Filtration and Separation Module Control Unit

Designed by Hubert Hellwig[a], under supervision of Jean-Christophe M. Monbaliu[a,b]

a) *Center for Integrated Technology and Organic Synthesis (CiTOS), MolSys Research Unit, University of Liège, B6a, Room 3/19, Allée du Six Août 13, 4000 Liège (Sart Tilman), Belgium; webpage: https://www.citos.uliege.be*
b) *WEL Research Institute, Avenue Pasteur 6, B-1300 Wavre, Belgium*
E-mail: hhellwig@uliege.be; jc.monbaliu@uliege.be

Explanation of the system

This project presents the design and construction of a controller for an automated continuous filtration and separation device used in continuous-flow chemistry research. The device was developed during research on a furfural flow nitration platform, where the need for continuous-flow filtration and separation of two liquid phases arose. See the simplified diagram of the setup in Figure 1.

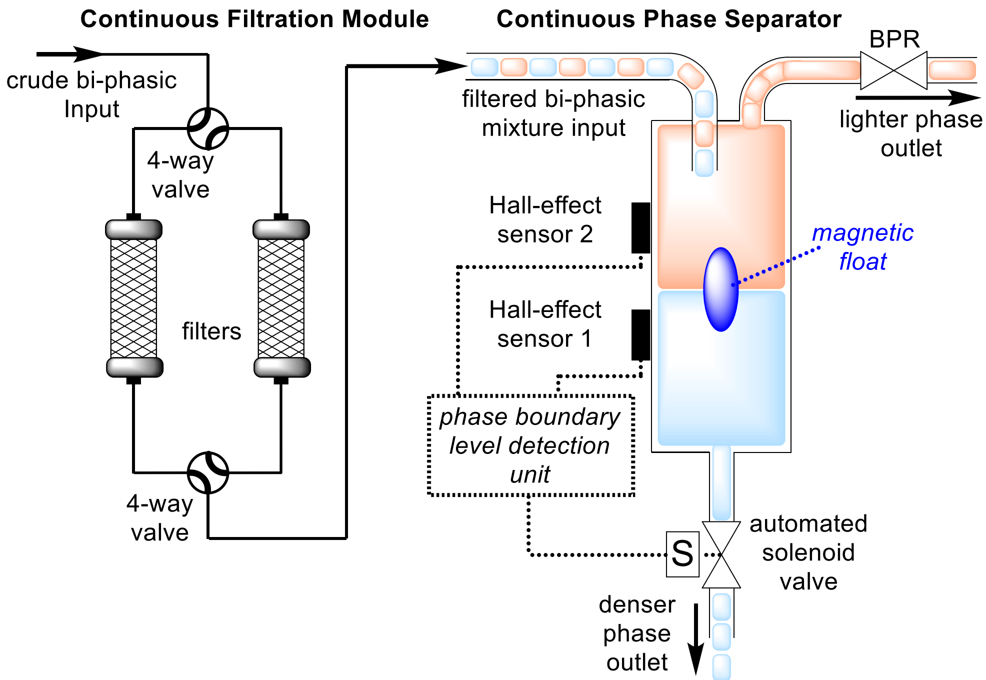

Figure 1. Simplified diagram of the Continuous Filtration and Separation Module.

The continuous filtration was achieved using two filtering devices operating alternately, allowing uninterrupted operation while the used filter could be replaced. Continuous phase separation was based on gravity separation of two immiscible liquid phases due to their density difference. Separation occurred in a vertical column equipped with a valve controlling the bottom outlet. The valve control was coupled with phase boundary level sensing, ensuring the phase boundary remained within a predefined range near the column's mid-height.

The position of the phase boundary was detected using a small floater containing an internal magnet. The floater's buoyancy was tuned to sink in the less-dense (ex. organic) phase and float on the denser (ex. aqueous) phase. The presence and intensity of the magnetic field were detected using a set of Hall-effect sensors. Specifically, two pairs of Hall-effect sensors were implemented to prevent unreliable sensing caused by the rotation of the magnetic floater (see Figure 2).

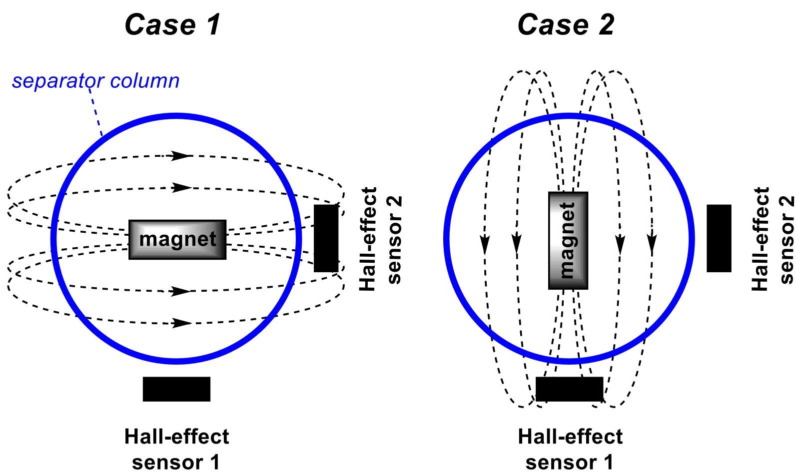

Figure 2. Explanation of the need for pairs of perpendicularly placed Hall-effect sensors at both detection levels. The dashed lines in the figure represent the magnetic field lines, illustrating that due to the rotation of the magnetic float, one of the Hall-effect sensors may fall outside the magnetic field, resulting in a loss of sensing capability. Implementing sensor pairs completely mitigates this issue while remaining simple and cost-effective.

To enable automatic operation of the system, several electrically actuated valves were implemented (see complete diagram, Figure 3). Valves V2, V3, and V6 are modified IDEX valves; a description of the modification is available within this repository (see *"Electrically-Actuated-Valves-for-Flow-Chemistry"*). These valves are actuated by standard servo motors. Valves V4 and V5 are commercially available solenoid-driven valves (12 V DC).

The pump P1 and the drying gas source allow washing and drying of the used filtering cartridge, ensuring safe and convenient replacement without requiring operators to handle connections with the presence of solvents or harmful chemicals. Valve V5, together with the BPR, is critical for the operation of the phase separator. While valve V5 controls the output of the denser phase (open/close), the BPR provides a controlled and constant flow restriction on the lower-density output, creating a small positive pressure. This ensures that the liquid exits the separator via the bottom output when V5 is open.

The pressure sensor ps1 monitors system pressure and indicates the correct moment for filter replacement.

See Figures 4–9 for more details on the system described here. The electronic components are described later in this document.

