A Conceptual and Architectural Framework for Remote Laboratories in Engineering Education: Pilot Implementations in Electrical Engineering

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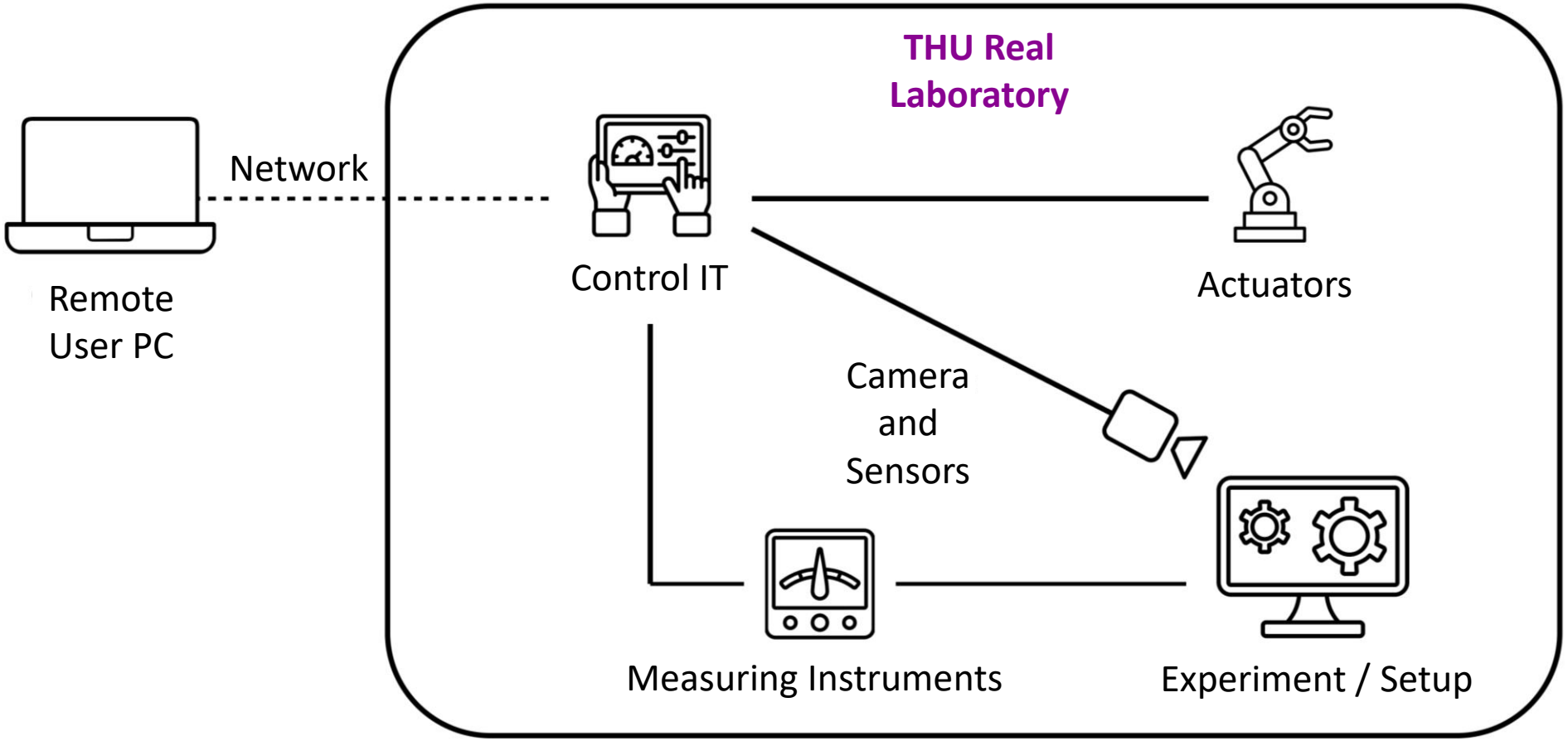
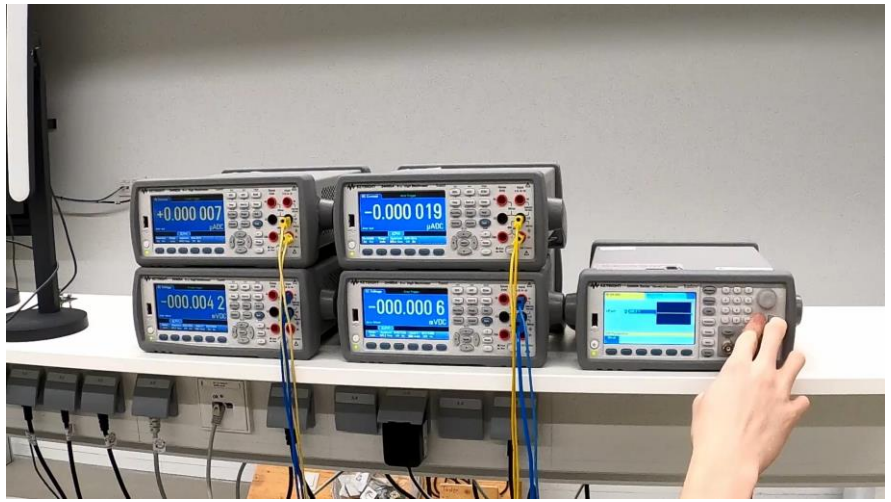
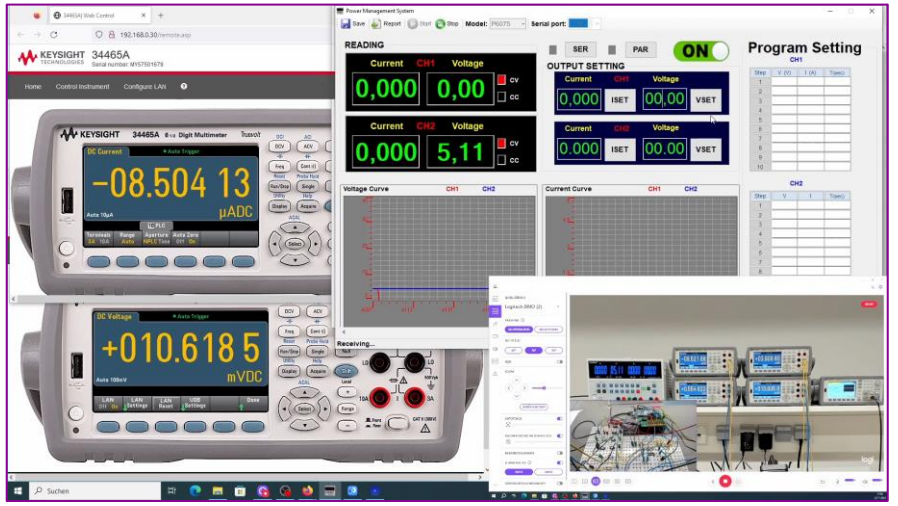
DiLa Digitalisierung in der Labordidaktik

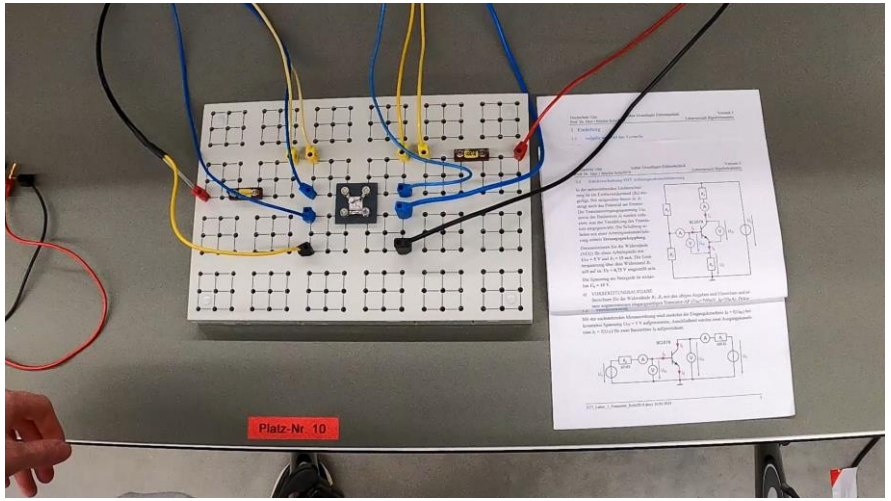
DiLa „Lab as a Service“ – remote control approach



