CYBRES®
beyond technology

Phytosensor

technical presentation

History of development: bio-hybrid EU research

*flora***robotica**

The *flora robotica* project develops and investigates bio-hybrid relationships between robots and natural plants and explore the potentials of plant-robot societies able to produce architectural artifacts and living spaces. The project is funded by European Commission under the programme Future and Emerging Technologies, H2020 Project no. 640959.

BIOHYBRIDS

HORIZON 2020

Biohybrid phytosensing system for plant-technology interactions in mixed-reality and smart-home systems

This innovation is related to an embedded electronic system connected to plants and trees – so-called phytosensor. The system is used as a bio-sensor and as a bio-hybrid interface device. As a bio-hybrid interface, the phytosensor provides physiological data from plants for plant-technology interactions: Mixed Reality or smart-Home systems, integration into digital infrastructures, controlling the robot actuators or performing autonomous phytoactuation. The project is funded by European Commission under the programme Future and Emerging Technologies, H2020 Project no. 945773.

watchPLANT

HORIZON 2020

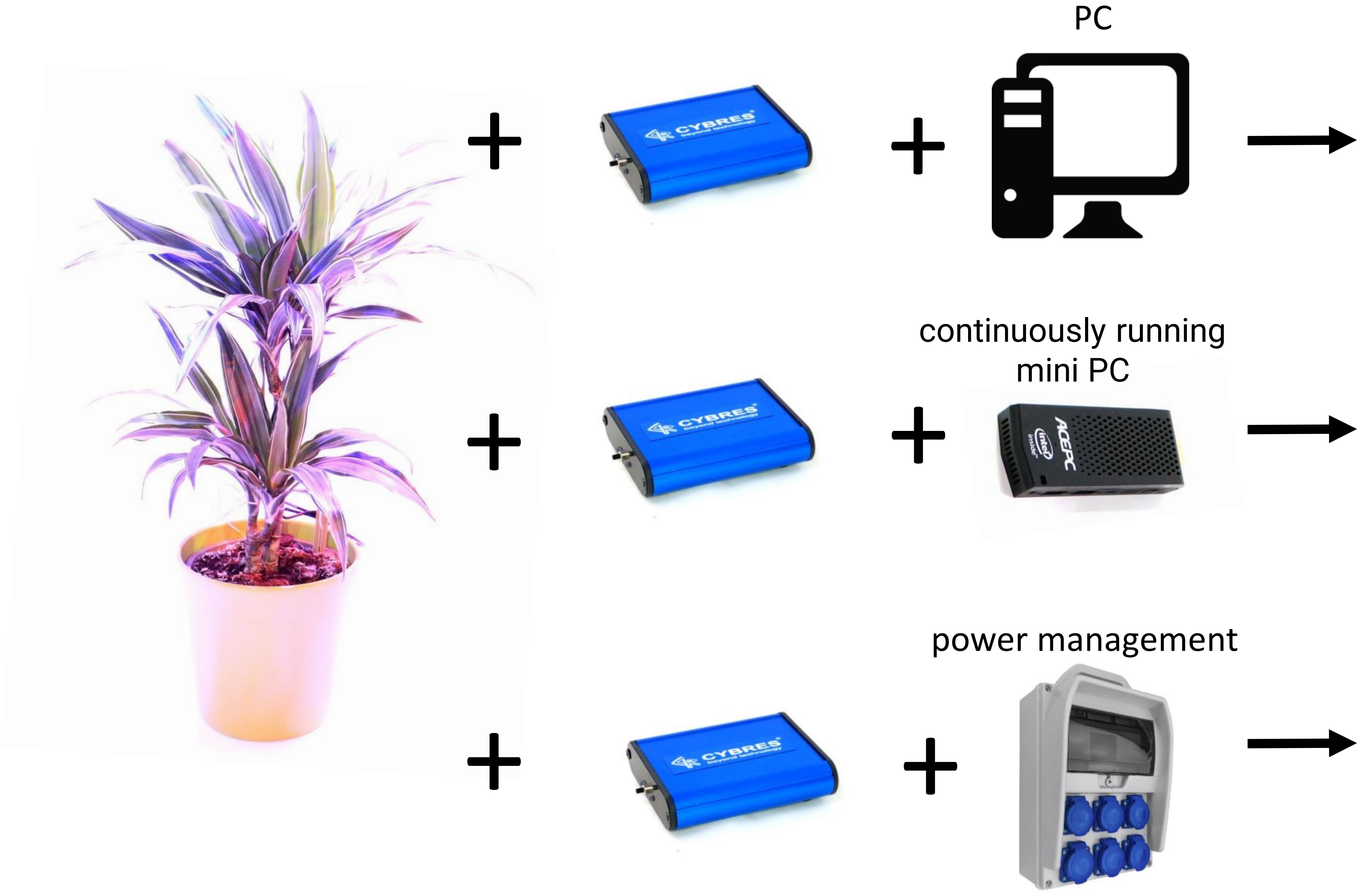
SMART BIOHYBRID PHYTO-ORGANISMS FOR ENVIRONMENTAL IN SITU MONITORING

WatchPlant develops a new biohybrid system technology, a wireless wearable self-powered sensor for in-situ monitoring of urban environments. This system equips urban biological organisms -plants- with Artificial Intelligence (AI) to create a smart sensor for measuring both, environmental parameters and the responding physiological state of plants. The project is funded by European Commission under the programme Future and Emerging Technologies, H2020 Project no. 101017899.