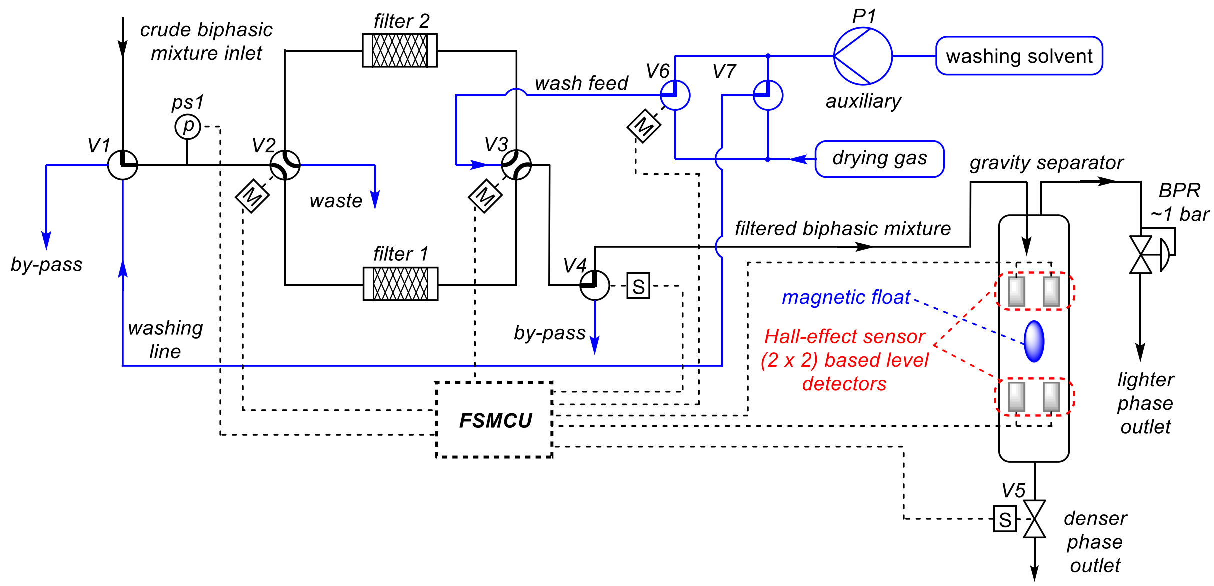

Figure 3. Detailed diagram of the Filtration and Separation module.

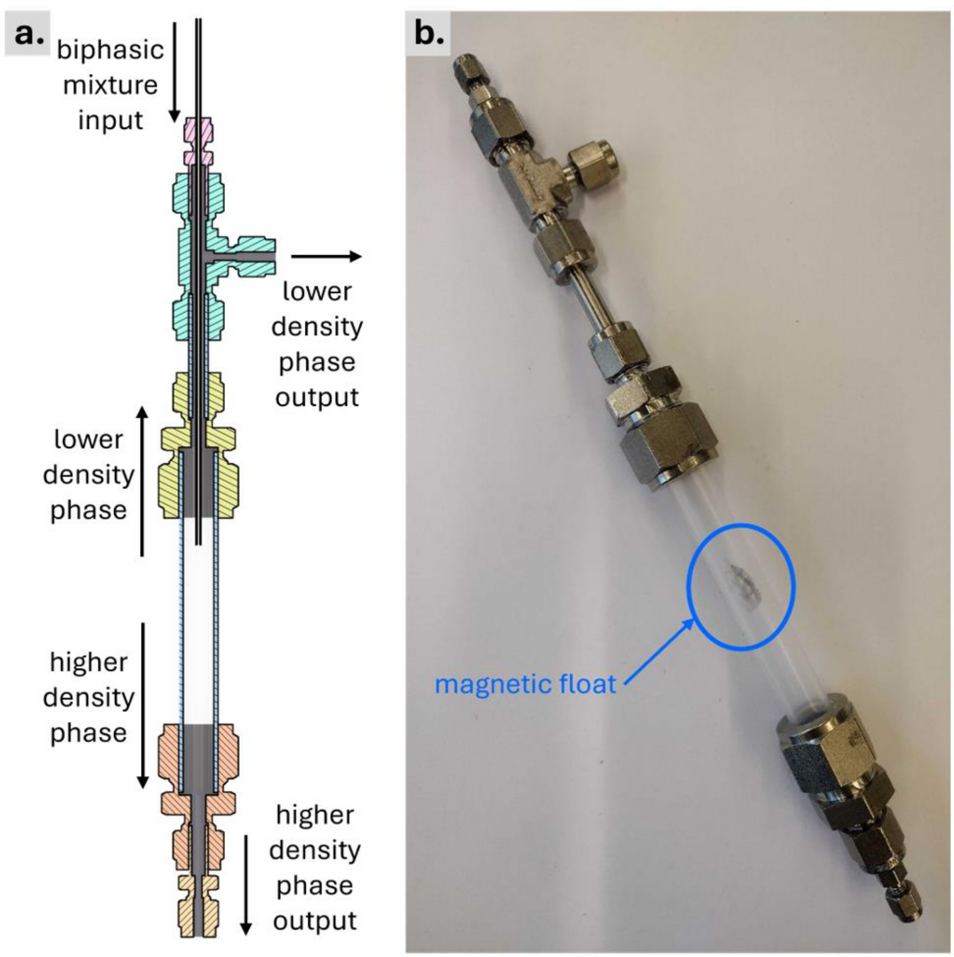

Figure 4. a. A schematic drawing of the separator column. b. A photograph of the assembled column using Swagelok components with the magnetic float visible inside. The transparent part is a piece of 1/2" PFA tubing.

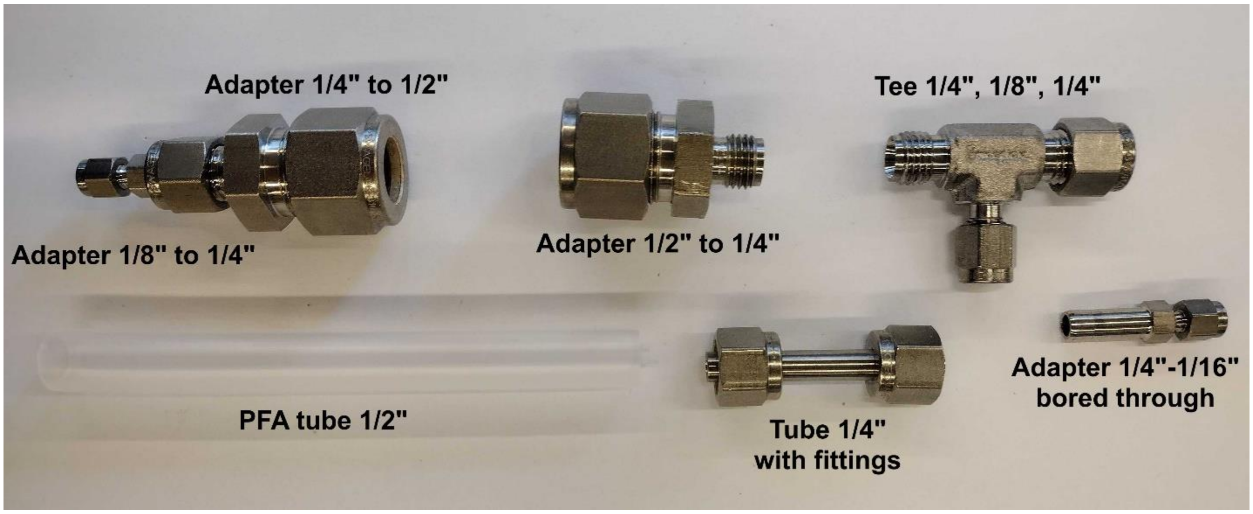

Figure 5. Components of the separator column. The 1/16 metal (stainless steel) tube is omitted.