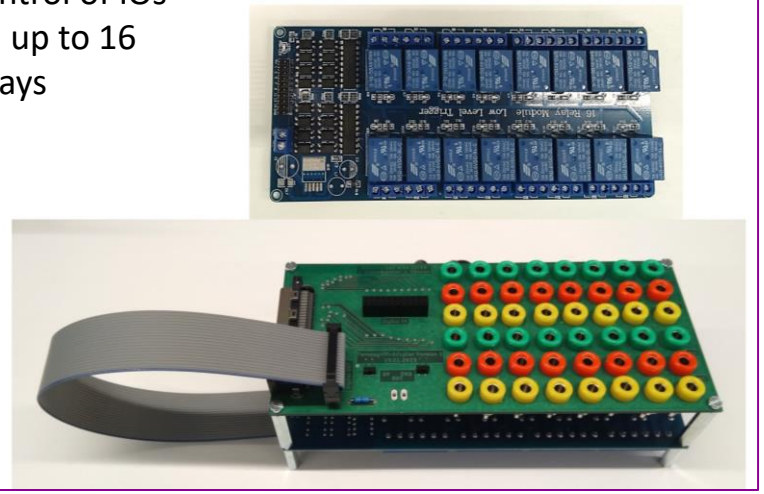
Pilot Implementations in Electrical Engineering





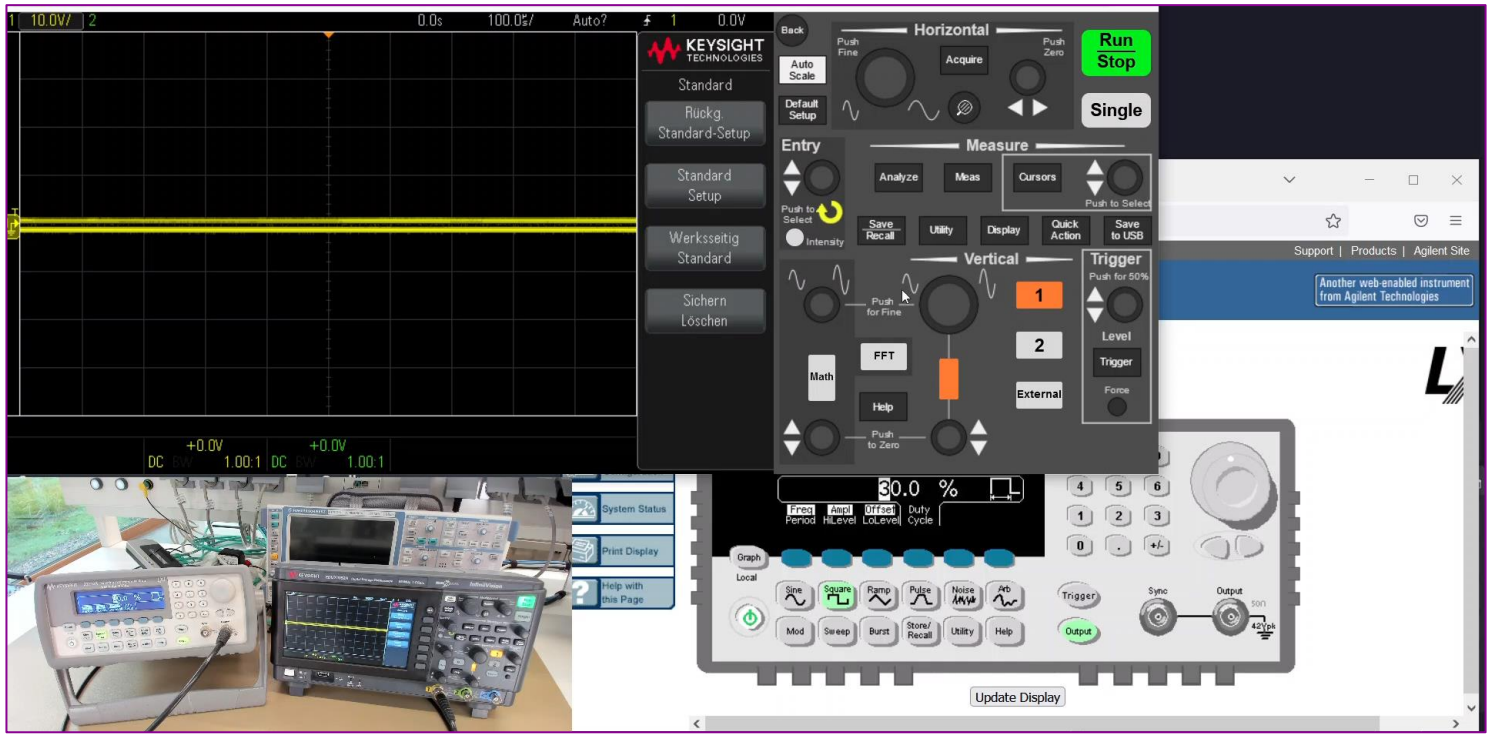


Control of IOs via up to 16 relays



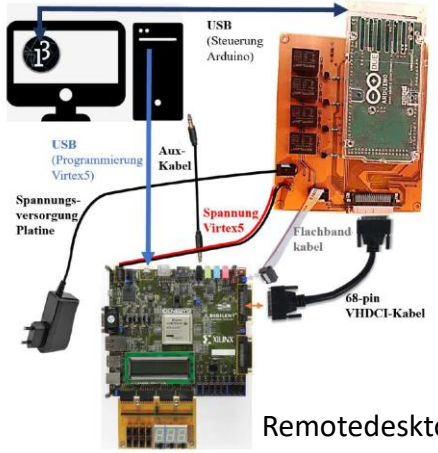
Pilot Implementations in Electrical Engineering

In this lab, students will learn how to use the measuring instruments (function generator and oscilloscope).
The image shows the view students see during remote access:

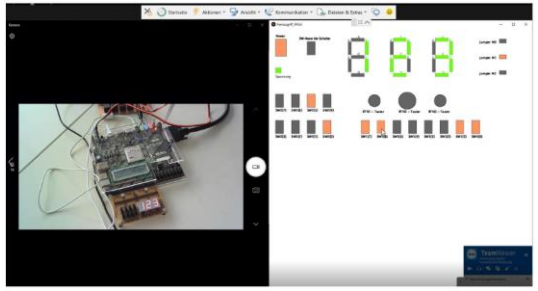


The devices are represented with control and display systems that are identical to their real-world counterparts.
Remote operation is intuitive and performed using the mouse.
To provide situational awareness of the equipment even from a distance, a live video of the setup is shown (bottom left of the image).

