shown here, with all cables securely connected and the system powered up. The LCD screen's contrast and readability are better than it appears in the photo.

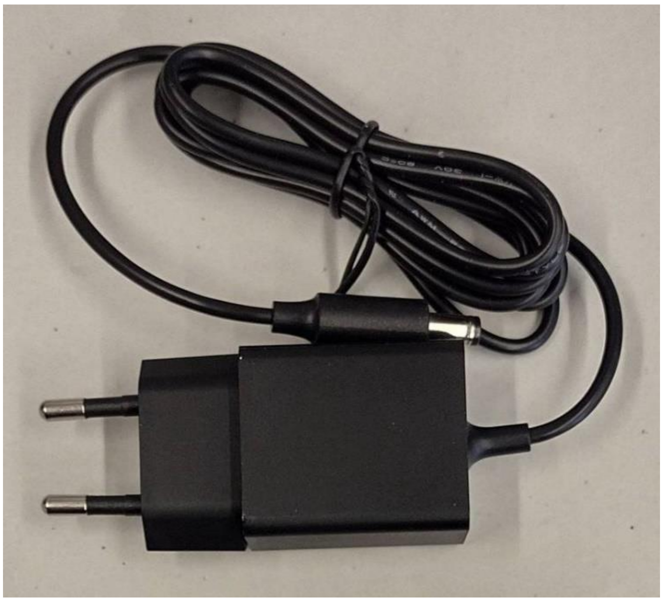

Figure 13. Grid adapter to 9V DC used as a reliable power source for the device.