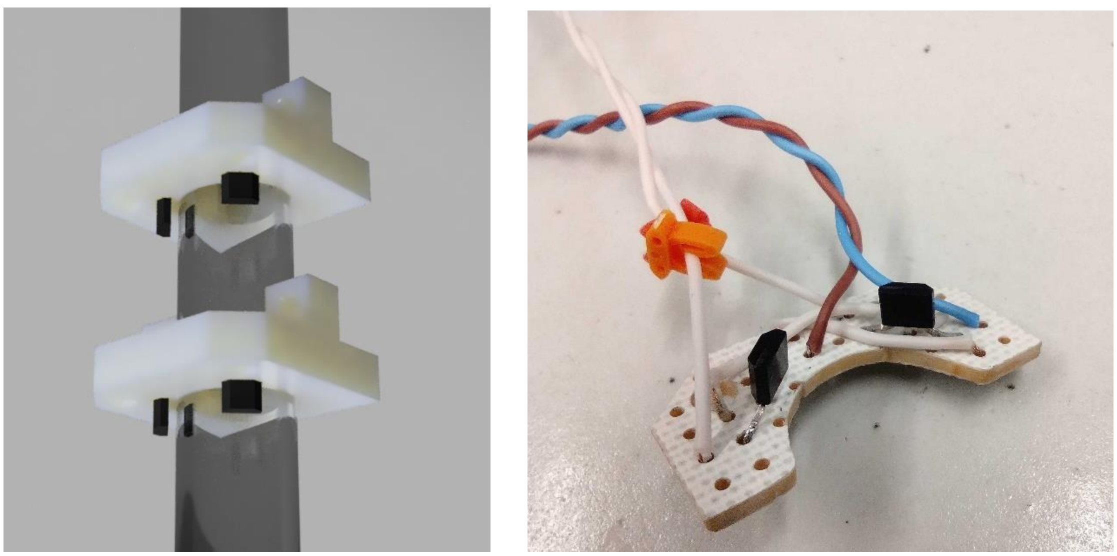

Figure 6. Left: 3D-designed drawing of the Hall-effect sensor holders. Right: Pair of Hall-effect sensors soldered to a prototype PCB board with a cut allowing to accommodate 1/2" PFA column.

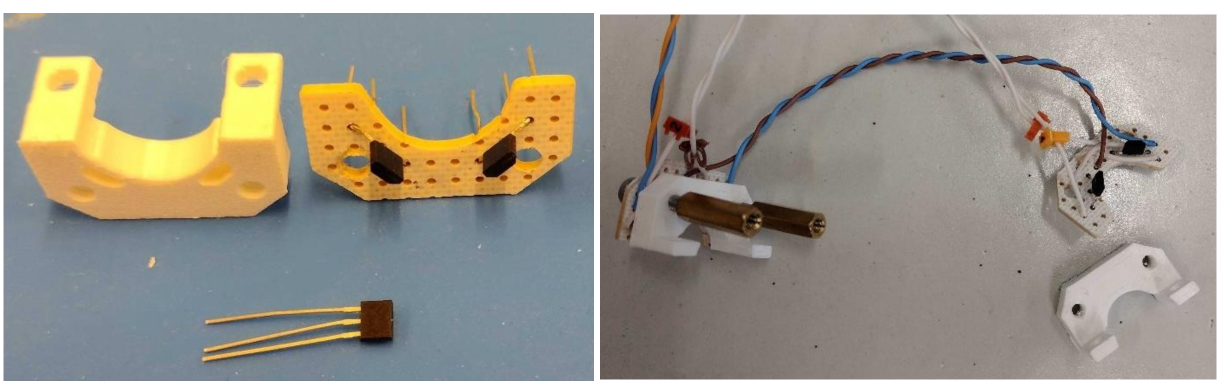

Figure 7. Left: 3D-printed Hall-effect sensor holder and the prototype PCB during assembly of the magnetic phase-boundary tracking system. Right: Final steps of the magnetic phase-boundary tracking system assembly.