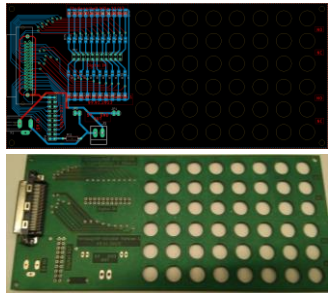
The development steps

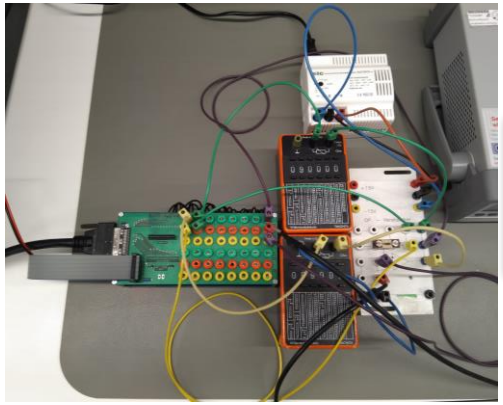


Remotedesktop-App

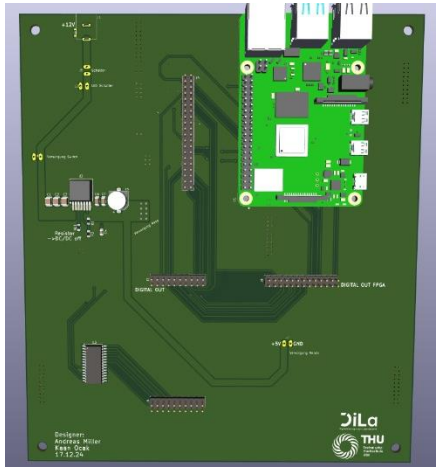


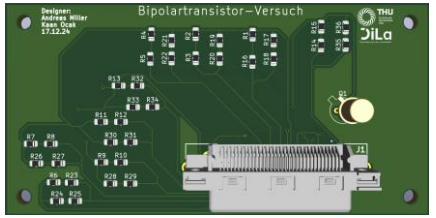
Project Haller/Riedinger





Project Hohenbleicher/Gökmen



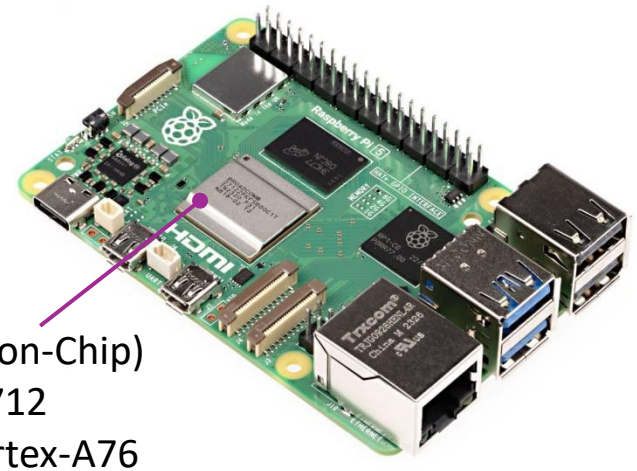


Project Miller/Ocak

2021 2023 2024

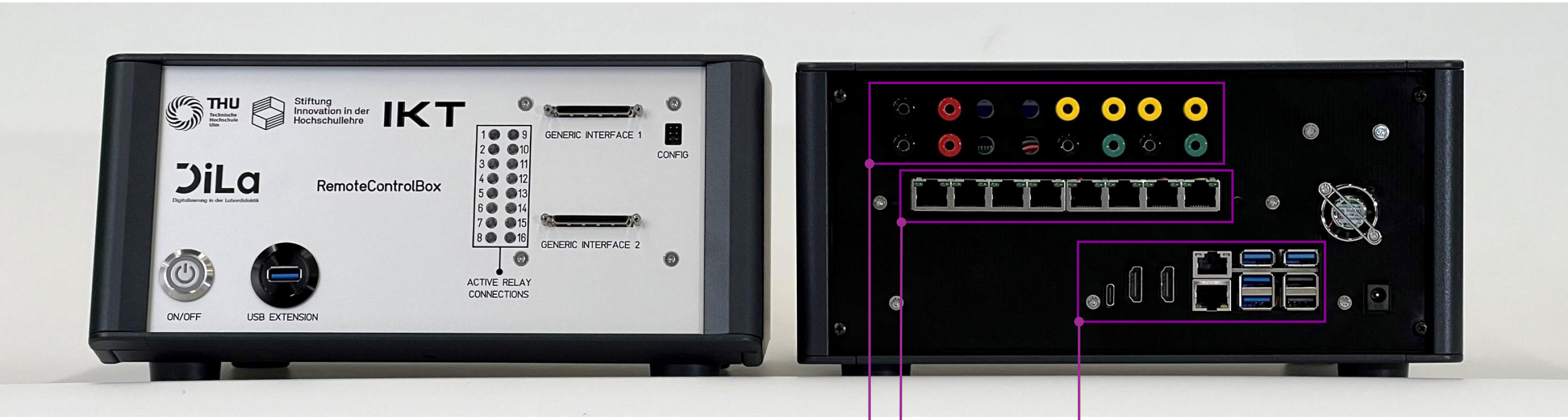
DiLa RemoteControlBox

- This unit was developed as a prototype within the framework of DiLa.
- It has LAN and WLAN connectivity and can connect to the overlay network.
- Two generic VHDCI interfaces with up to 40 general-purpose IOs.
- Control of IOs via up to 16 relays.
- Based on the Raspberry Pi 5 microcomputer:

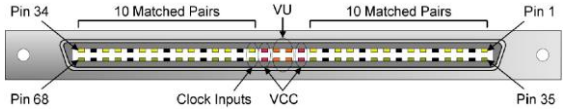


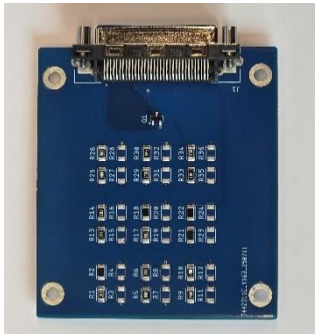
SoC (System-on-Chip)
BCM 2712
4 x Cores Cortex-A76