The main goal of ASSISI project is to establish a robotic society that is able to develop communication channels to animal societies and bio-hybrid systems. The project is funded by European Commission under the programme Future and Emerging Technologies, EU-FP7 Project no. 601074

1. General setup,
I/O signals and devices,
connection to the plant

Modes of operation



PC

- research
- different analytic tools
- bio-hybrid applications
- plant-technology interfaces

continuously running mini PC

- autonomous sensing/actuation
- ecological networks
- “well-being” sensor
- smart plant + AI systems
- entertainment applications
- smart home systems

power management

- precision agriculture
- vertical/indoor farms
- control of phyto-light, irrigation and fertilization
- $50m^2$ - $75m^2$ growth area
- stable and reliable long-term operation

Modes of operation

fixed-protocol growth

- currently used in small-size vertical farming
- easy of operation
- low- to medium- cost

+

- adaptive to plant’s needs
- achieving higher productivity
- intelligent control for light, irrigation and fertilization
- detection of stress and pathogens
- return of investment in ~6-12 months

bio-feedback growth

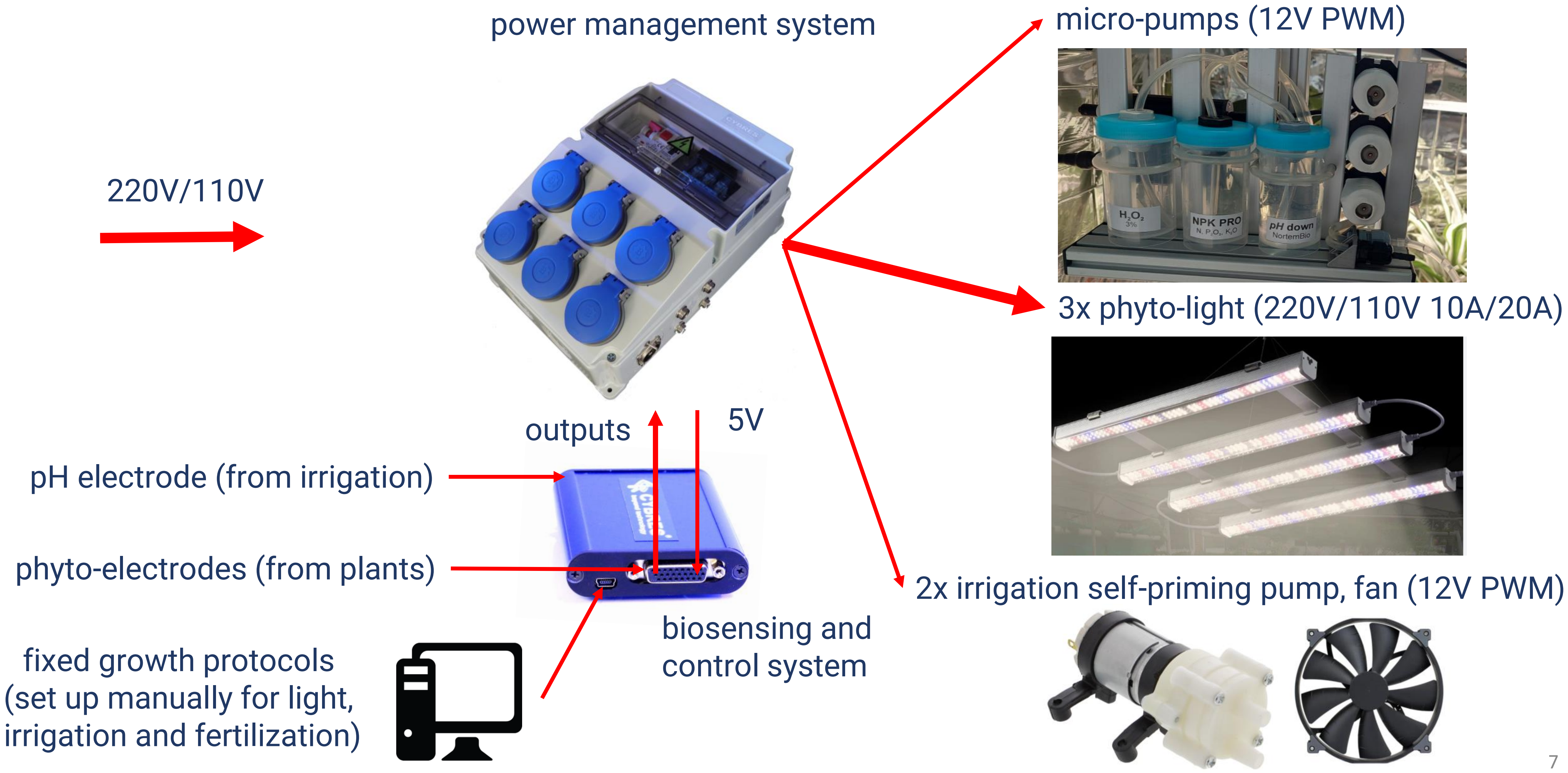
Setup

UART port:
- Communication: BLE, Bluetooth, ZigBee, WiFi, GSM
- DMX bus (UART-DMX bridge is required)

Tested mini PC with Win10 PRO and Ubuntu:
- CPU: Intel Atom Z8350, Celeron J3355/J3455/J4115/J4125
- popular models from: ACEPC, Beelink, MinisForum, MeLE, etc.

Data storage:
- internal flesh memory
- external mini PC (required for computation, actuation and connectivity)

Setup for hydroponics, vertical and indoor farms



power management system

220V/110V

micro-pumps (12V PWM)

3x phyto-light (220V/110V 10A/20A)

2x irrigation self-priming pump, fan (12V PWM)