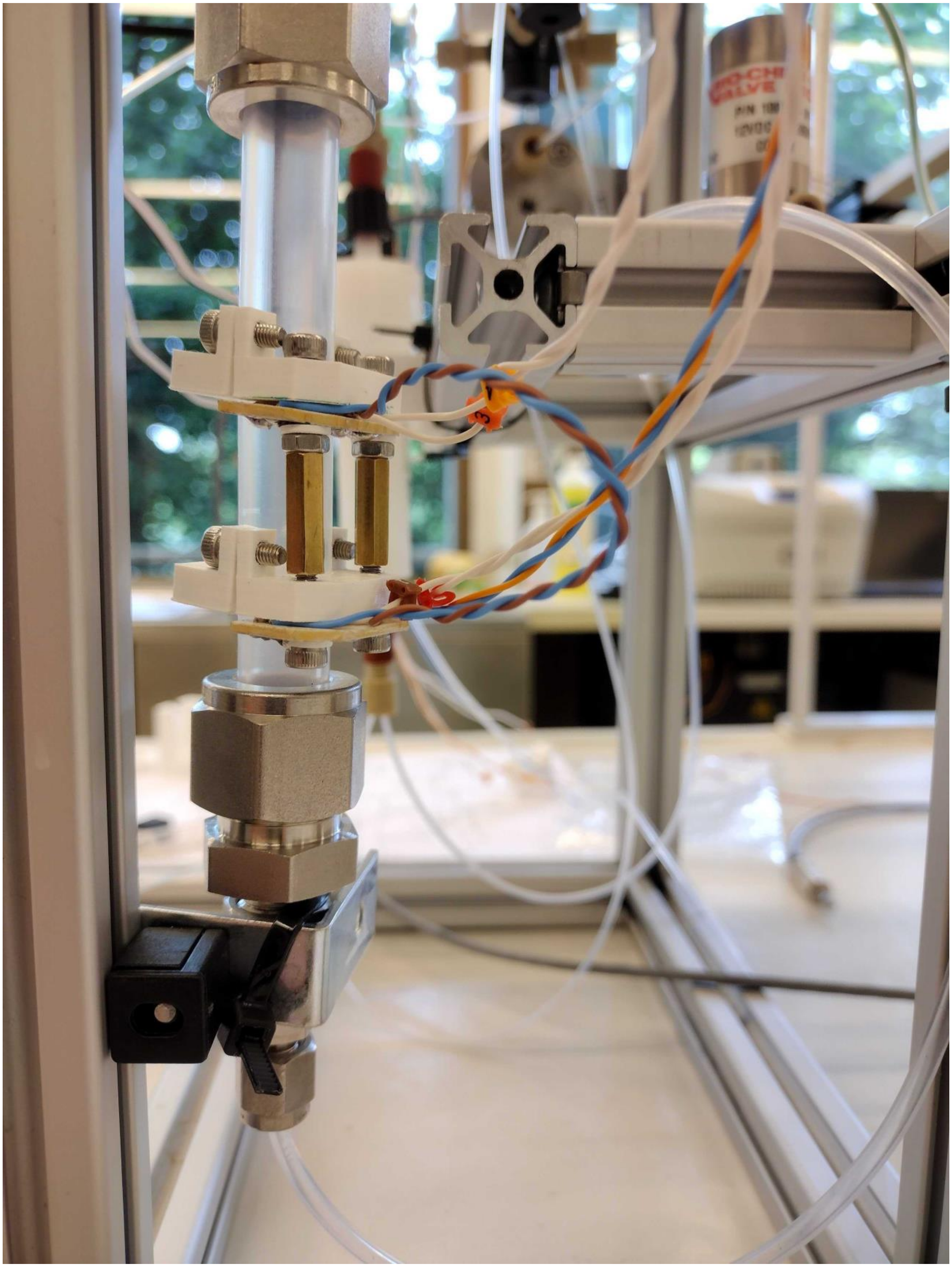

Figure 8. A photograph of the separator column with the complete Hall-effect sensor module (2 x 2 sensors) installed withing Filtration and Separation Module.

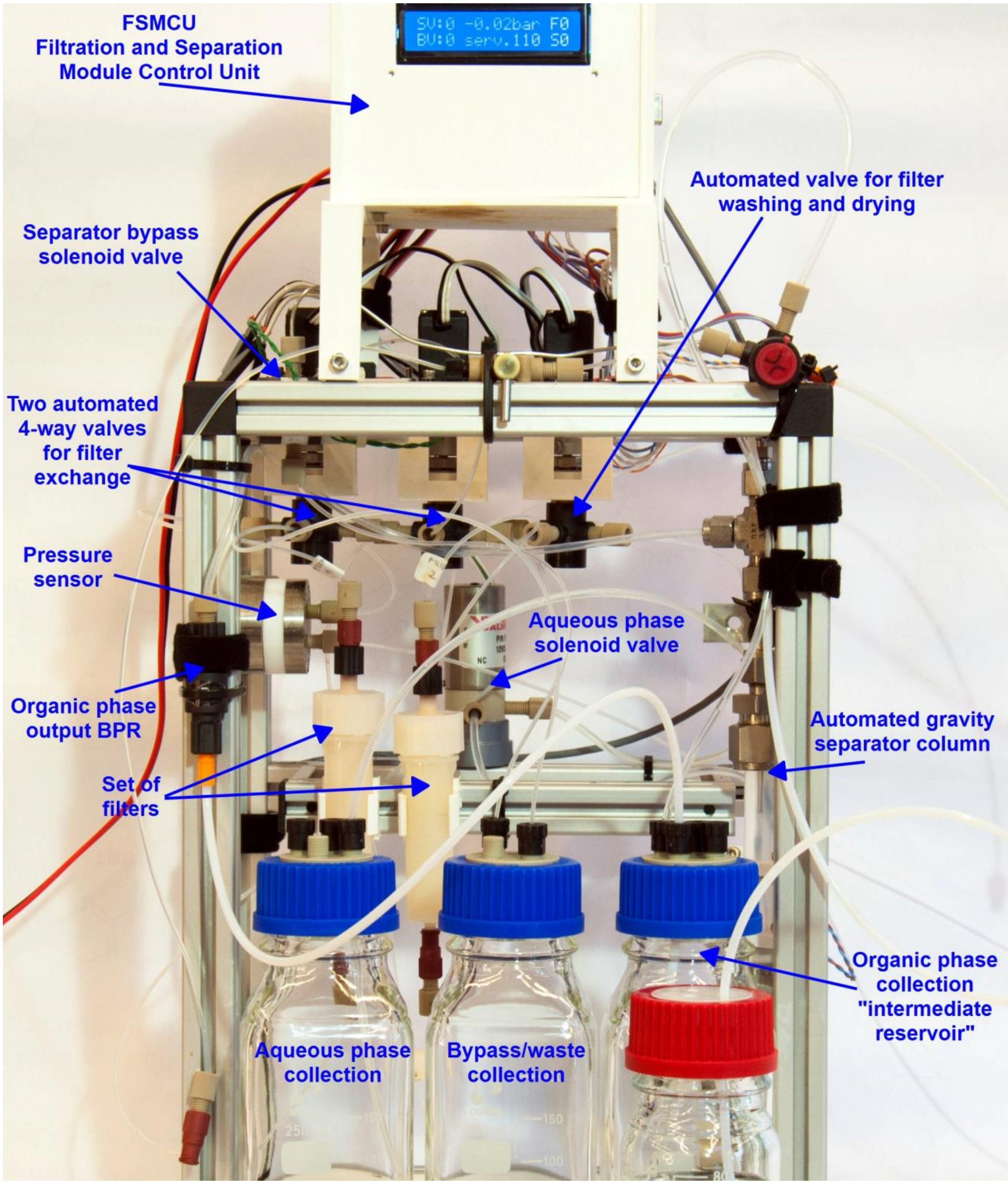

Figure 9. A photograph of the Filtration and Separation Module with descriptions (refer to diagram in Figure 3).

Description of the electronic parts – FSMCU

The FSMCU (Filtration & Separation Module Control Unit) is an Arduino Uno-based system responsible for processing and acquiring signals from the Hall-effect sensors and pressure sensor, as well as controlling the electrically actuated valves. Additionally, the FSMCU connects to a PC via serial communication, allowing remote control while providing real-time status updates on all its elements (4 Hall-effect sensors, 5 valves, and a pressure sensor).

The circuit diagram is provided in Figure 10. Instructions for setting the voltage dividers for AH49E linear Hall-effect sensors (adjusting the voltage level to obtain near-zero measurement from ADS1115 modules) are included in the diagram (Figure 10). Descriptions for configuring the DC-DC step-down converter are also provided.

