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UbiLAB

Networked Control Systems and Remote Laboratories

UbiLAB-Erasmus+

Faculty of Electrical Engineering and Computer Science

University of Maribor

8.11-12.11.2021

Erasmus+ project no. 2020-1-MK01-KA226-HE-094548

Introduction

- System design
  - Hardware selection
  - Firmware development
  - Mathematical modelling
  - Testing
- Communication properties (TCP/IP, UDP, OPC…)
- Protocol development for NCS
- NCS Control system structure
- NCS Controller design

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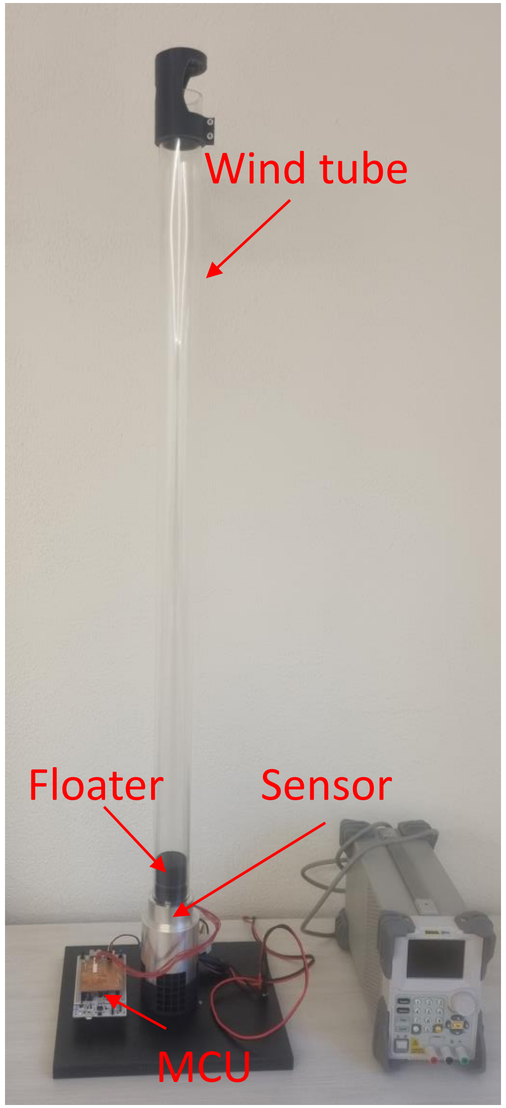
Wind Levitation System-WLS



- Wind tube
- Floater – levitating object
- Wind force controller
- Distance sensor

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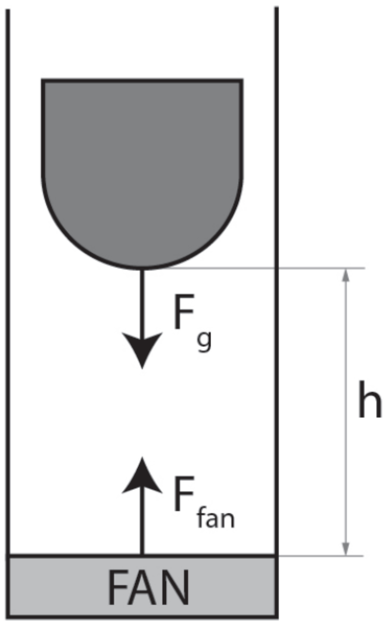
Mathematical Modeling of WLS



Second Newton law of motion:

$$m\ddot{h} = -mg + F_{fan}$$

Second order differential equation:

$$\ddot{h} = -g + \frac{1}{m}F_{fan}$$

State space equations:

$$\dot{x}_1 = x_2,$$
$$\dot{x}_2 = -g + \frac{1}{m}F_{fan}$$

where is: $F_{fan} \approx \frac{1}{2}\varrho v_1^2 S$

ρ-air density, v- air velocity, S-cross surface

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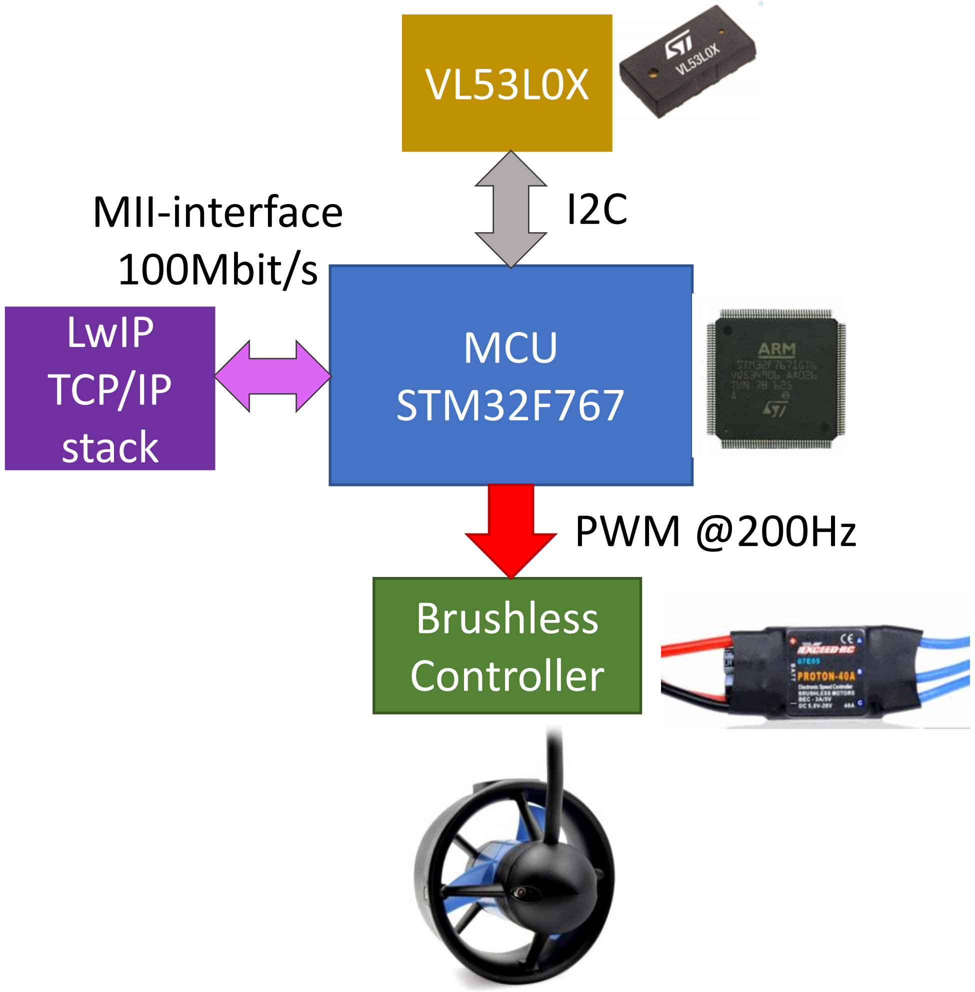
Wind Levitation System-Hardware