outputs

5V

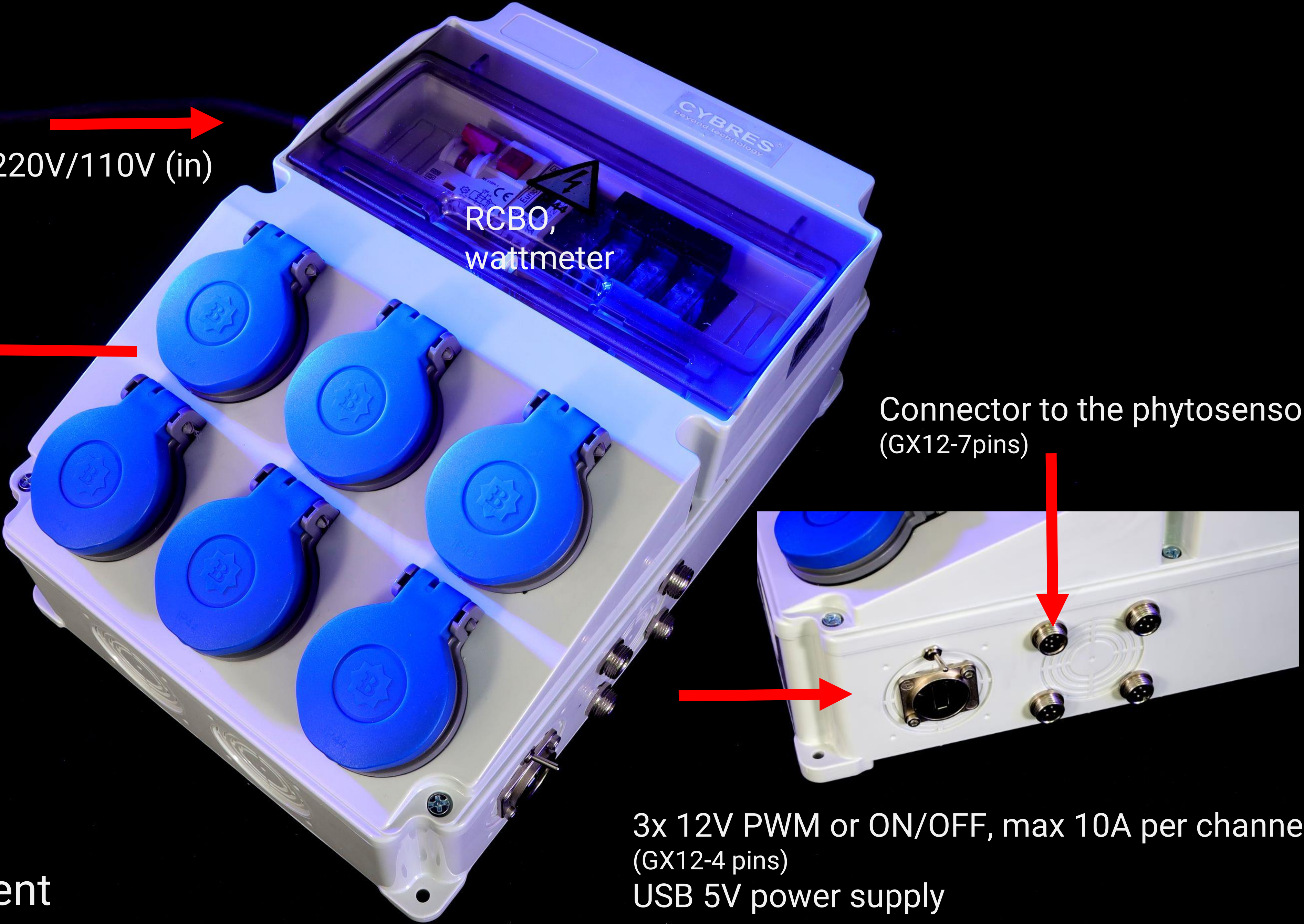
pH electrode (from irrigation)

phyto-electrodes (from plants)

biosensing and control system

fixed growth protocols
(set up manually for light,
irrigation and fertilization)

Power management



220V/110V (in)

RCBO,
wattmeter

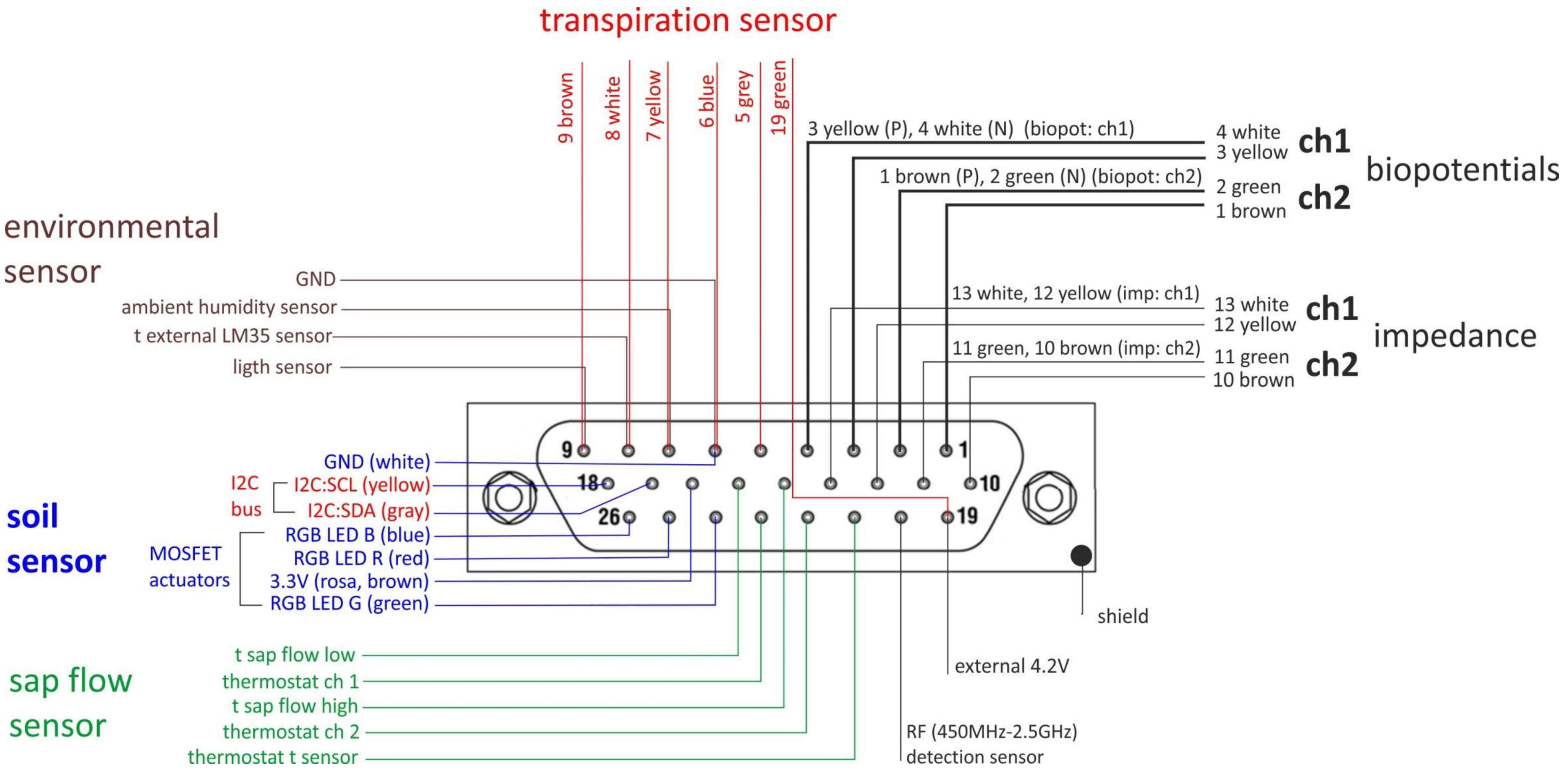
6x switchable ON/OFF
220V/110V (out)
max 10A per channel