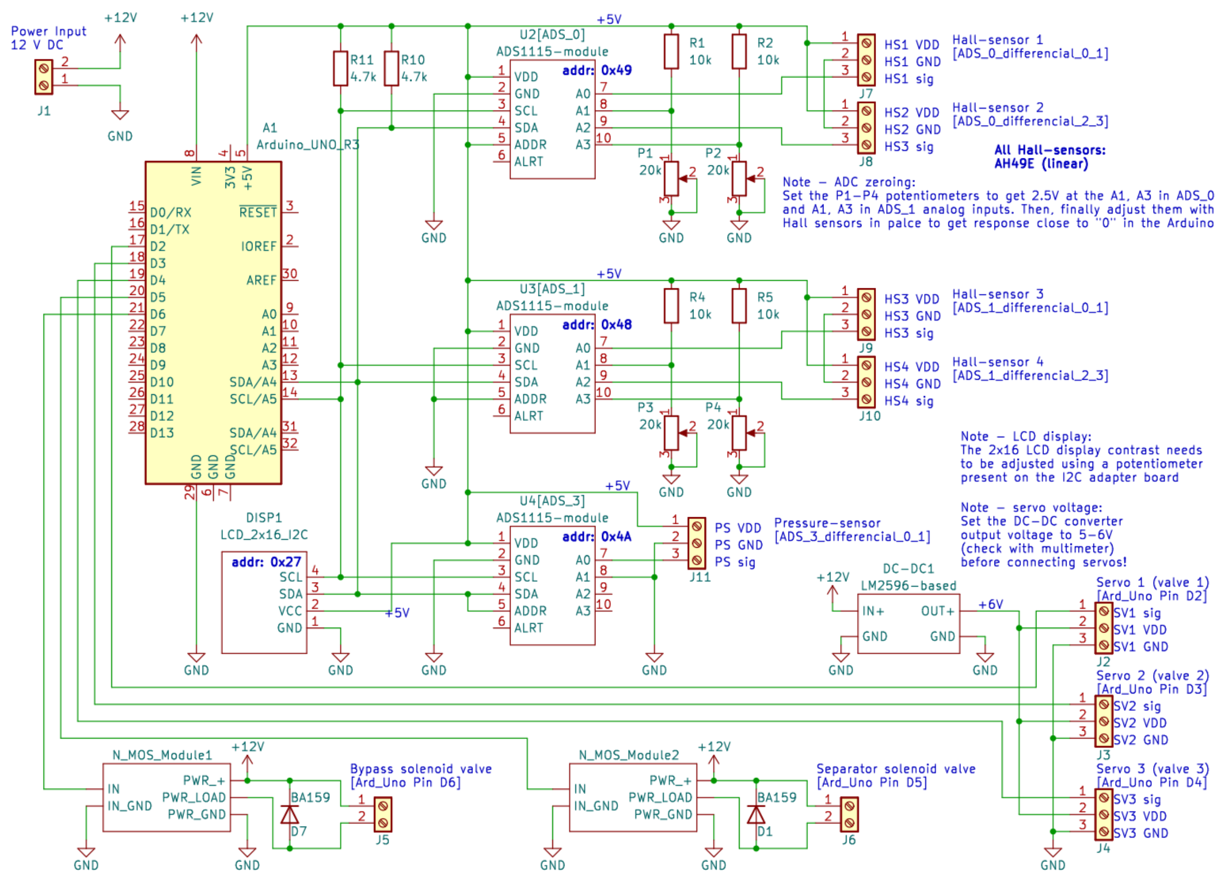

Figure 10. Electronic circuit diagram of FSMCU. The circuits were created using universl PCB ("matrix board"), thus no PCB design is available. This diagram is available within this repository in KiCad schematic format.

The electronics are housed in a custom-designed, 3D-printed case. The 3D files are available in this repository, along with mounting angle brackets that provide a more flexible way to attach the case to the main frame supporting the FSM.

See figures 11–18 for detailed views of the electronic circuit and 3D-printed housing. Attached photographs present how the electronic cirucuit was assembled using two prototype PCB boards.

The code for Arduino Uno is available within this repository (see "FSMCU_Arduino_code_V2_6")

Component list

Name	Type	Vendor
Arduino Uno Rev.3	ATmega328 based	AZ-Delivery
2x16 LCD module (with I2C interface)	HD44780 type with I2C-FC113 adapter	AZ-Delivery
ADS1115 module	4-channel, 16 bit ADC, I2Cinterface	AZ-Delivery
MOSFET module	FR120N based (max 9.4 A, 100 V)	Amazon
DC-DC Step-Down Voltage Converter Module	XL4015, 8-36V input, 1.25-32V output, max 5 A; set to 6V	AZ-Delivery
Multiturn potentiometer	20 k	Amazon
Resistors	10 k, 4.7 k	Amazon
Diodes	BA159	Amazon
Screw terminals	2.54 mm pitch	Amazon
Hall sensor	AH49E (linear, TO-92S package)	Amazon
Power Supply	Regulated Laboratory Power Supply, Hanmatek HM305	Amazon

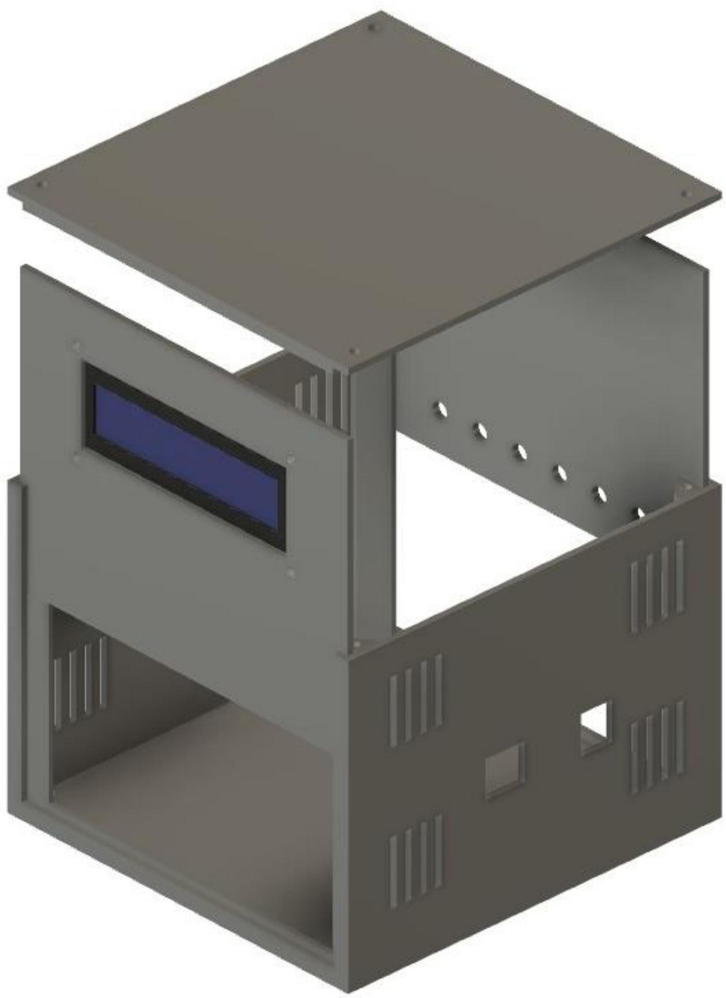

Figure 11. "Exploded" view of the 3D-designed housing for FSMCU.