- Hardware
  - STM32F767 platform
    (NUCLEO-dev. board)
  - VL53L0X ToF – distance sensor
  - Brushless wind thruster – Wind turbine 14V- 80W
  - Brushless controller 10A/16V
  - Power supply 14V/4A
  - Floater 40g

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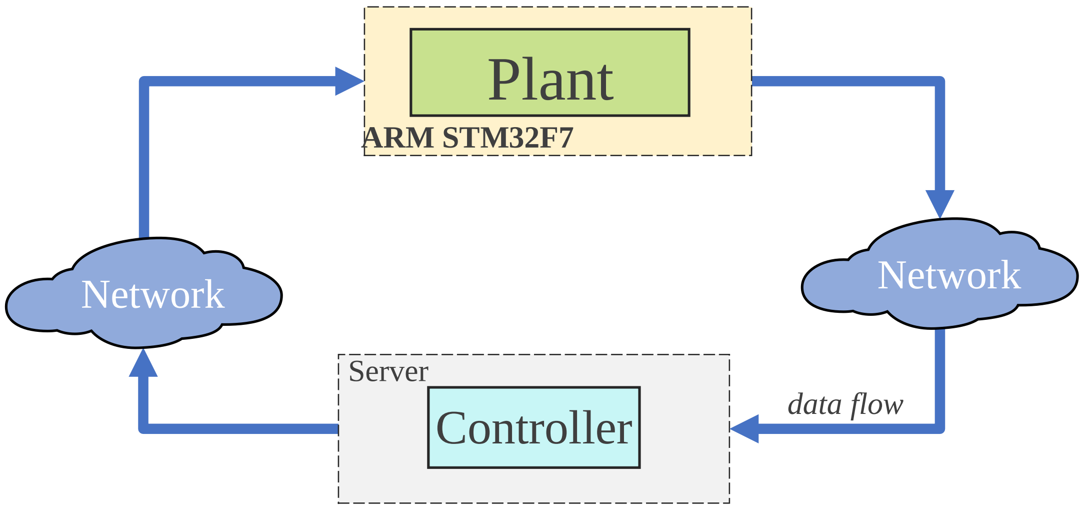
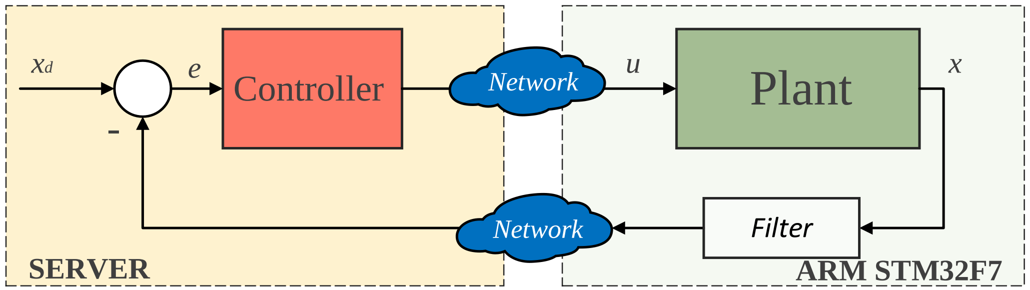
NCS Control System Structure of WLS

NCS network architecture



NCS feedback structure



- UDP protocol (LwIP-stack)
- Data transmission:
  - Height measurement (floater)
  - Velocity measurement
  - Turbine speed estimation
  - Round trip time measurements (RTT)
  - Server (UDP client/server)
    - Matlab script support
    - Matlab Simulink support
    - Python
    - Labview