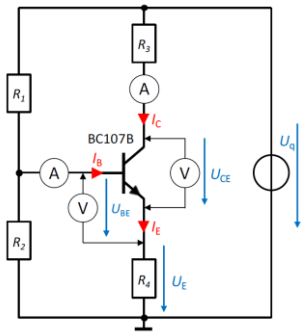
DiLa RemoteControlBox



VHDCI connection





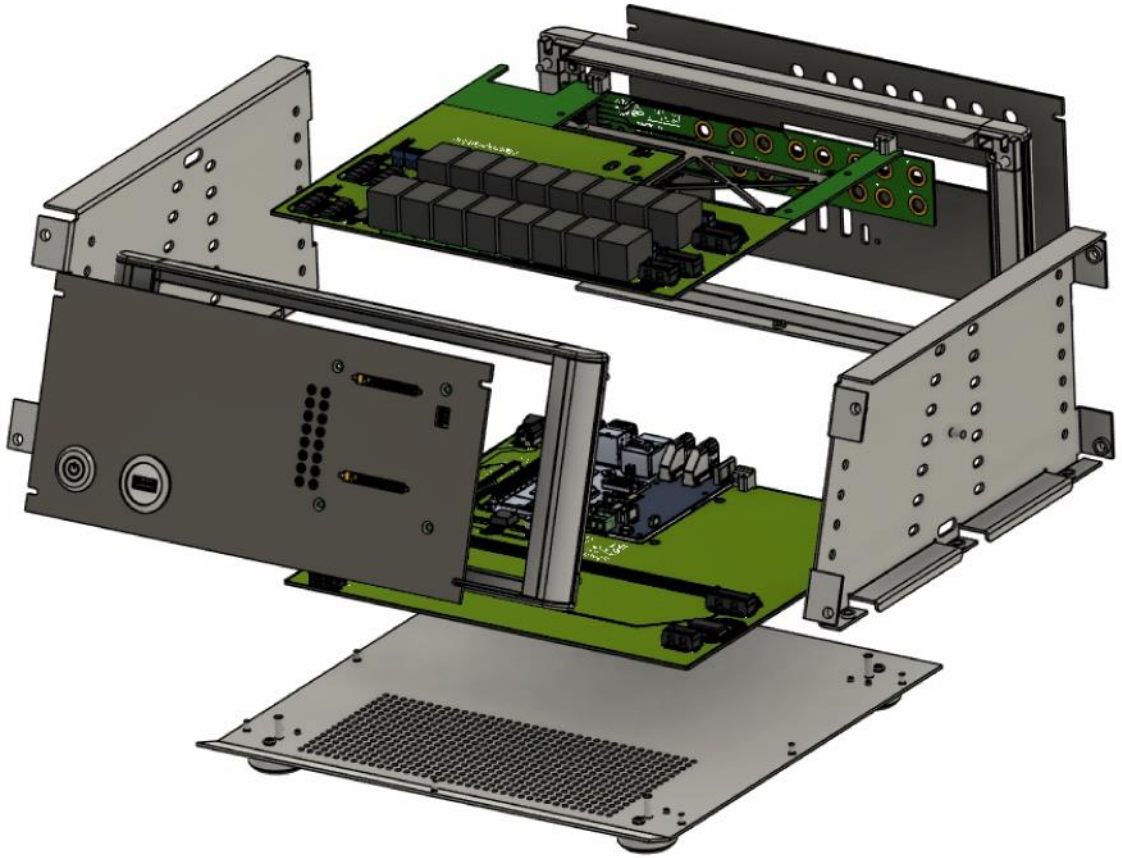


Connectivity of the RemoteControlBox

LAN connections for the remote control of measuring devices

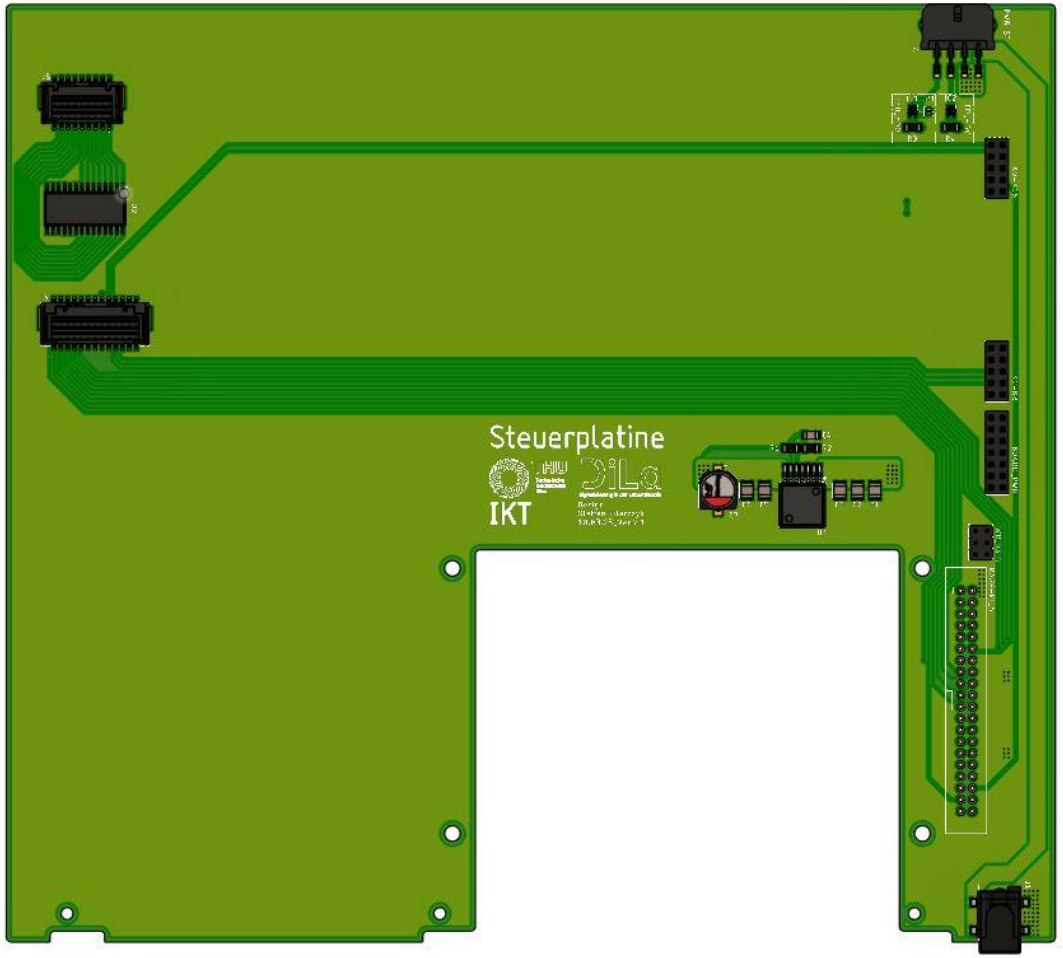
Connection of the measuring cables

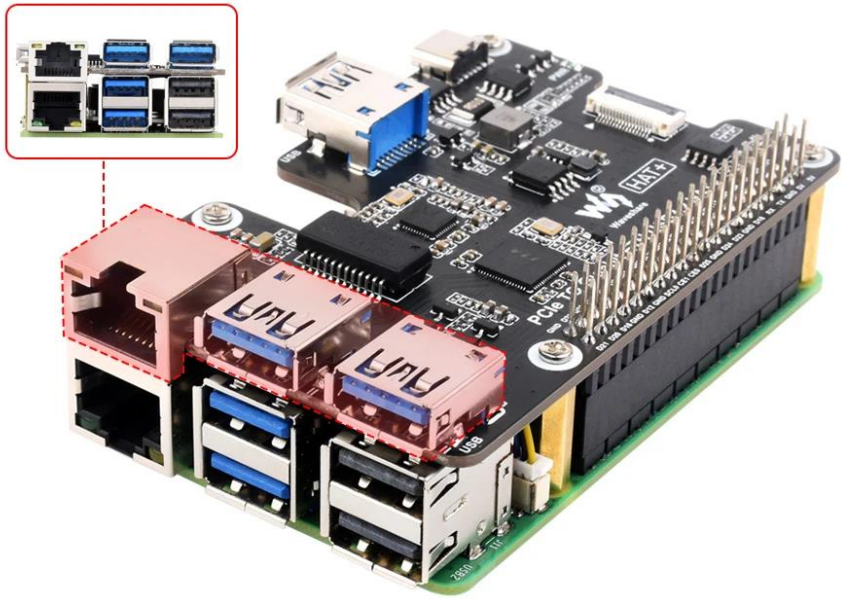
DiLa RemoteControlBox



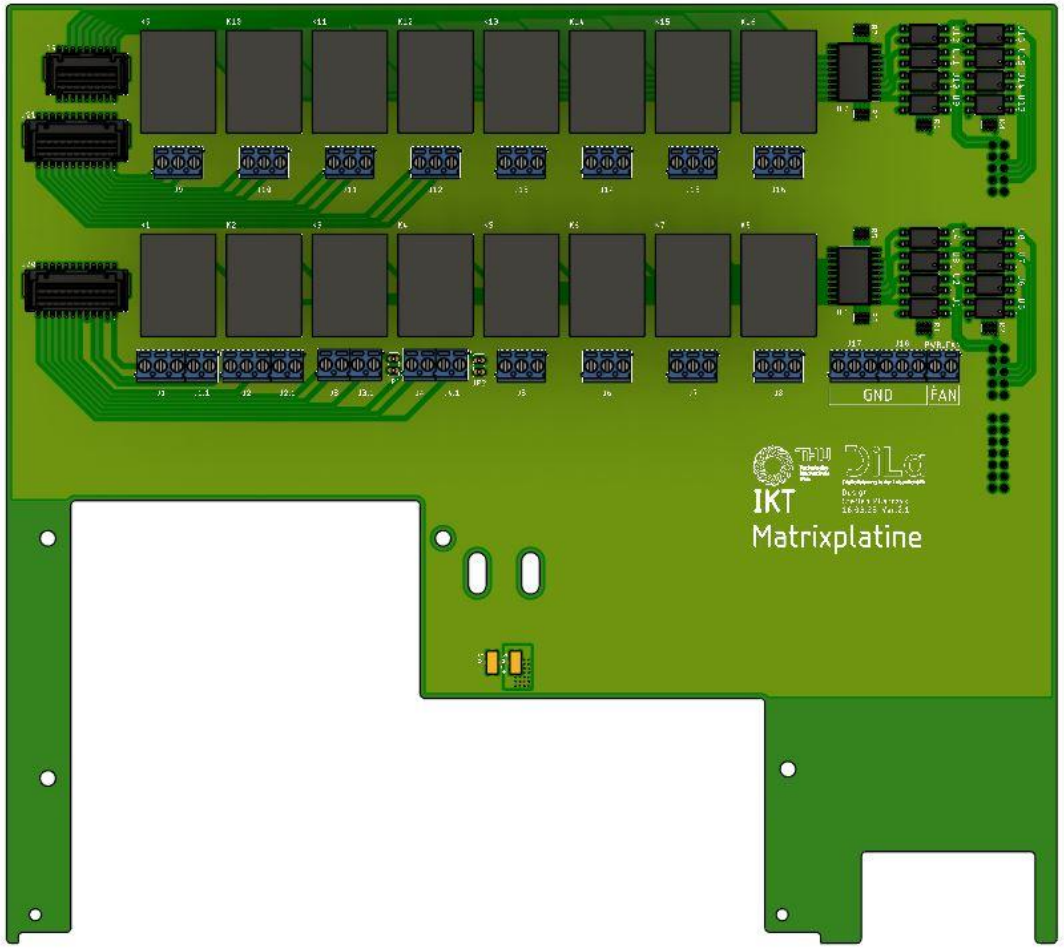
Animation & CAD: S. Pilarczyk IKT/THU

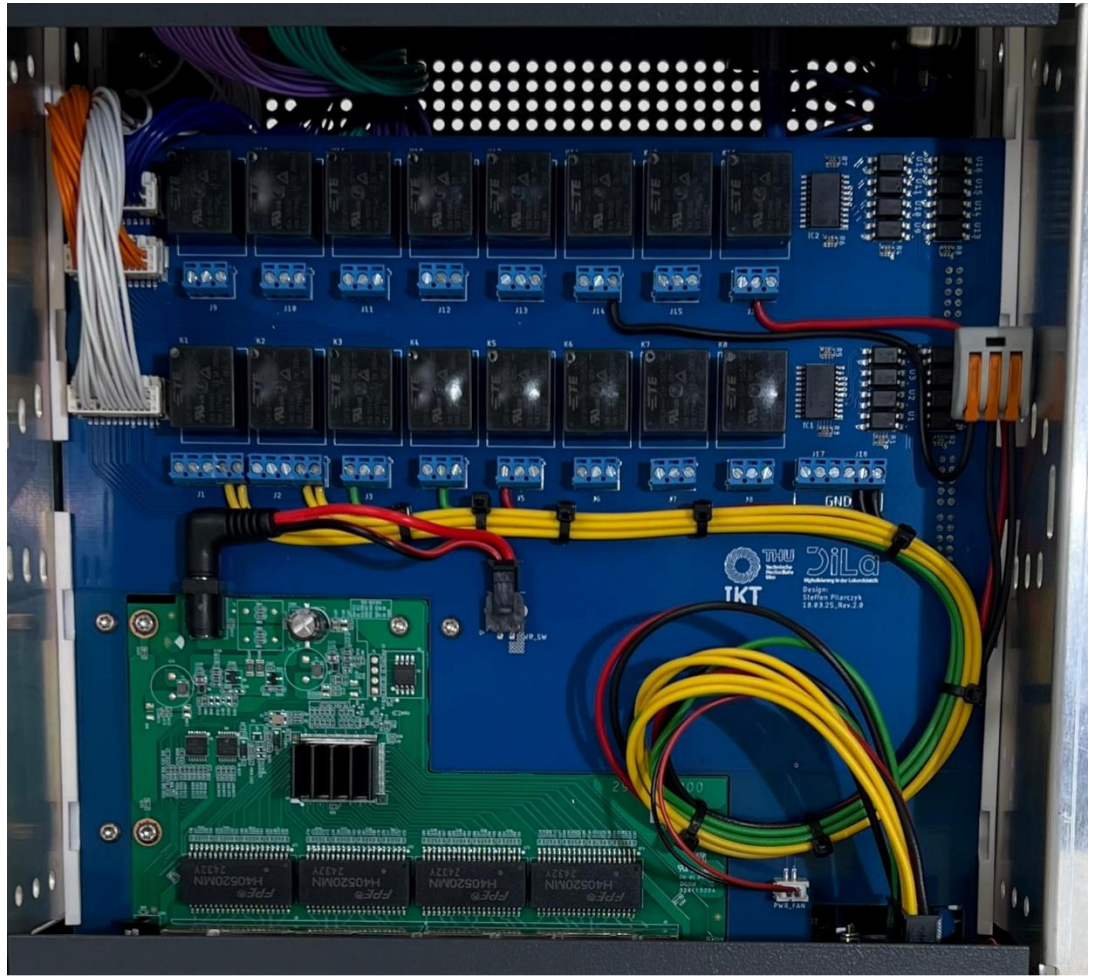