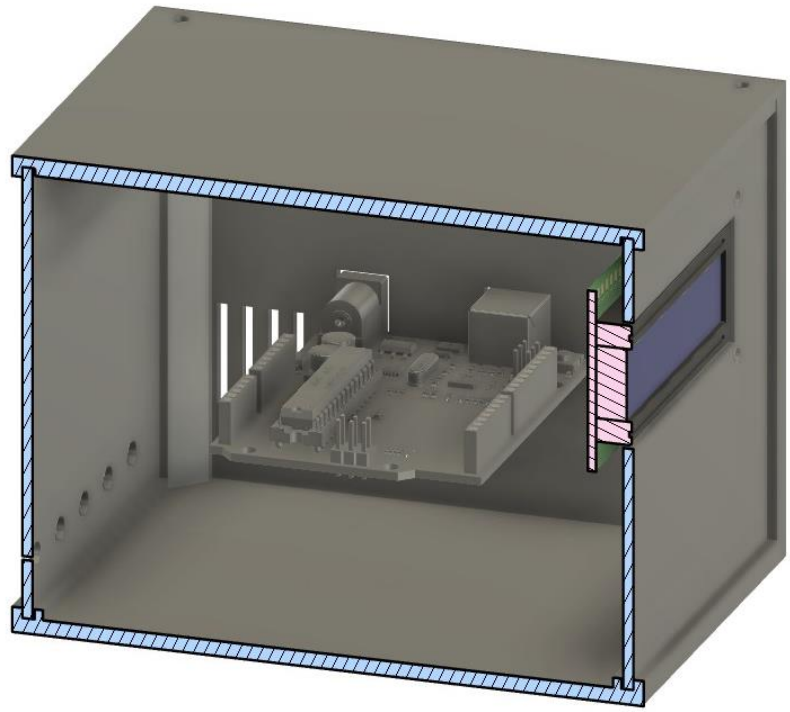

Figure 12. Cross-section view of the 3D-desinged housing for FSMCU.

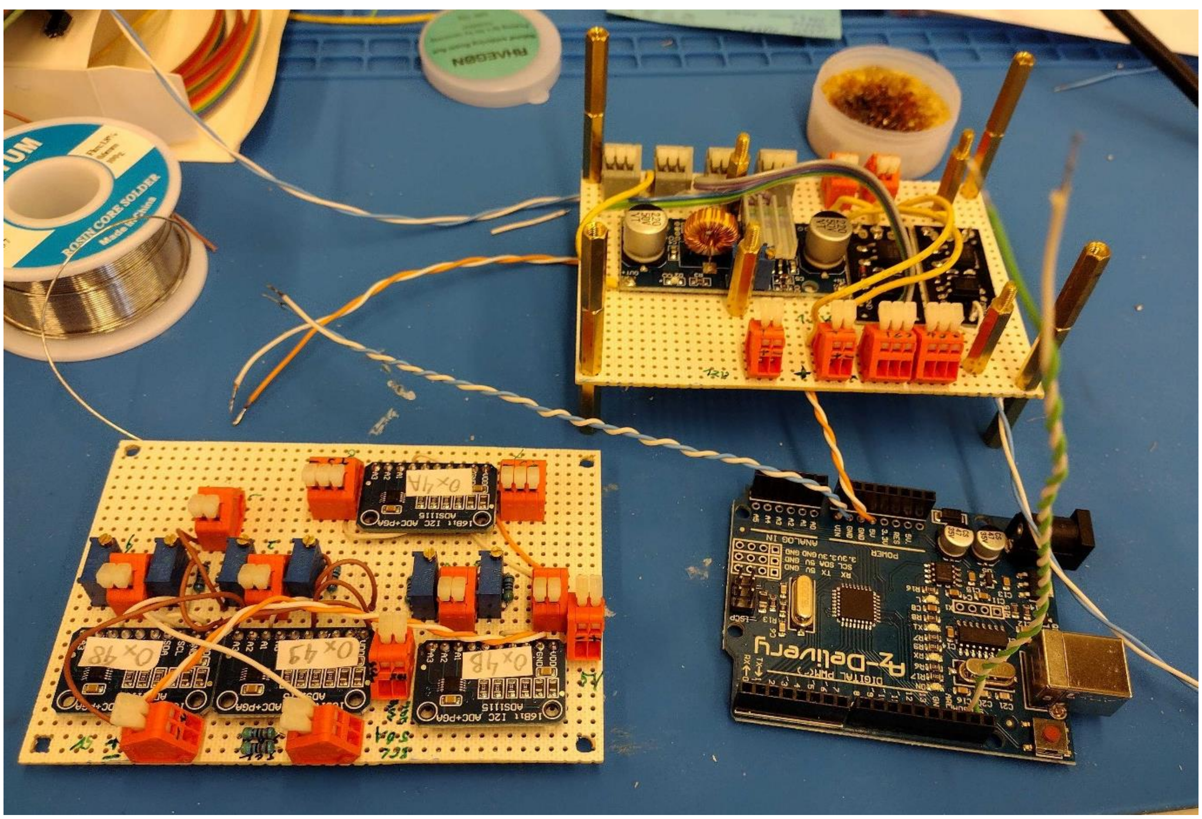

Figure 13. FSMCU circuits during construction, using prototype PCB boards. Connecting the Arduino Uno R3 clone and the two boards (top right – DC-DC converter and 2 MOSFET modules, bottom left – ADS1115 modules for Hall-effect sensors and pressure sensor signal measurements). The device was equipped with total 4 ADS1115 modules for possible additional features (not included on the circuit diagram and finally not used).