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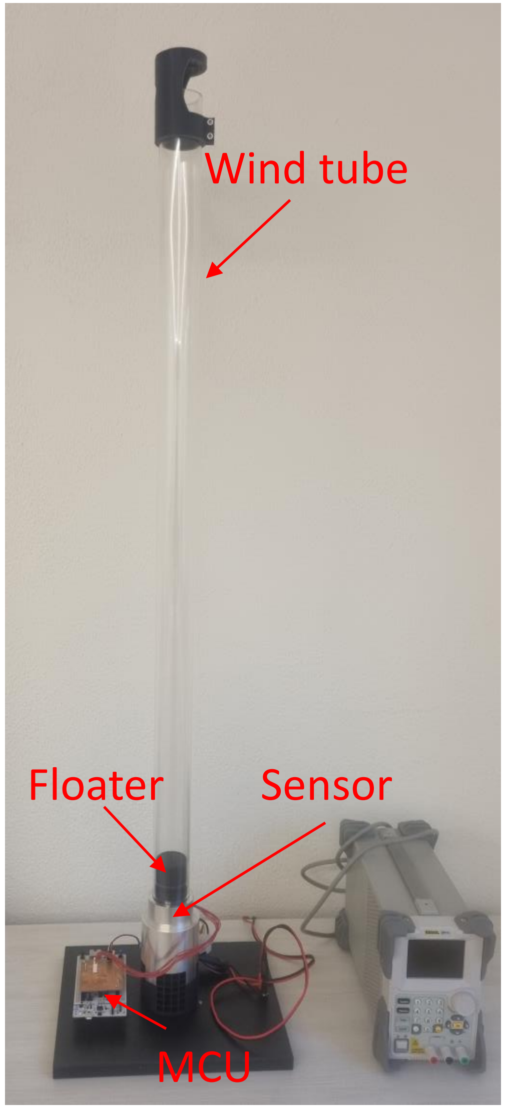

Wind Levitation System-WLS

- Wind tube
- Floater – levitating object
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- Distance sensor

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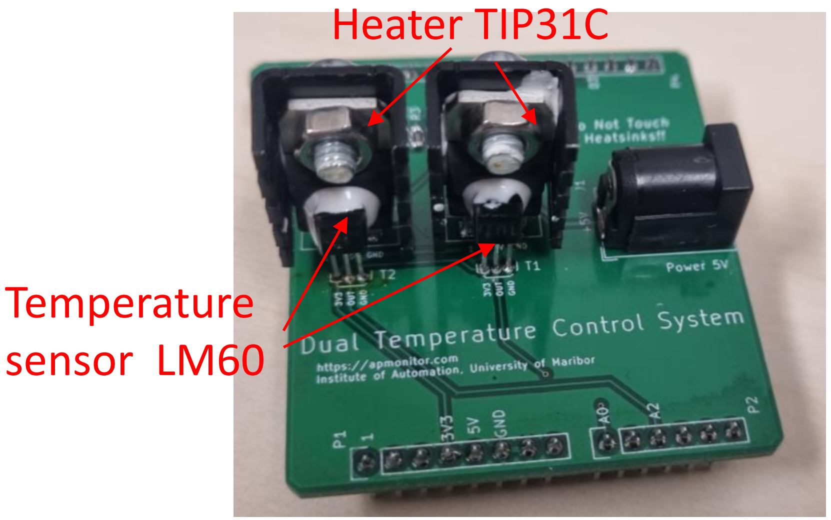
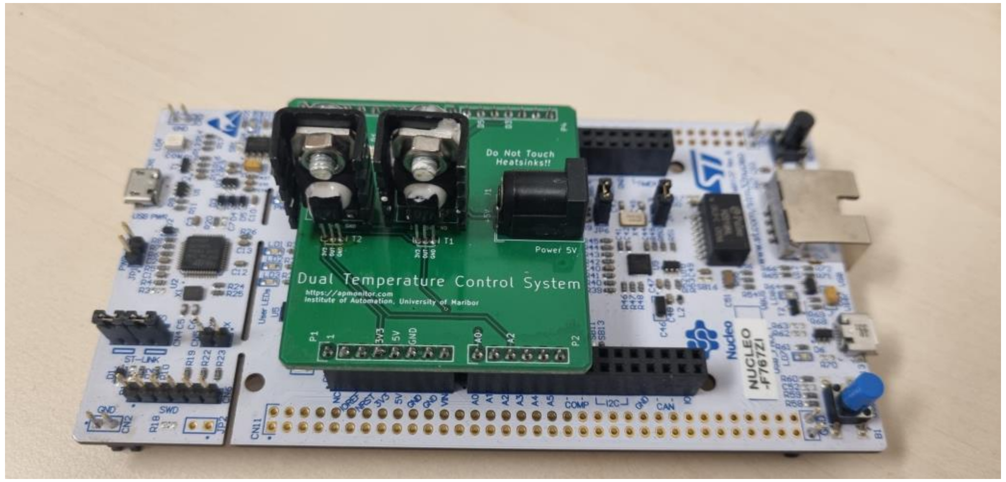
Dual Temperature Control System - DTCS





- Heater TIP31C – power transistor
- Temperature sensor LM60
- SMT32F7 - LwIP-stack
- Power Supply 5V/2A

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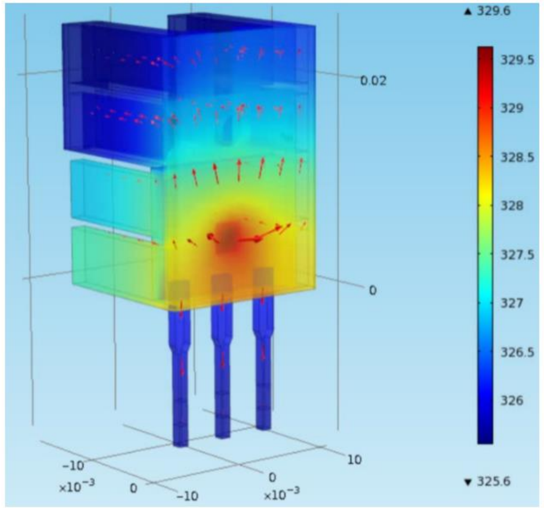
Mathematical Modeling of the Single Heater System(DTCS) – SISO case



https://apmonitor.com/pdc/index.php/Main/ArduinoModeling

Energy balance equation:

$$m\, c_p \frac{dT}{dt} = \sum \dot{h}_{in} - \sum \dot{h}_{out} + Q$$

Extended form with convection and radiation terms:

$$m\, c_p \frac{dT}{dt} = U\, A\, (T_\infty - T) + \epsilon\, \sigma\, A\, \left(T_\infty^4 - T^4\right) + \alpha Q$$