Control-PCB



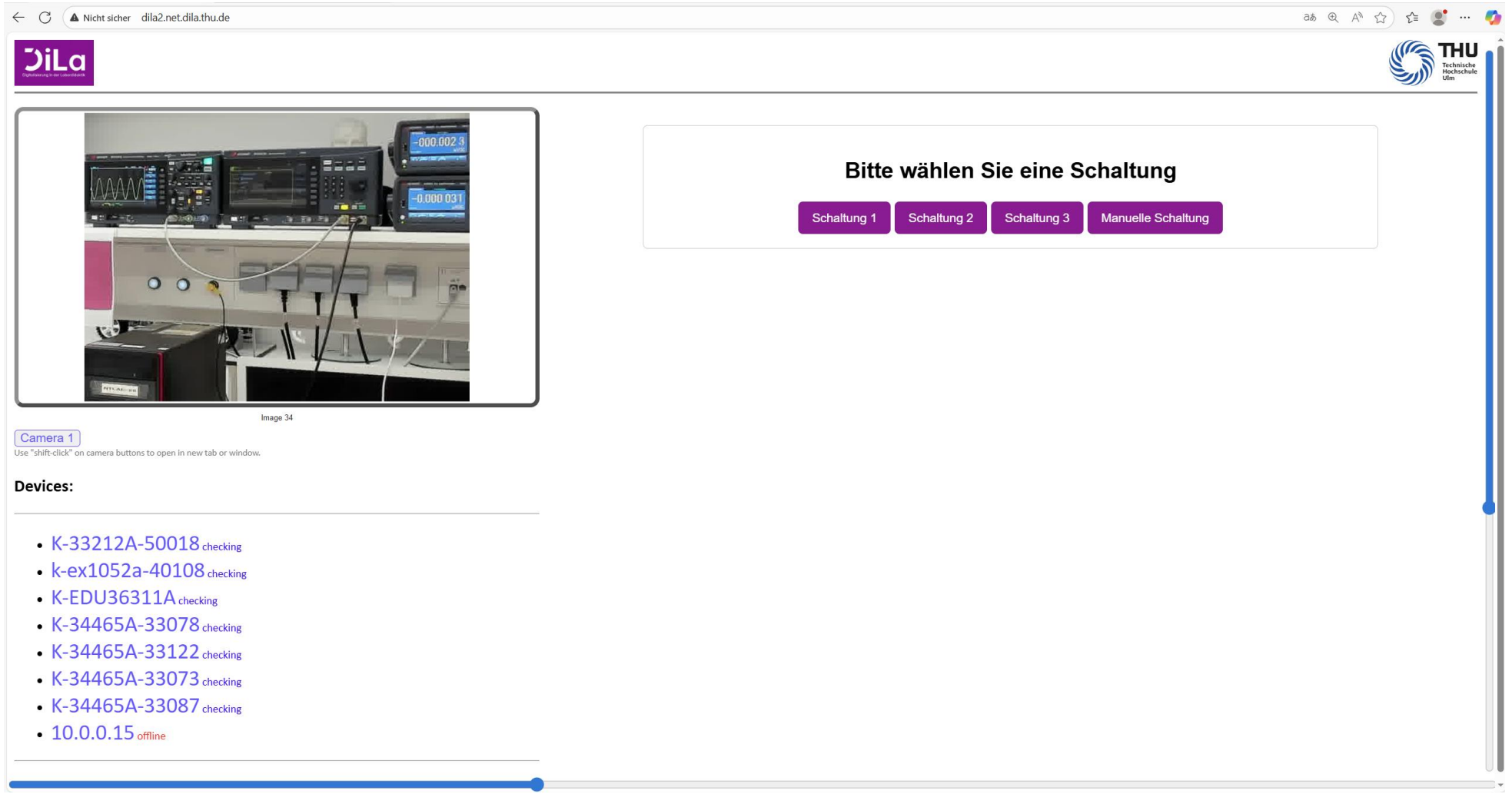


Matrix-PCB

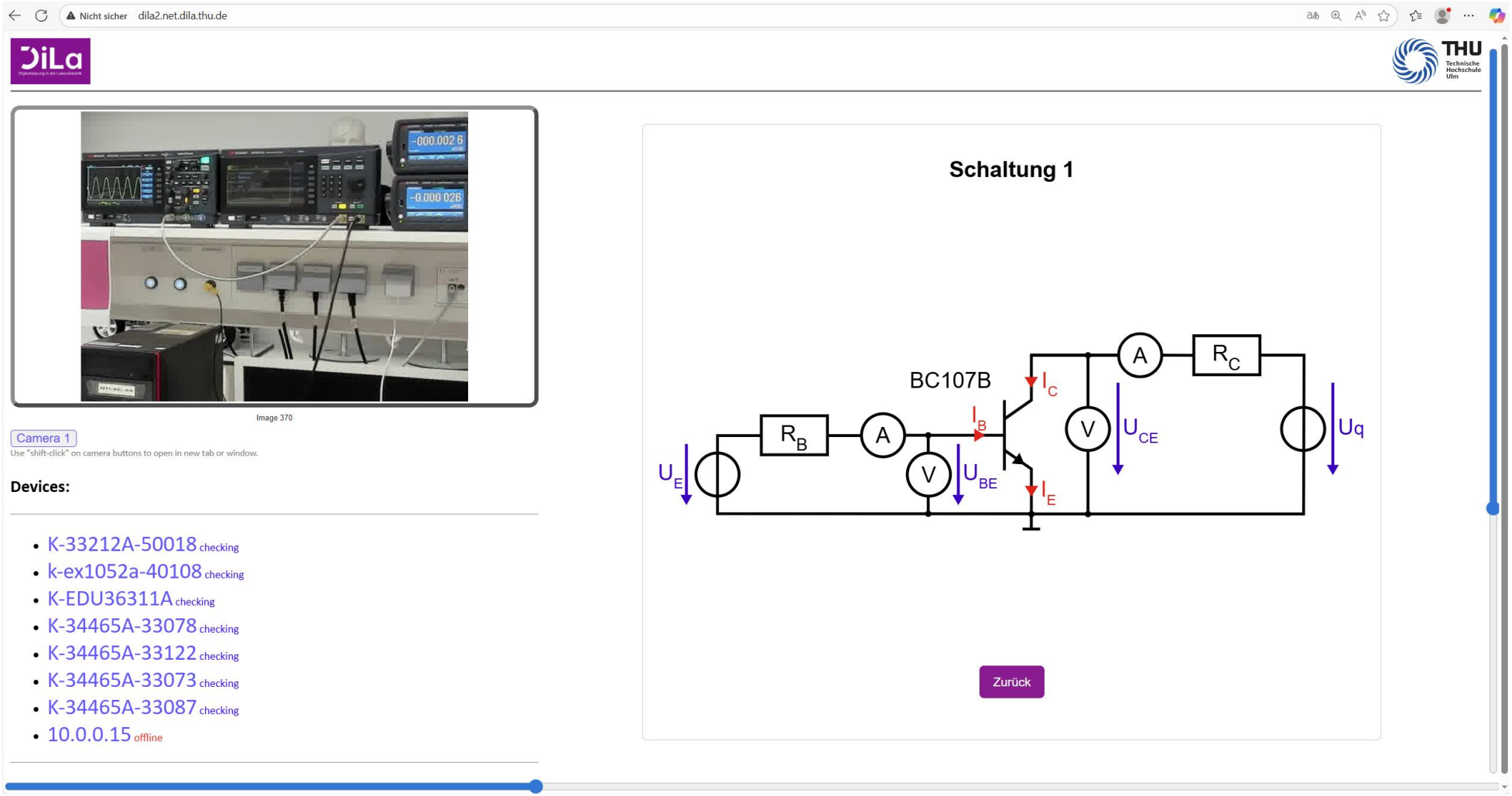




Example Frontend



Example Frontend



DHCP

Frontend

DHCP-Server

10.20.0.10/24

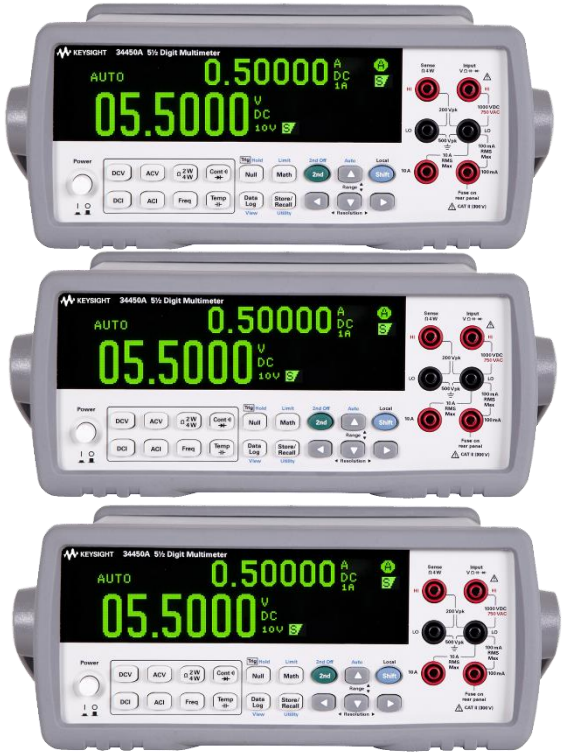
10.20.0.11/24

10.20.0.12/24

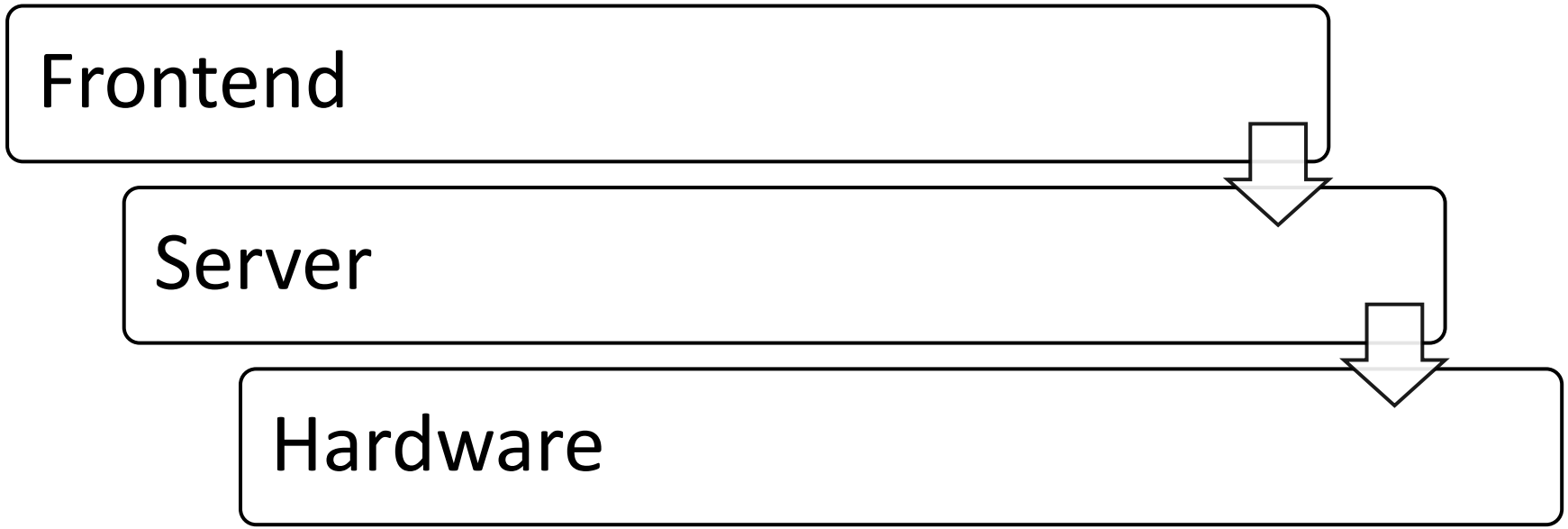
Measuring device 1

Measuring device 2

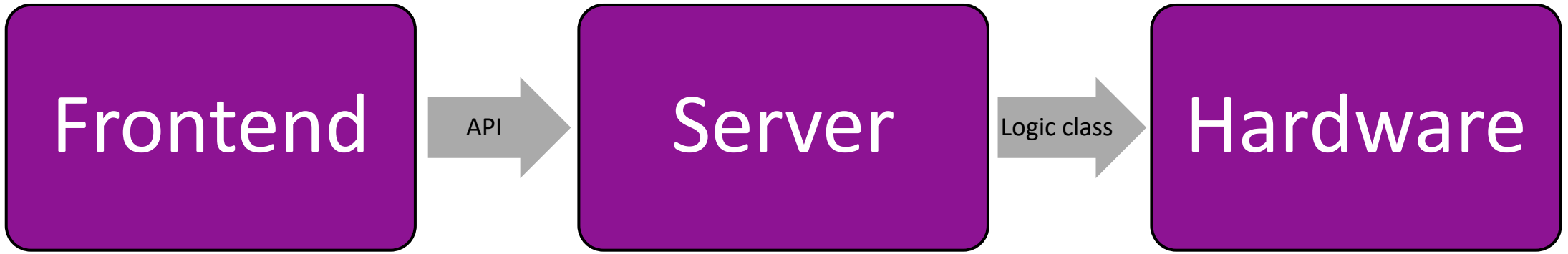
Measuring device 3



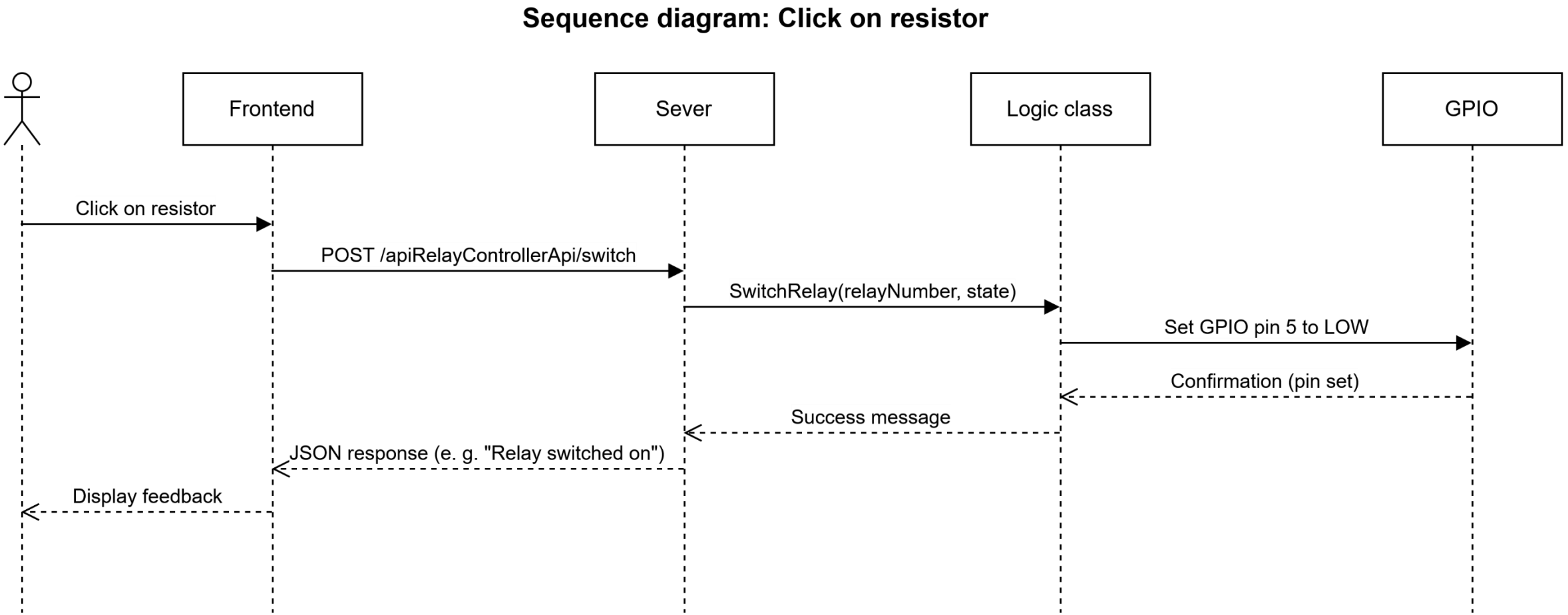
Architecture of the Software application



Concept Software communcation



Example



Results

Methodology:

- Exploratory qualitative pilot study with a small sample of electrical engineering students.
- Mixed approach combining questionnaire-based data collection and semi-structured interviews.
- Questionnaire used to systematically capture user experience and perceived learning outcomes.
- In-depth expert interviews (conducted by experienced professors) to interpret and validate the findings.
- Objective:
  Generate initial insights into the effectiveness and acceptance of digital lab didactics within the DiLa project.

Results
Methodology

Laborversuch: Digitales Oszilloskop und Signalgenerator

1. Einleitung

Das Symbol ▶ weist auf eine Hilfestellung in Form eines Videos aus der PowerPoint “Versuchsanleitung: Bedienung der Laborgeräte” hin.

1.1 Ziel des Versuches

Der Versuch soll die Funktionen des Signalgenerators und des Digitaloszilloskops vermitteln. Dabei sollen Kenngrößen verschiedener Signale vertieft werden.