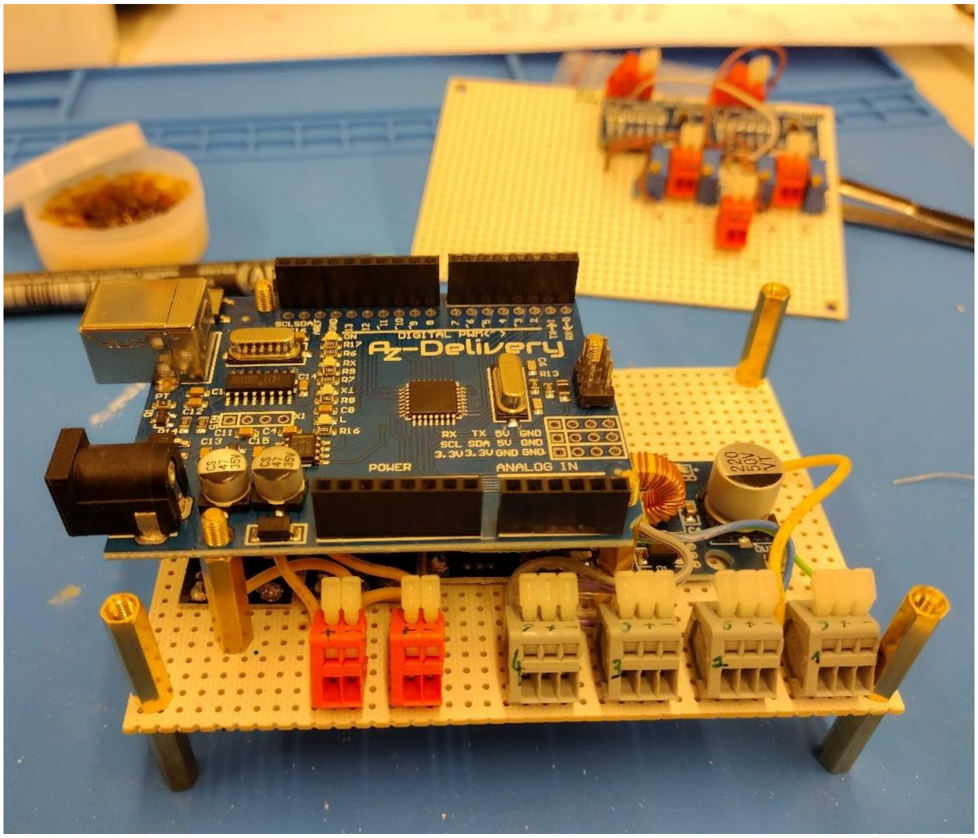

Figure 14. FSMCU circuits during construction, using prototype PCB boards.

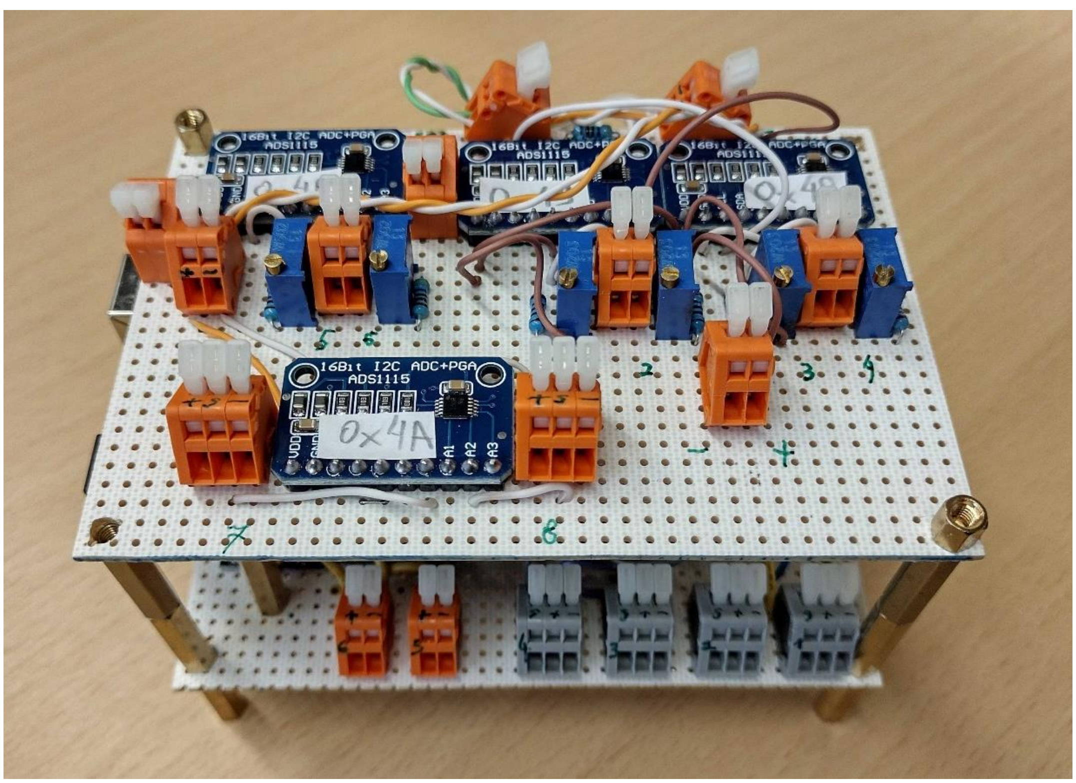

Figure 15. The FSMCU build on prototype PCB before installation within its custom-made housing.

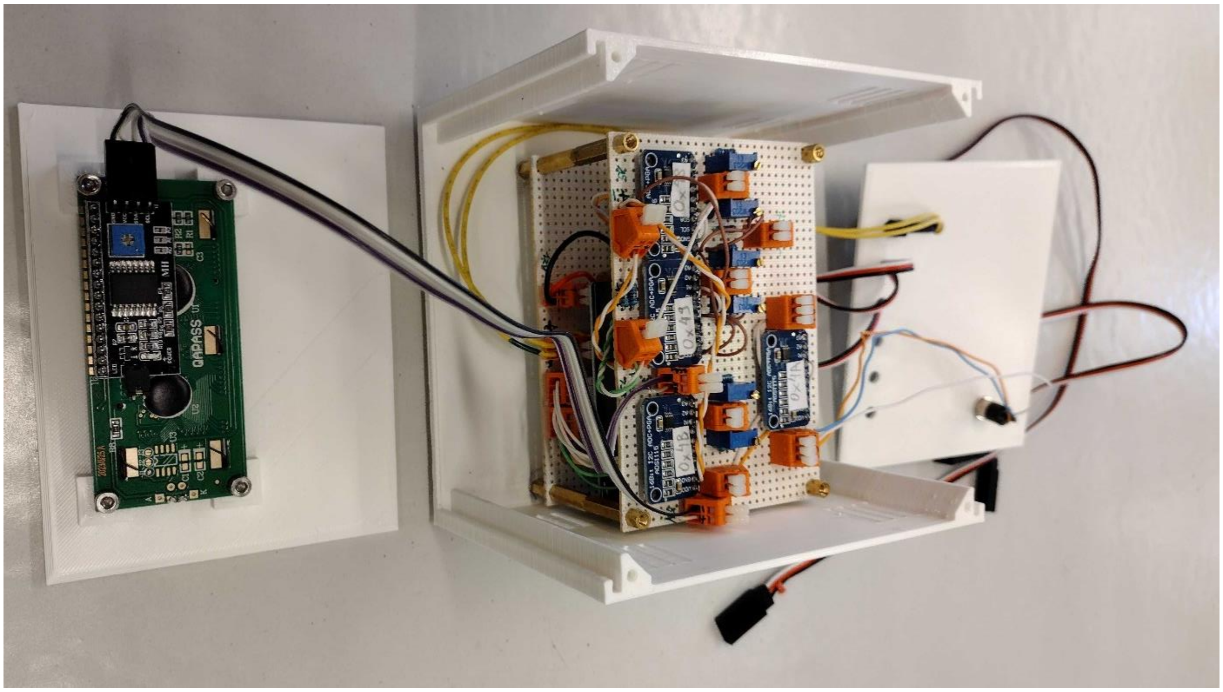

Figure 16. FSMCU during installation in the 3D-printed housing.