Quantity	Value
Initial temperature (T_0)	296.15 K (23°C)
Ambient temperature (T_∞)	296.15 K (23°C)
Heater output (Q)	0 to 1 W
Heater factor (α)	0.01 W/(% heater)
Heat capacity (C_p)	500 J/kg-K
Surface Area (A)	1.2×10^{-3} m^2 (12 cm^2)
Mass (m)	0.004 kg (4 gm)
Overall Heat Transfer Coefficient (U)	10 W/m^2-K
Emissivity (ε)	0.9
Stefan Boltzmann Constant (σ)	5.67×10^{-8} W/m^2-K^4

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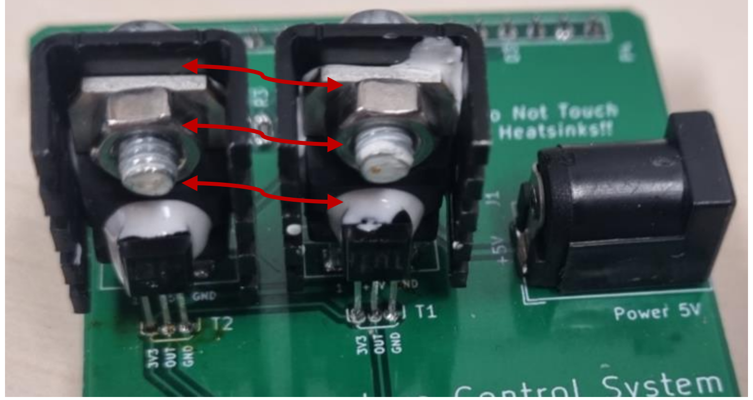
Mathematical Modeling of the Dual Heater System (DTCS) – MIMO case

Heat transfer



Input 1 Input 2

Energy balance equations:

$$m\,c_p\frac{dT_1}{dt} = U\,A\,(T_\infty - T_1) + \epsilon\,\sigma\,A\,\left(T_\infty^4 - T_1^4\right) + Q_{C12} + Q_{R12} + \alpha_1 Q_1$$

$$m\,c_p\frac{dT_2}{dt} = U\,A\,(T_\infty - T_2) + \epsilon\,\sigma\,A\,\left(T_\infty^4 - T_2^4\right) - Q_{C12} - Q_{R12} + \alpha_2 Q_2$$

where convection and radiative heat transfer between the two heating elements are:

$$Q_{C12} = U\,A_s\,(T_2 - T_1)$$

$$Q_{R12} = \epsilon\,\sigma\,A\,\left(T_2^4 - T_1^4\right)$$

Quantity	**Value**
Heater output (Q_1)	0 to 1 W
Heater factor (α1)	0.01 W/(% heater)
Heater output (Q_2)	0 to 1 W
Heater factor (α2)	0.0075 W/(% heater)
Surface Area Not Between Heaters (A)	1.0×10^{-3} m^2 (10 cm^2)
Surface Area Between Heaters (A_s)	2×10^{-4} m^2 (2 cm^2)

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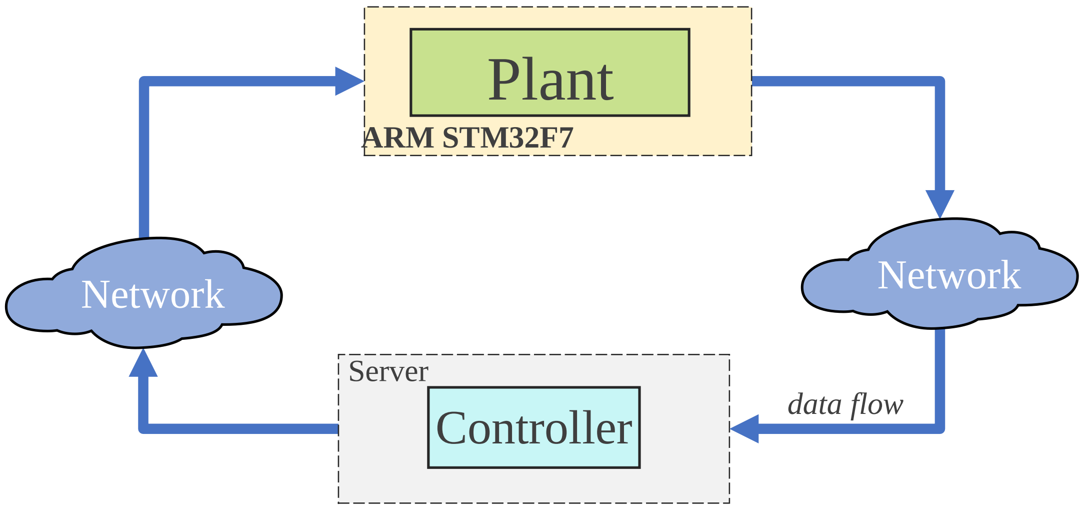
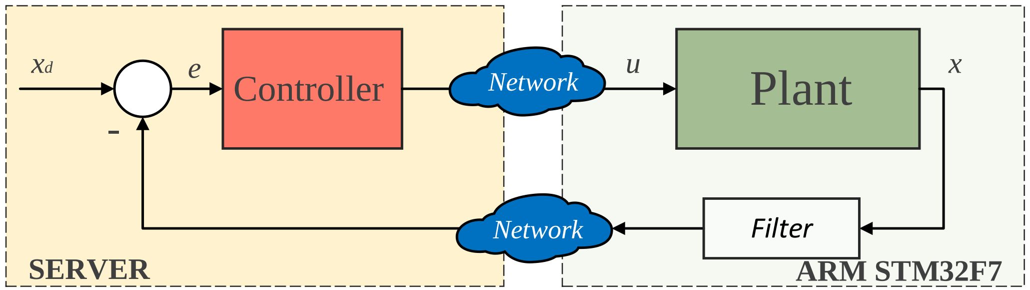
NCS Control System Structure of DTCS