Im Versuch kommen folgende Geräte zum Einsatz:

Digitales Oszilloskop:	Keysight EDUX1052A
Signalgenerator:	Keysight EDU3312A

Allgemeiner Hinweis zum Signalgenerator:

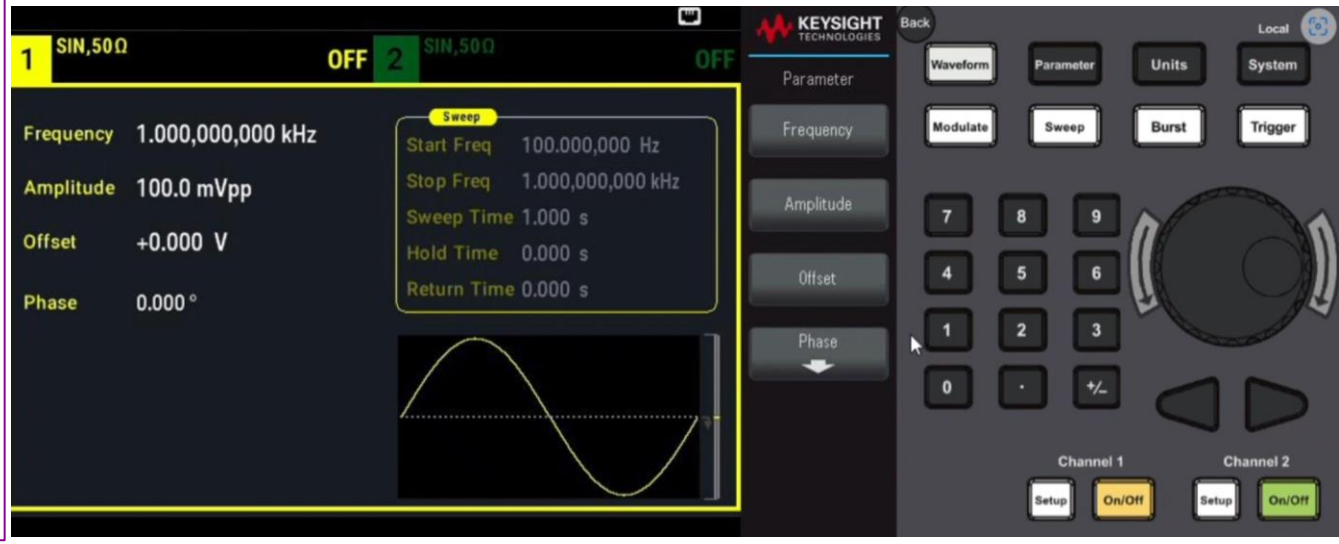
Der Signalgenerator ist standardgemäß auf einen Innenwiderstand von 50 Ω eingestellt.

Stellen Sie den Innerwiderstand auf niederohmig ein:

“Setup (Channel 1) – Output Load – High Z“

▶ Folie 4 „Einstellen der Ausgangslast“

The lab instructions now include links to explanatory videos for each step.
For example, the video shows the settings in the devices' submenus.
An AI-generated voice provides additional audio explanations.



Project Work 2026: Bolsinger & Röger

Results
Experiment 1: Understanding the equipment (Gerätekunde)

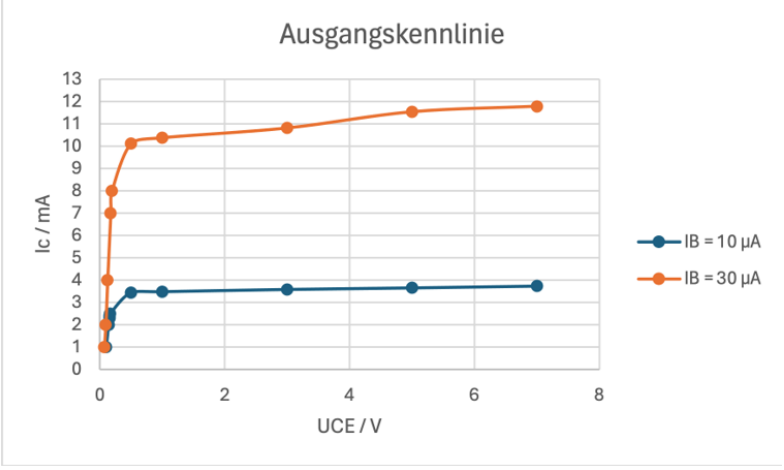
- The experiment can be conducted remotely.
- Overall feasible despite existing system latency.
- Comparable learning outcomes to on-site laboratory sessions.
- Active exploration of device functionality remains essential (“learning by doing”).
- Tasks can be completed within the allocated time.
- Supporting videos enhance understanding and reduce workload for lab staff (asynchronous support).
- A single monitor is enough for remote access.
- Contributes to increased flexibility through digital lab access (DiLa project objective).

Results
Experiment 2: Transistor characteristic curve

3. Messung Ausgangskennline

Nehmen Sie die Ausgangskennlinien für die Basisströme I_B = 10 und 30 µA auf. Wegen der Rückwirkung des Kollektorstroms auf den Basisstrom muss dieser immer wieder nachgestellt werden (ACHTUNG: Temperatureffekte). Grenzwerte sind I_C = 20 mA und U_{CE} = 5 V.

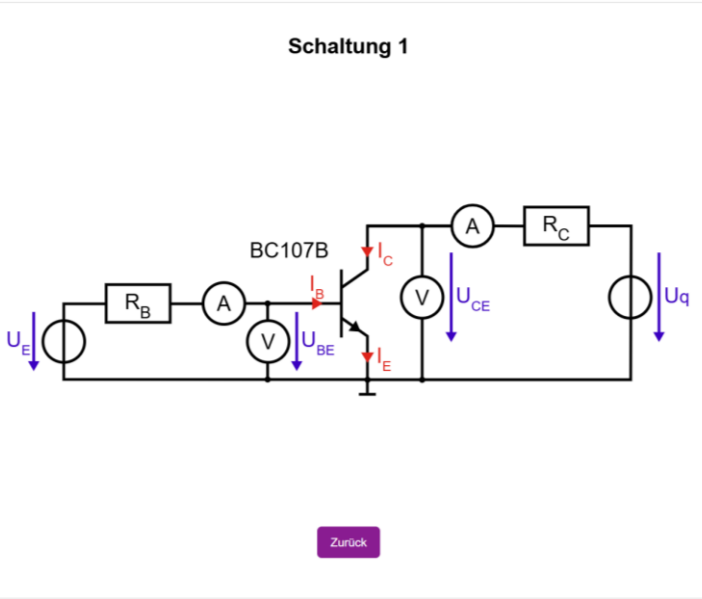
I_B = 10 µA		I_B = 30 µA	
U_{CE} / V	I_C / mA	U_{CE} / V	I_C/mA
0,101	1	0,071	1
0,140	2	0,095	2
0,153	2,3	0,124	4
0,156	2,4	0,174	7
0,162	2,5	0,195	8
0,5	3,45	0,5	10,110
1	3,49	1	10,371
3	3,59	3	10,809
5	3,66	5	11,534
7	3,74	7	11,780



2.2 Messung Eingangskennlinie

Nehmen Sie die Eingangskennlinie auf. Wegen der Rückwirkung des Kollektorstroms auf den Basisstrom muss die Kollektorspannung **U_{CE} = 5 V konstant** gehalten und gegebenenfalls nachgestellt werden. Die Grenzwerte sind I_B = 100 µA und U_{BE} = 0,75 V. Notieren Sie auch den Kollektorstrom I_C (auch wenn er nicht zur Eingangskennlinie dazugehört).

U_{BE} / mV	I_B / µA	U_{CE} / V	I_C/mA
560	0	5	0,102
601	1	5	0,349
619	2	5	0,707
629	3	5	1
642	5	5	1,8
657	10	5	3,68
670	20	5	7,5
672	30	5	16
674	50	5	18,7
674	70	5	22



Project Work 2026: Bolsinger & Röger

Results
Experiment 2: Transistor characteristic curve

- The experiment can be conducted remotely.
- System latency becomes a issue during adjustment processes.
- Reduced interactivity leads to less variation in the experimental experience.
- Potential difficulties in later real-world lab work due to missing physical practice.
- Suitable as:
  - Supplement to in-person labs
  - Preparation or follow-up activity
- Relevant contribution to the development of hybrid lab didactics within the DiLa project.
- Two monitors are recommended for remote access in this experiment.

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