Connector to the phytosensor
(GX12-7pins)

3x 12V PWM or ON/OFF, max 10A per channel
(GX12-4 pins)
USB 5V power supply

Back connector 26 pins high density

phytoelectrodes: biopotentials, impedance, transpiration, sap flow and soil sensors (connector side)



transpiration sensor

9 brown
8 white
7 yellow
6 blue
5 grey
19 green

3 yellow (P), 4 white (N) (biopot: ch1)
1 brown (P), 2 green (N) (biopot: ch2)

4 white
3 yellow
ch1
2 green
1 brown
ch2
biopotentials

13 white, 12 yellow (imp: ch1)
11 green, 10 brown (imp: ch2)

13 white
12 yellow
ch1
11 green
10 brown
ch2
impedance

environmental sensor

GND
ambient humidity sensor
t external LM35 sensor
ligth sensor

soil sensor

GND (white)
I2C bus
I2C:SCL (yellow)
I2C:SDA (gray)
MOSFET actuators
RGB LED B (blue)
RGB LED R (red)
3.3V (rosa, brown)
RGB LED G (green)

sap flow sensor

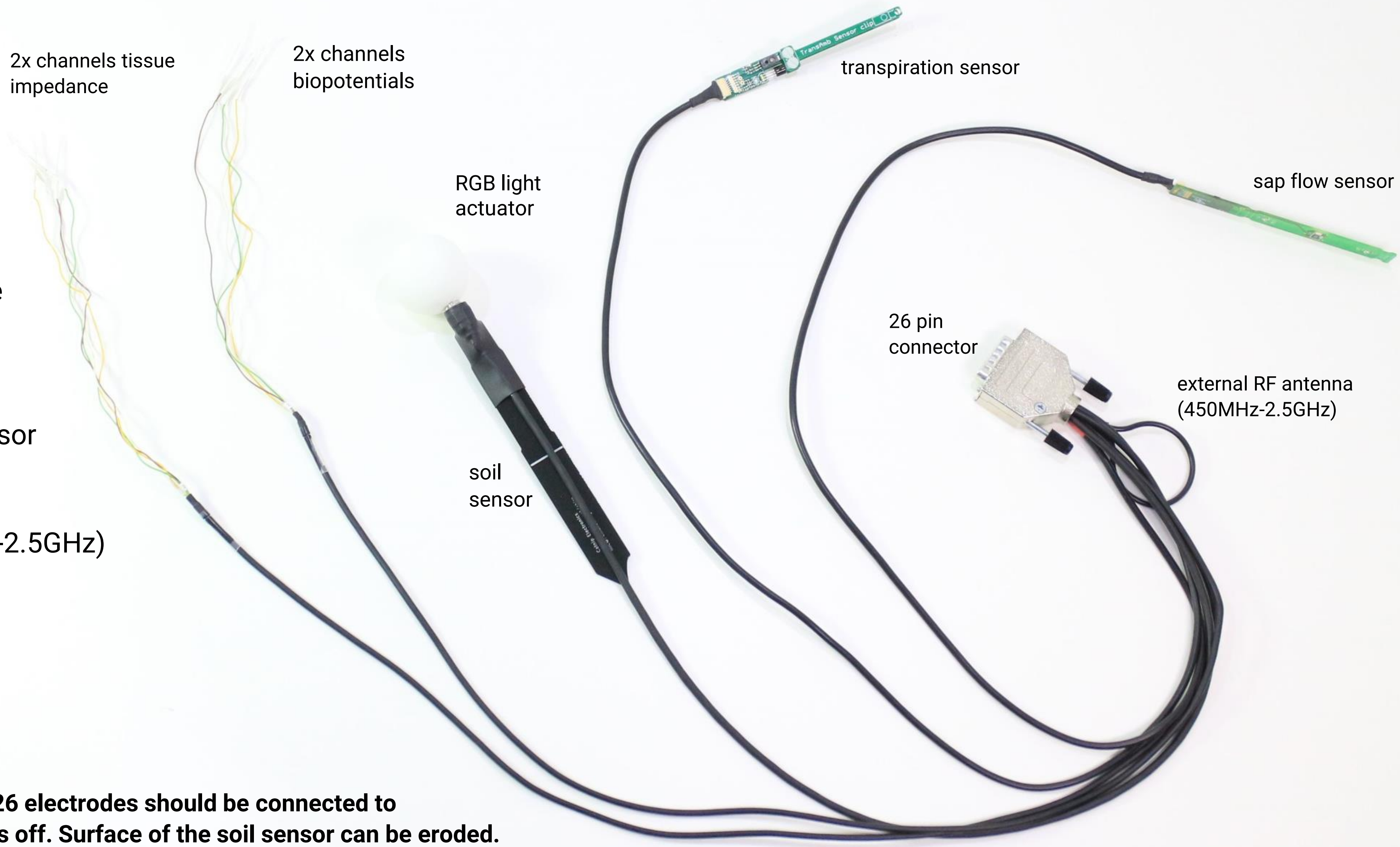
t sap flow low
thermostat ch 1
t sap flow high
thermostat ch 2
thermostat t sensor

RF (450MHz-2.5GHz) detection sensor
external 4.2V
shield

Typical electrodes and sensors

phytosensor electrodes Phy-IBTSF-26

- Ag99 needles
- 2x channels tissue impedance
- 2x channels biopotentials
- external temperature sensor
- external air humidity sensor
- external leaf transpiration sensor
- sap flow sensor
- external light sensor
- external RF antenna (450MHz-2.5GHz)
- power supply LED
- soil moisture sensor
- soil temperature sensor
- RGB light actuator "Light Ball" with 4 pin connector