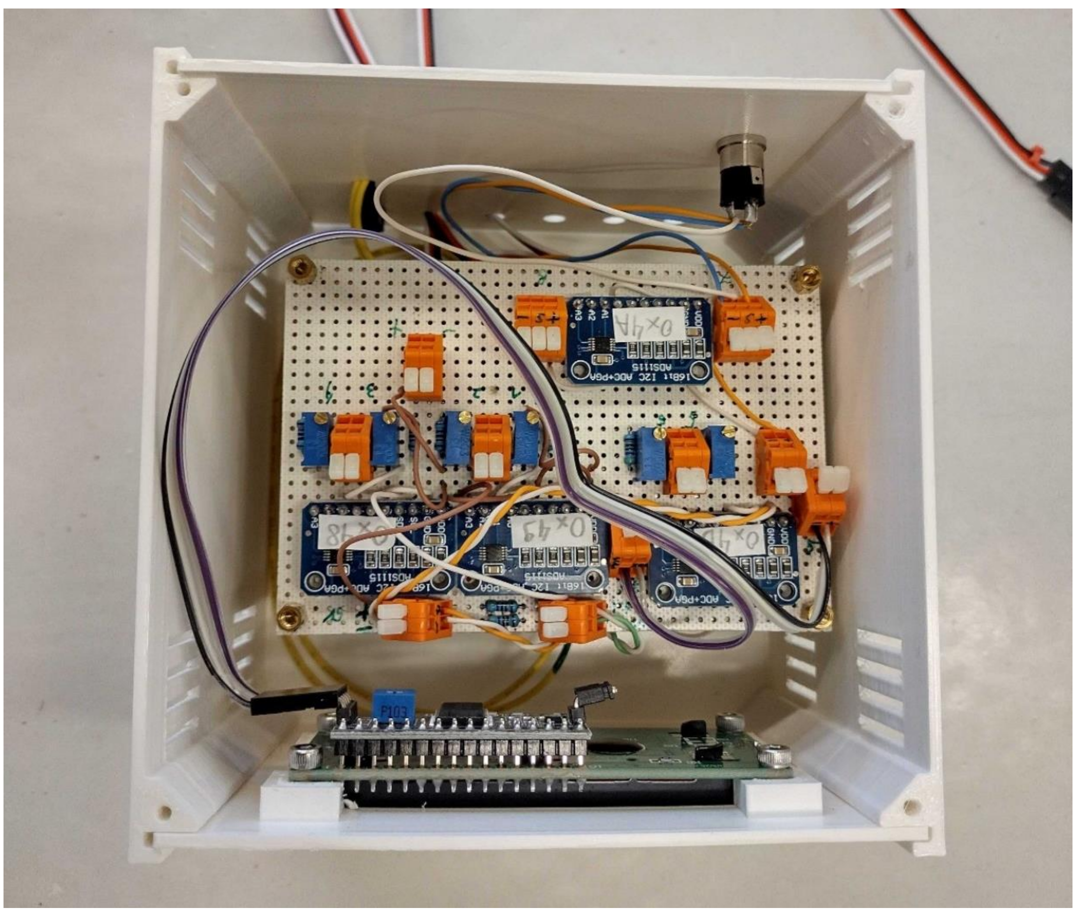

Figure 17. FSMCU installed in the housing.

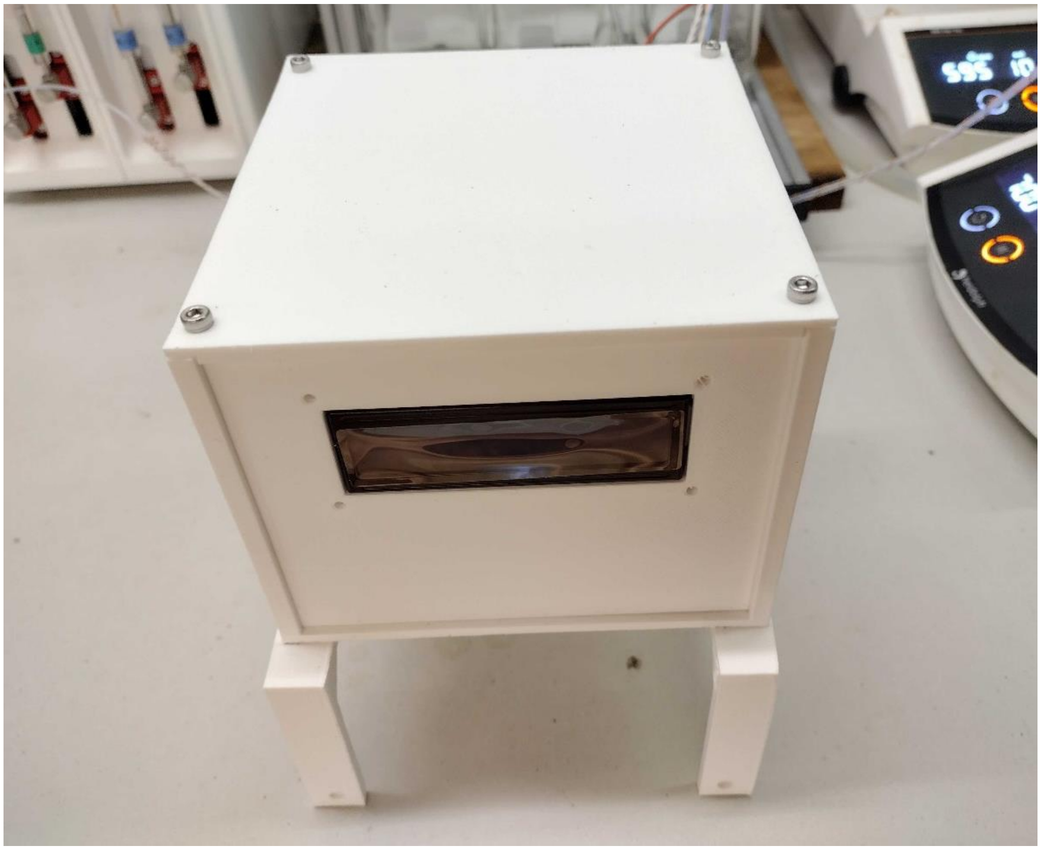

Figure 18. FSMCU installed in the housing.

Example of implementation

A detailed description and example application of this system were published in the research paper "*A Continuous Flow Generator of Acetyl Nitrate for the Synthesis of Nitrofuran-Based Pharmaceuticals*", H. Hellwig et al., in Angewandte Chemie (2025). A full reference can be found in the README.md file on the main page of this repository. Additional details, including the construction of the separator column, are available in the supporting information accompanying the publication.

Acknowledgements

This research was supported by the U.S. Food and Drug Administration under the FDA BAA-22-00123 program, Award Number 75F40122C00192. The authors acknowledge the University of Liège and the “Fonds de la Recherche Scientifique de Belgique (F.R.S.-FNRS)” (Incentive grant for scientific research MIS under grant No F453020F, JCMM).