NCS network architecture



NCS feedback structure



P*A2

- UDP protocol (LwIP-stack)
- Data transmission:
  - Temeprature measurements
  - Round trip time measurements (RTT)
  - Server (UDP client/server)
    - Matlab script support
    - Matlab Simulink support
    - Python
    - Labview

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NCS Control System Structure over WebSocket protocol

- Possible integration on different platforms
- Secure
- Fast data exchange
- Real-time operation
- Extension to different MOOC platforms
  - Remote laboratories
  - Collaborative learning
  - E-learning
- Support of different development programming environments
  - C/C++
  - Javascript
  - Matlab script
  - Matlab Simulink
  - Python
  - Labview

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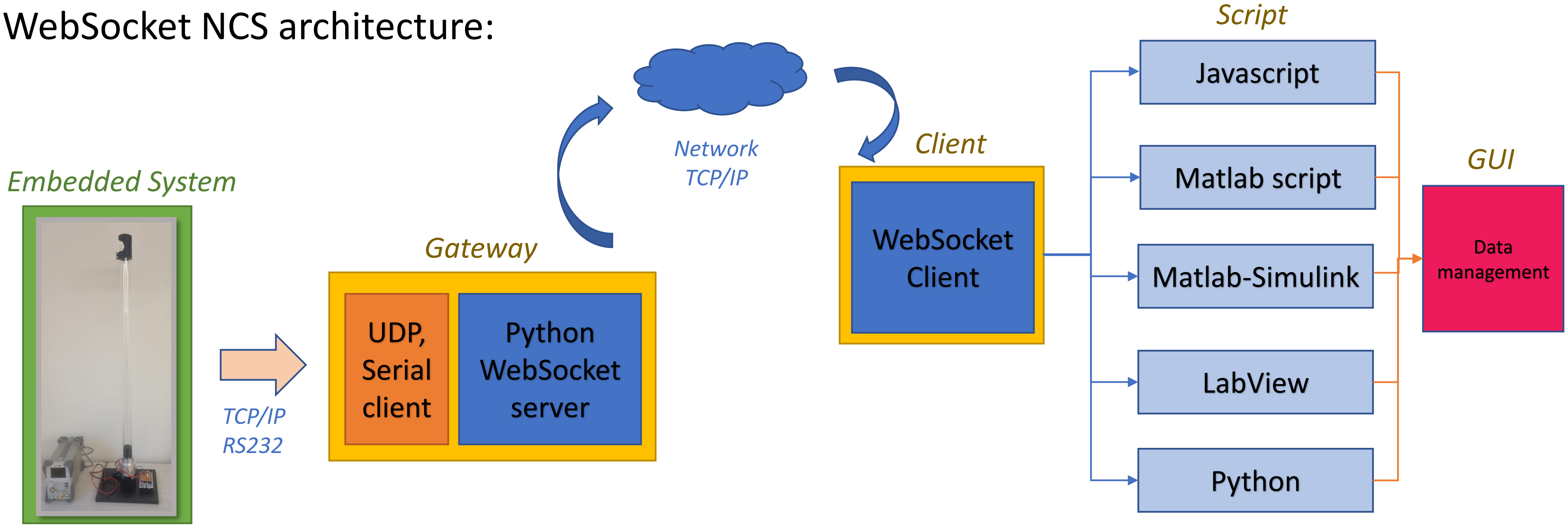
NCS Control System Structure over WebSocket protocol

WebSocket NCS architecture:



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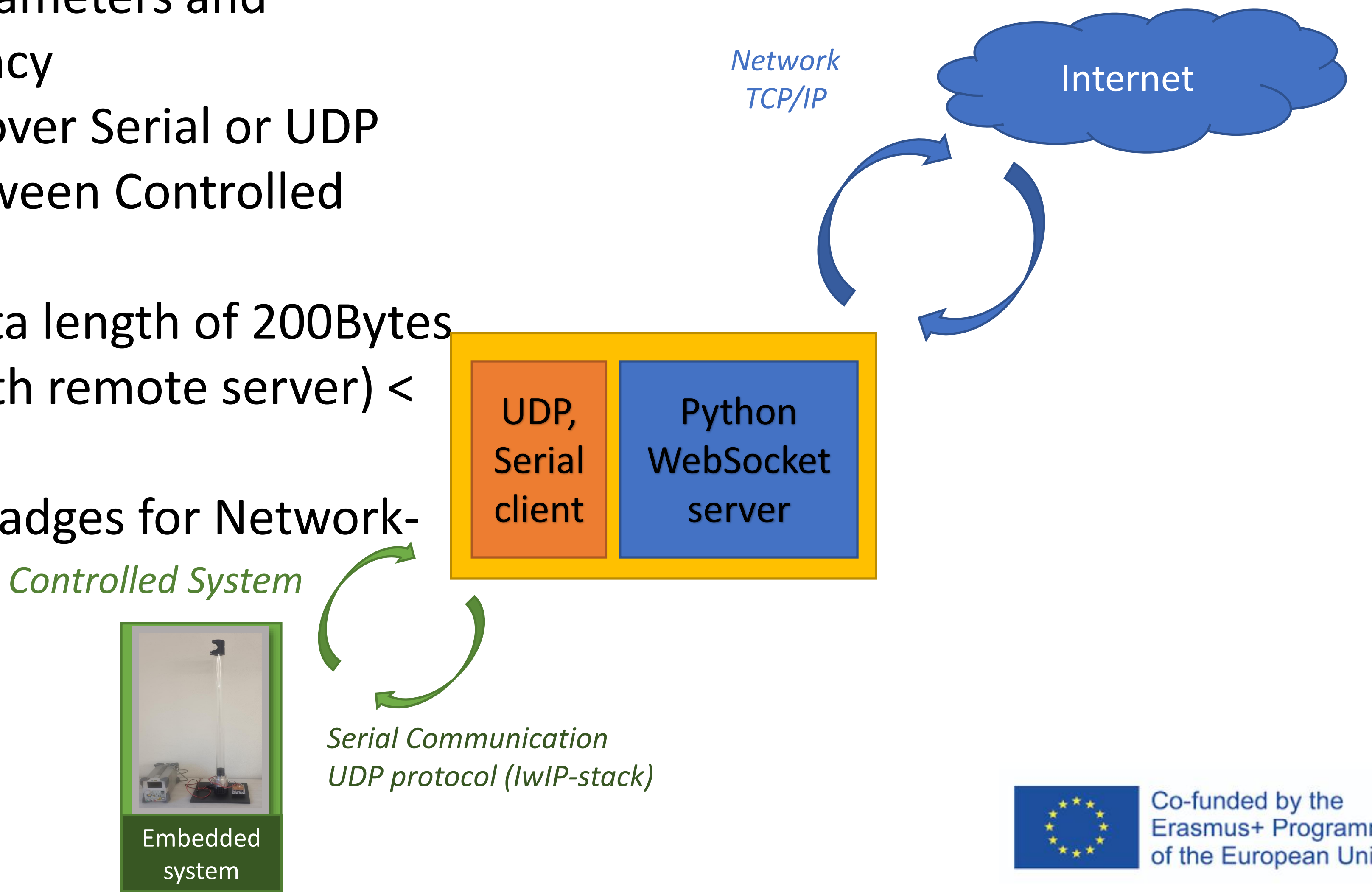
WebSocket Server – Gateway and Embedded System

- Real-time data strimming (parameters and measurements) with low latency
- Bidirectional communication over Serial or UDP protocol. Communication between Controlled System and WebSocket server
- Estimated latency for fixed data length of 200Bytes < 2ms (for serial) and UDP (with remote server) < 10ms
- Data transmission with time-badges for Network-delay estimation
- CRC data encoding



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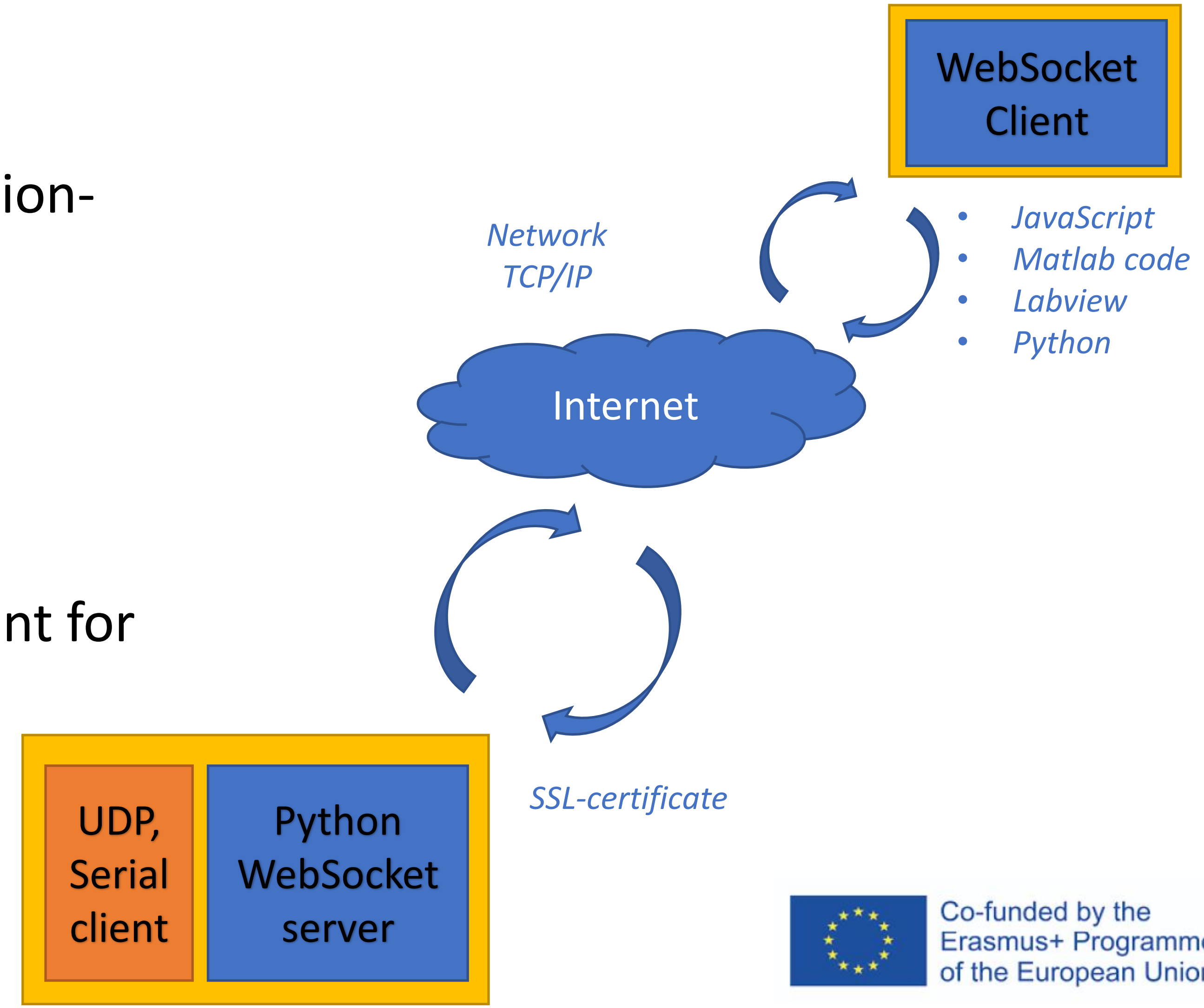
WebSocket Server and Security