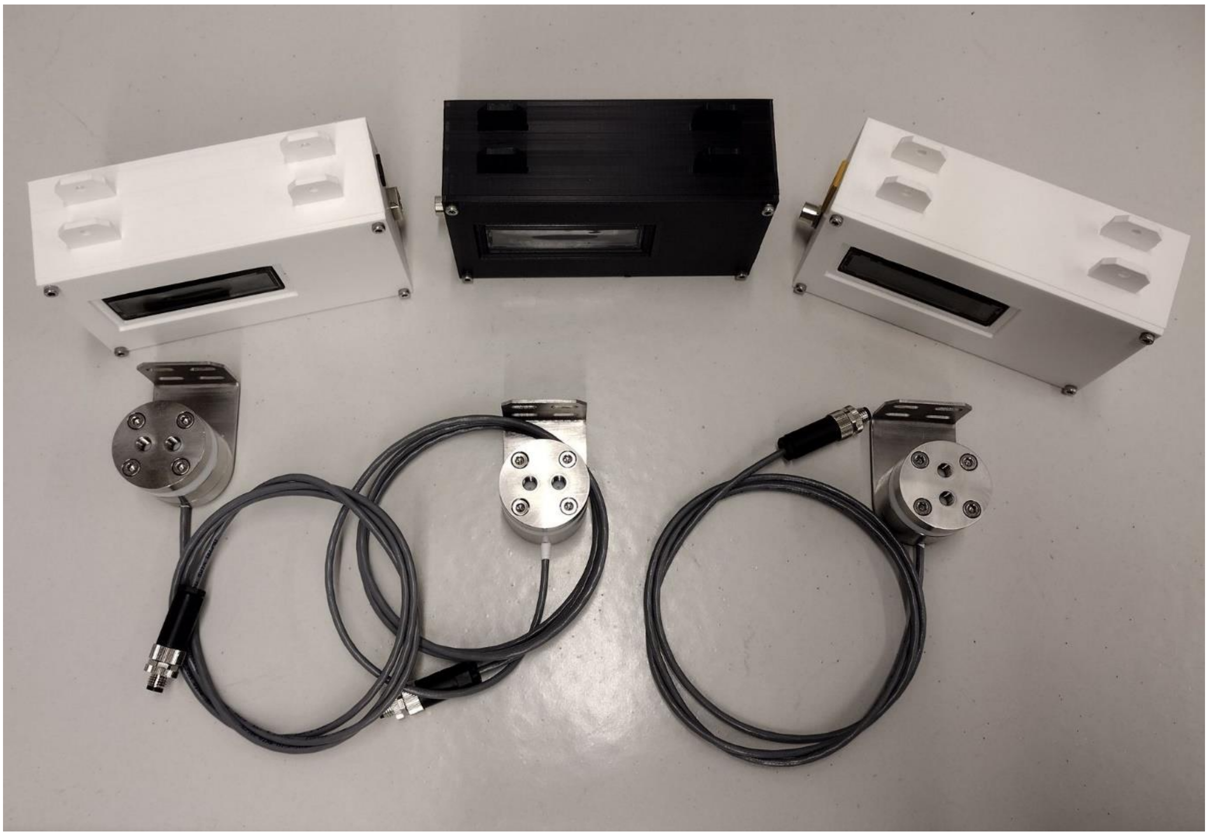

Figure 14. Three devices described here, and custom-made pressure transducers described in another folder of this repository.

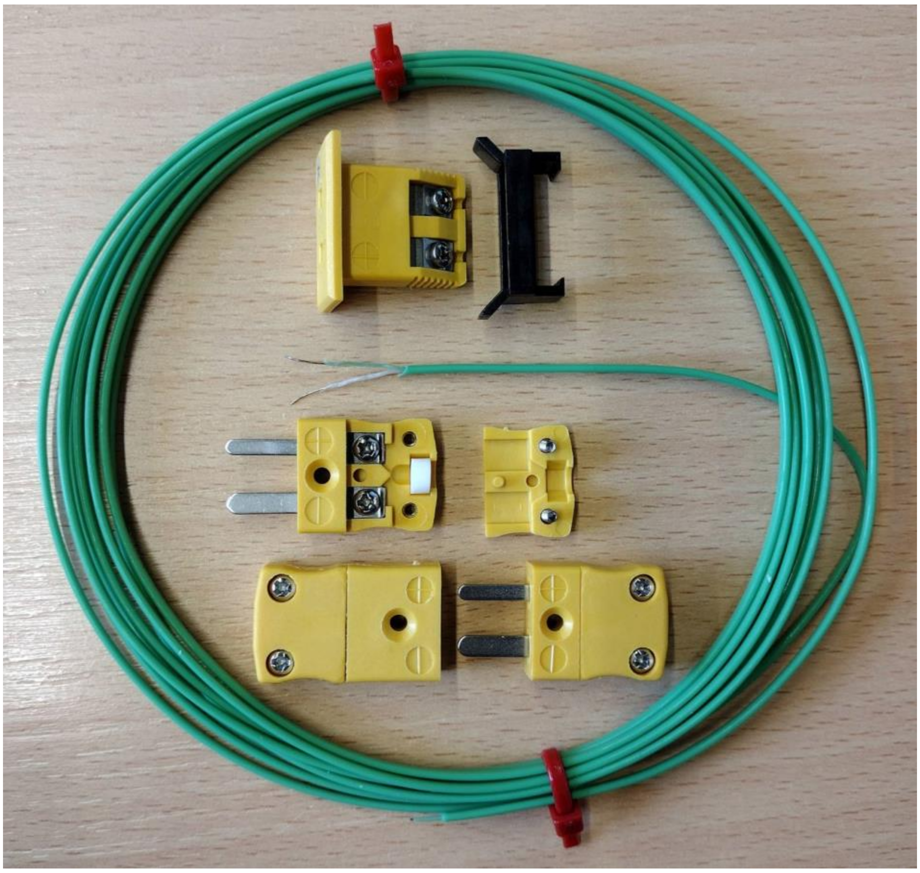

Figure 15. Special K-type thermocouple cable, sockets, plugs, and the panel-mount socket used in the described device. When establishing thermocouple connections, it is crucial to observe the correct polarity of the cable (color coding – data available online according to local standards).

Acknowledgements

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