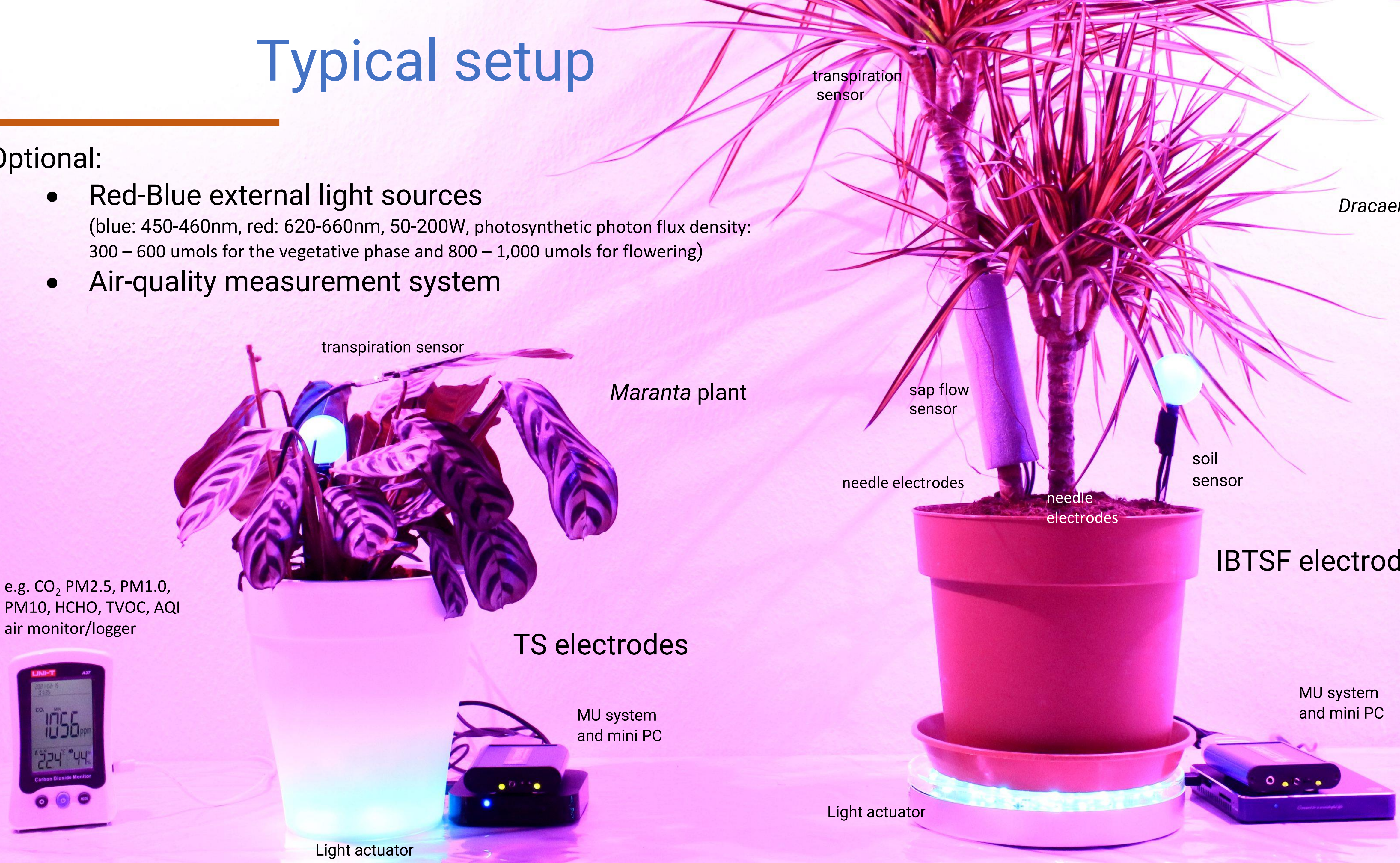
Note, the Phy-IBTSF-26 and Phy-IBTS-26 electrodes should be connected to the measurement module when power is off. Surface of the soil sensor can be eroded.

Electrodes of type IBTS, IBT and IB (without corresponding sensors) are available for delivering

Typical setup

Optional:

- Red-Blue external light sources
  (blue: 450-460nm, red: 620-660nm, 50-200W, photosynthetic photon flux density: 300 – 600 umols for the vegetative phase and 800 – 1,000 umols for flowering)
- Air-quality measurement system