- Real-time data strimming
- Secure connection with SSL-Certificate
- Registered domain on Institute for Automation-University of Maribor
- Network delay of approx. 40ms.
- Client request data from the server
- Purposeful data package for network delay estimation
- Package Round-Trip-Time (RTT) measurement for system safety and emergency shoot down.



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Client and Data presentation

- Data presentation with Graphical User Interface (GUI)
- Support for different programming language with integrated GUI modules
    - HTML/JavaScript
    - Matlab code and Matlab GUIDE
    - Labview interface
    - Python QT-designer
- Integration to the MOOC platforms

Graphical interface

- *HTML/JavaScript*
- *Matlab code*
- *Labview*
- *Python*

WebSocket Client

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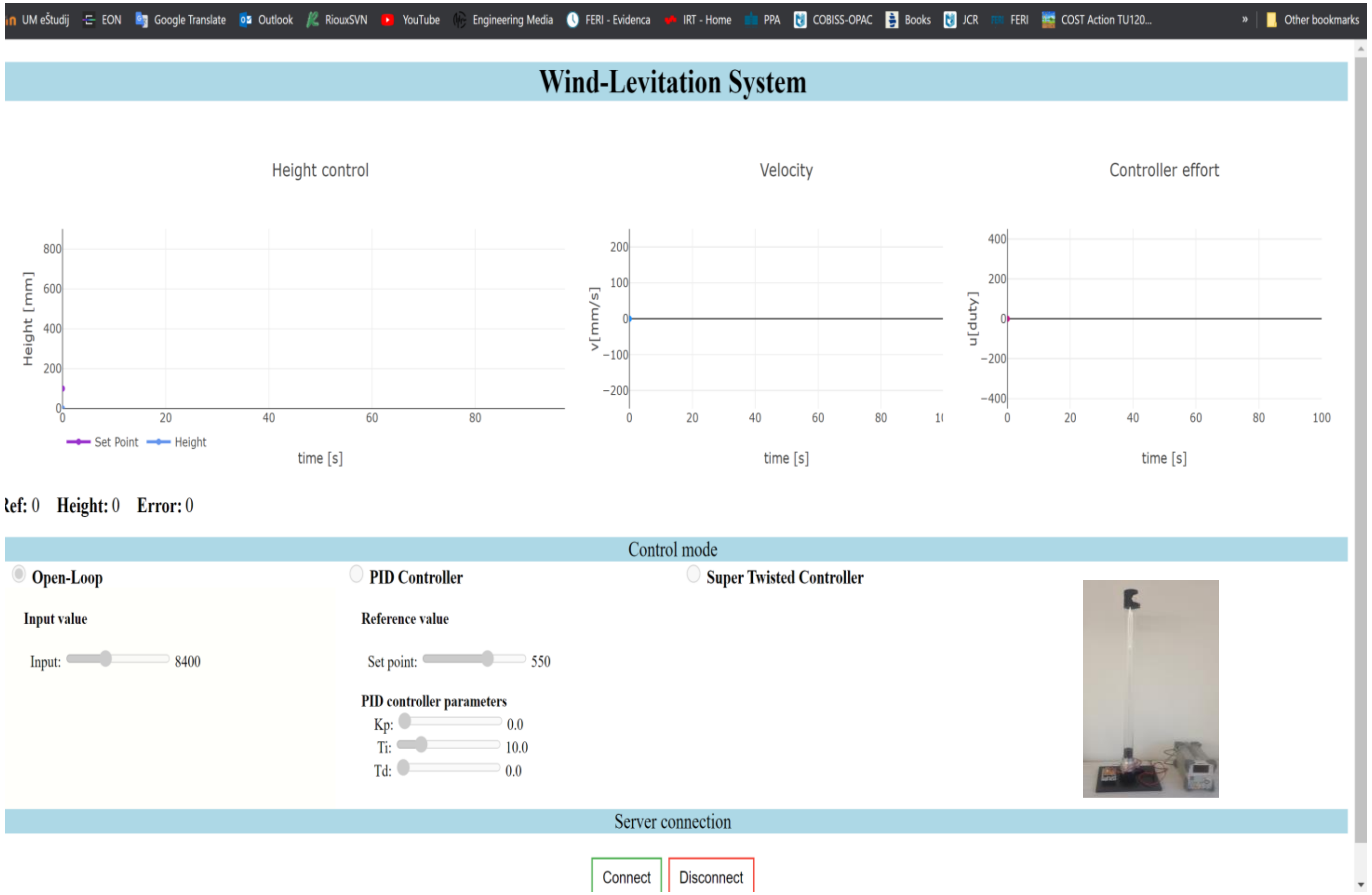
HTML-JavaScript GUI for Wind Levitation Control as Remote Laboratory System

- Intuitive graphical user interface
- With possibility to run system in open-loop (without controller)
- Support of industrial controllers such as P, PI, PID structures.
- Support of nonlinear control methods, with adjustable parameters for Super Twister Nonlinear Controller.
- Streaming video



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HTML-JavaScript GUI for Temperature Controlv System as Remote Laboratory

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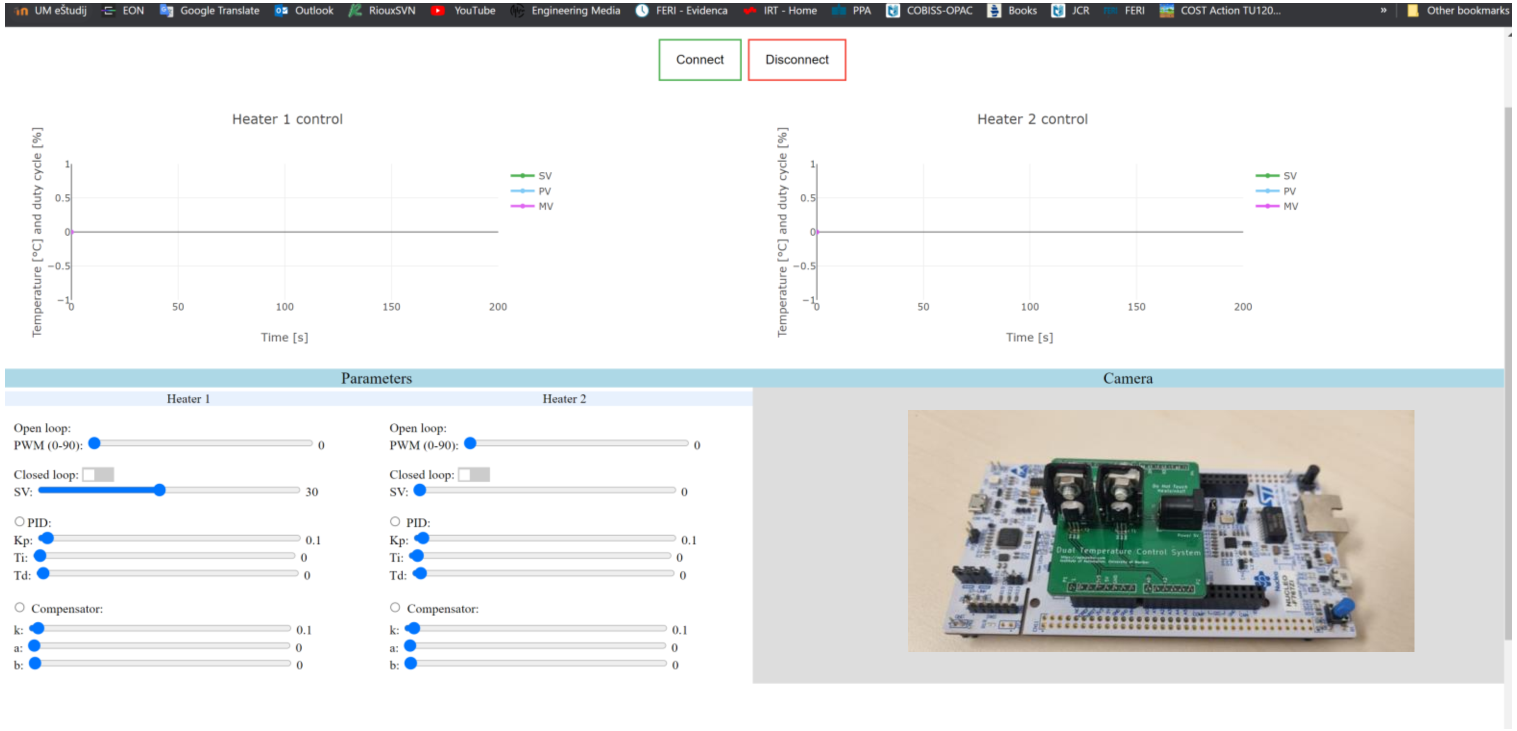

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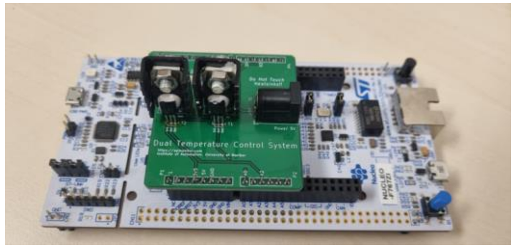
HTML-JavaScript and MOOC

- Both HTML-JavaScript GUI can be further integrated into MOOC platform
- Systems are tested on Moodle platform
- HTML-GUI can be imported as Assignment
- All the functionalities of Moodle plugins can be used
  - Time dependencies (start the exercise, end of the exercise etc..)
  - Scheduling regarding enrolled users
  - Provide exercises to the specific groups of users
  - Exercise report submission
  - Exercises grading system
  - Communication Teacher and Students



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