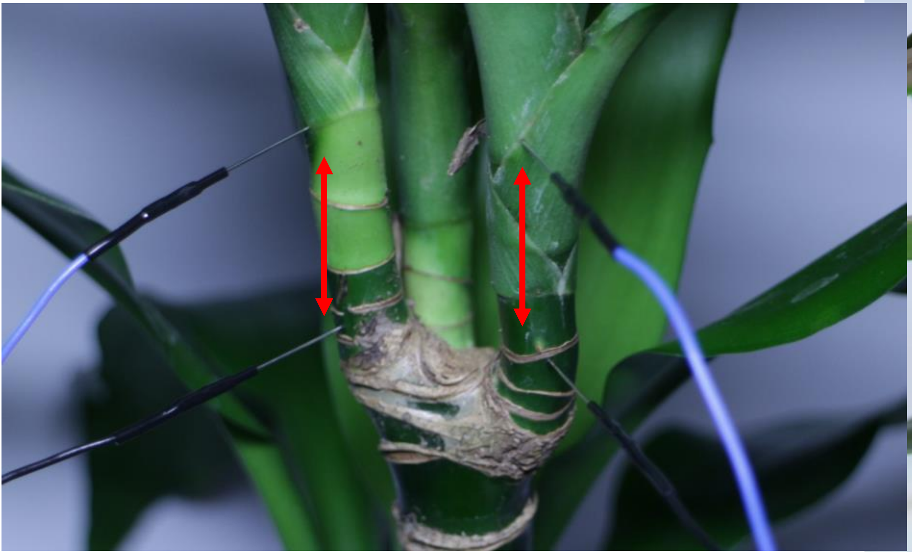


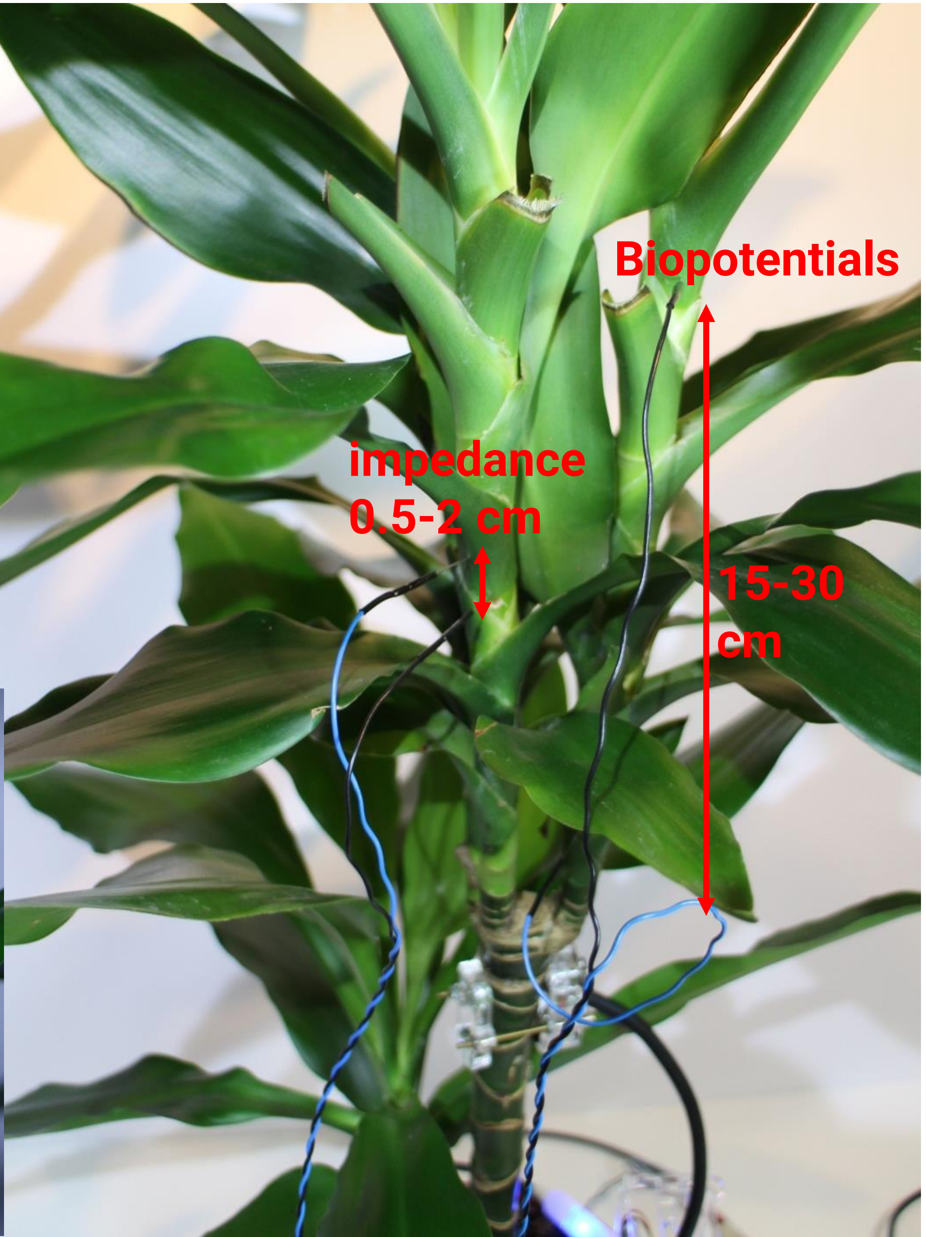
Connecting electrodes and sensors to the plant

tissue impedance

- *for measurements*: short distance btw electrodes (0.5-2 cm)
- *for electro-stimulation*: depends on stimulation system

- make use of differential measurements





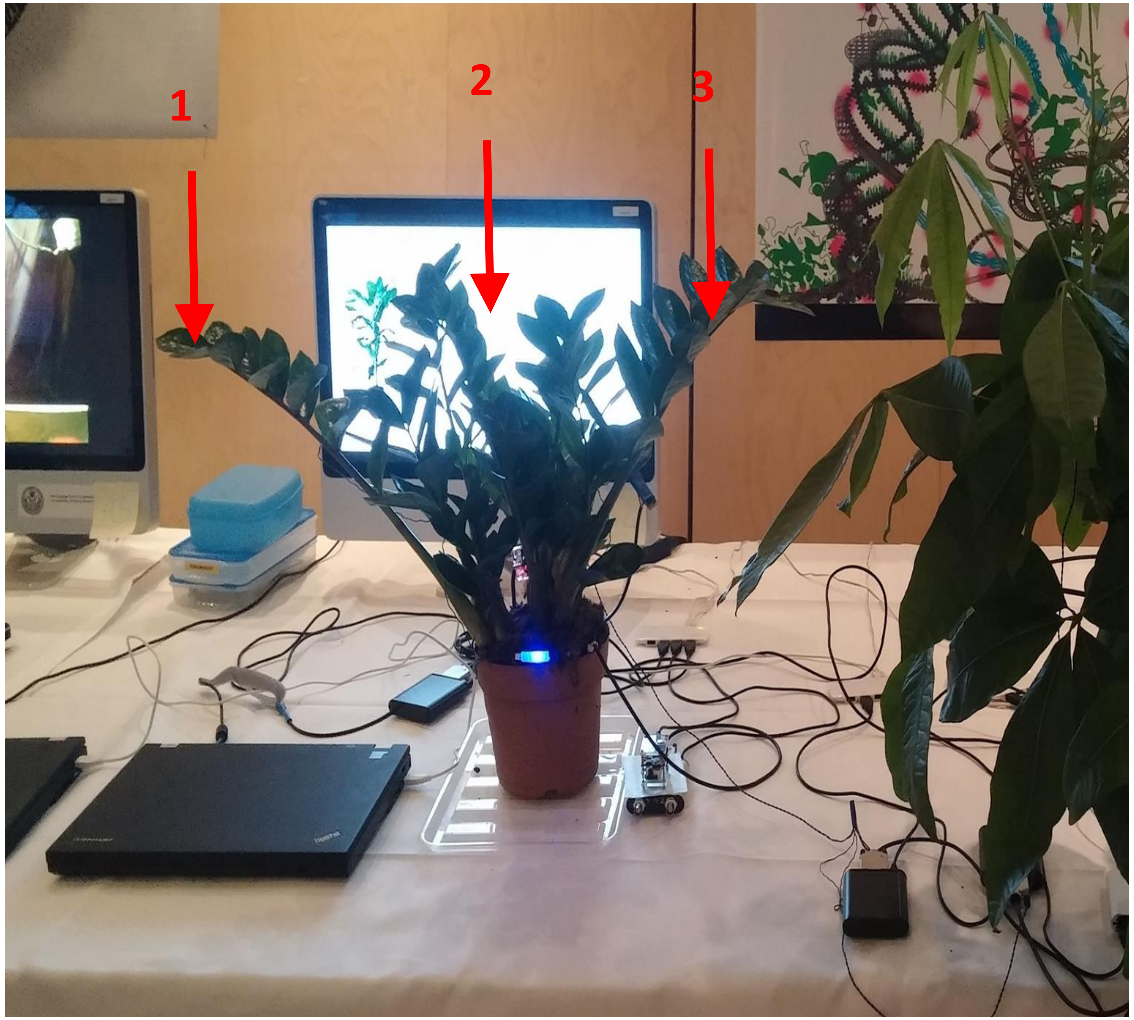
biopotentials

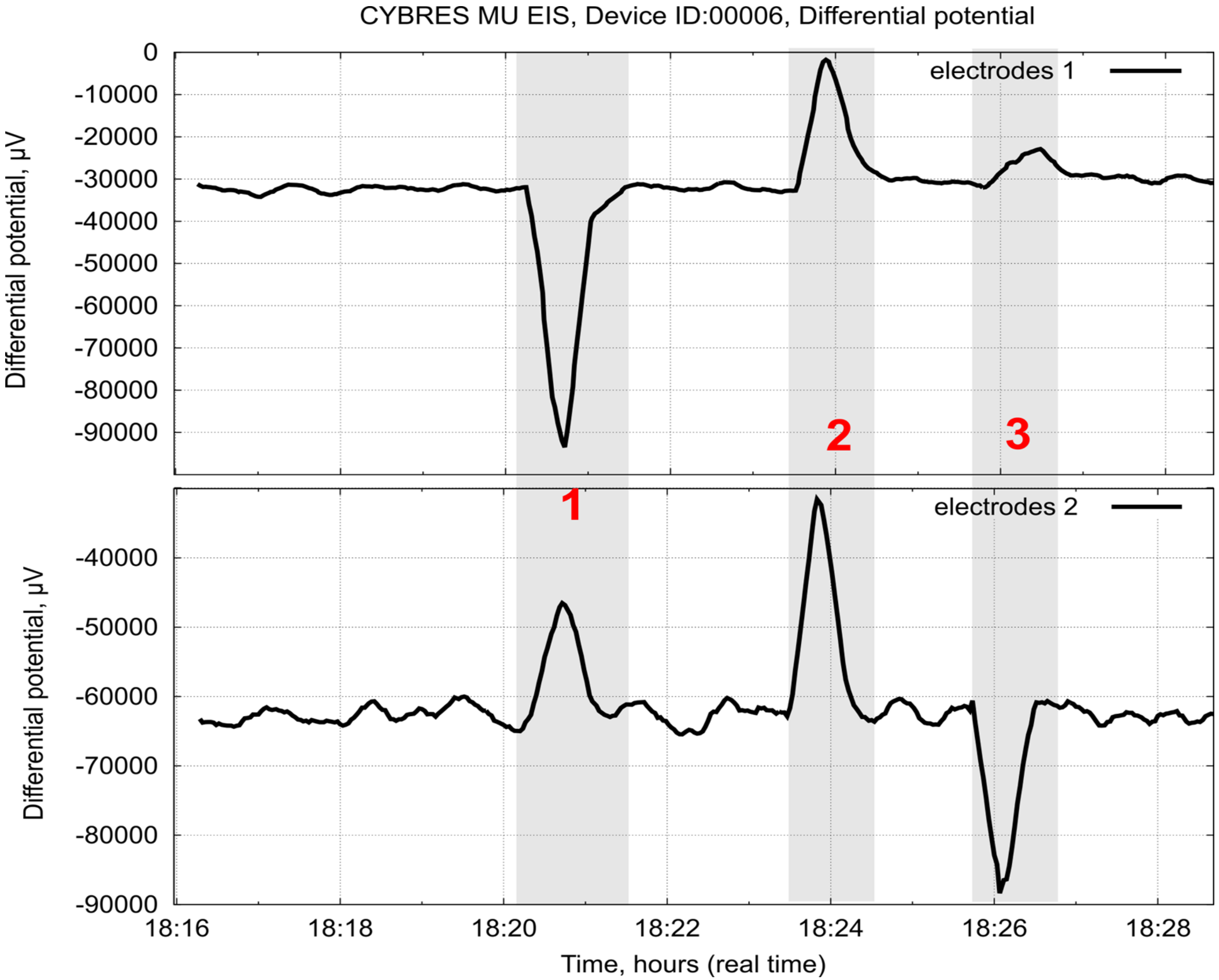
- long distance between electrodes (15-30 cm)
- use differential signals or with reference ground
- use plant topology for differential electrodes (see next slide)
- fouling/wooding issues
- wet surface electrodes as alternative to needles

Surface Electrodes EMG (electromyography)

Connecting electrodes and sensors to the plant

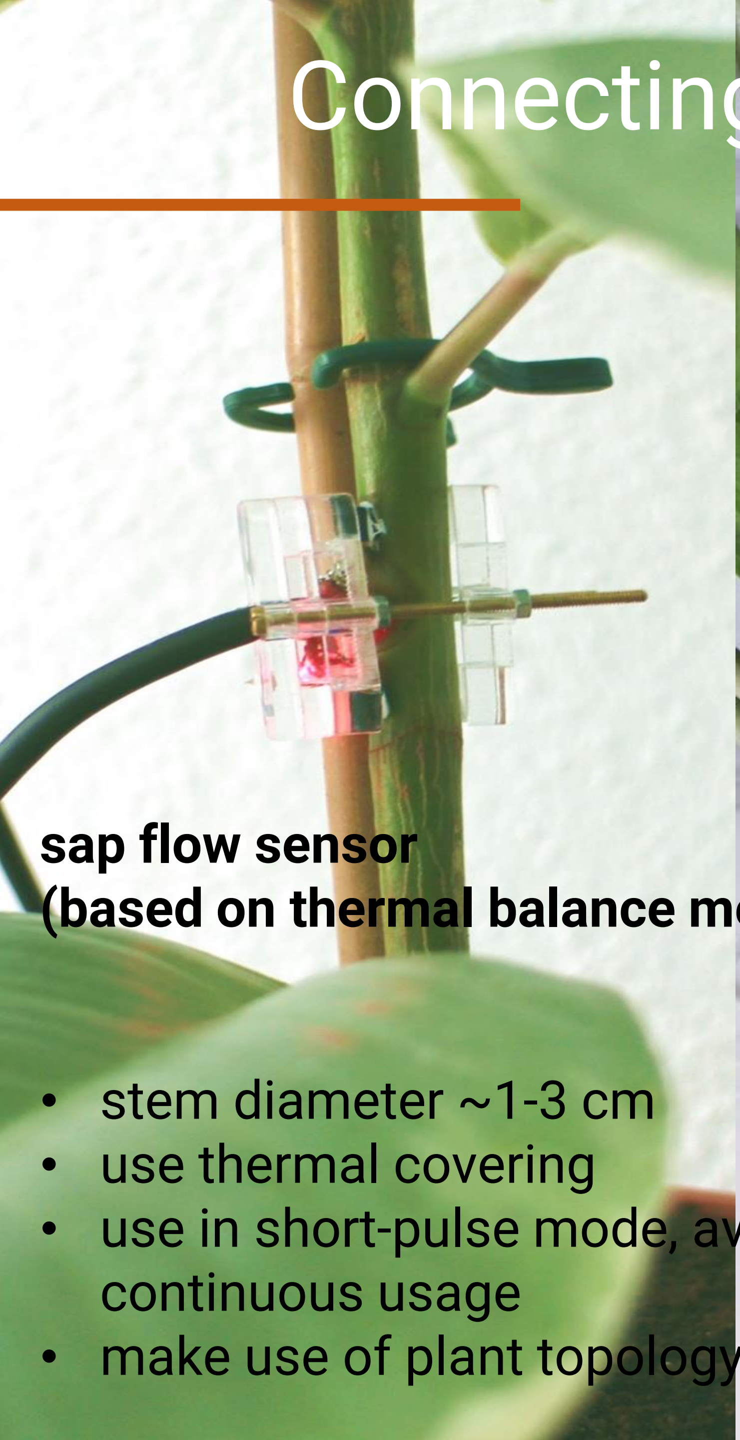
use plant topology for differential signals





- put inverse polarity (biopotential electrodes) to plant branches to localize the touch position
- use electro-stimulation as a feedback (actuation) method

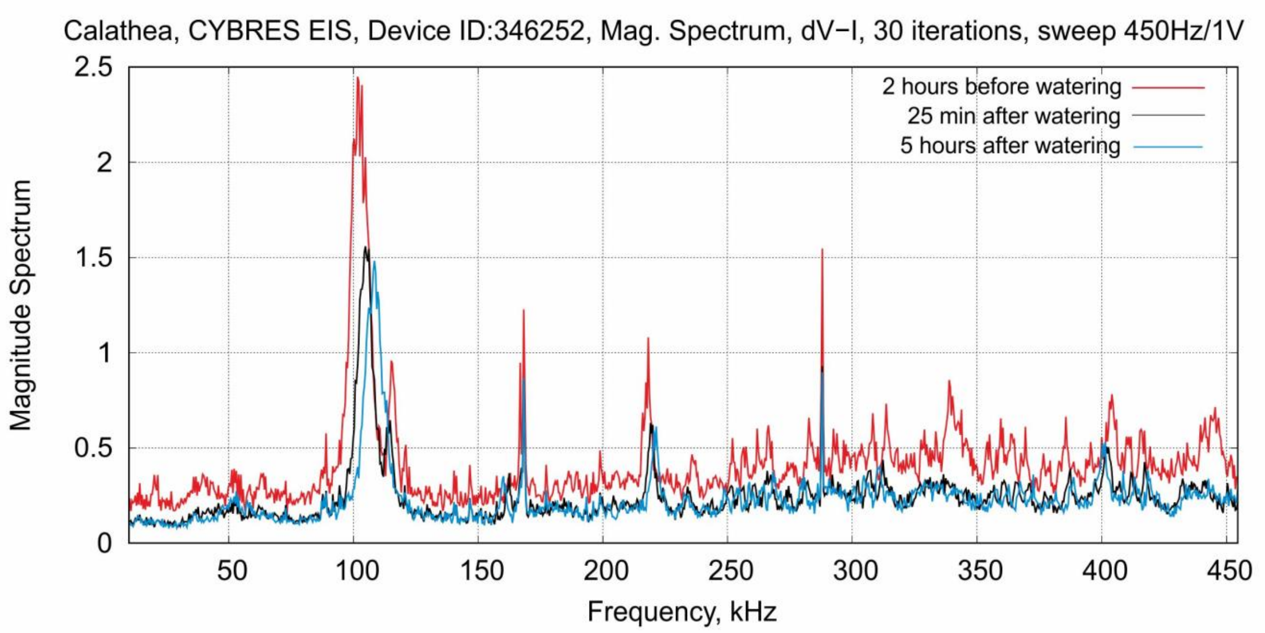
Connecting electrodes and sensors to the plant

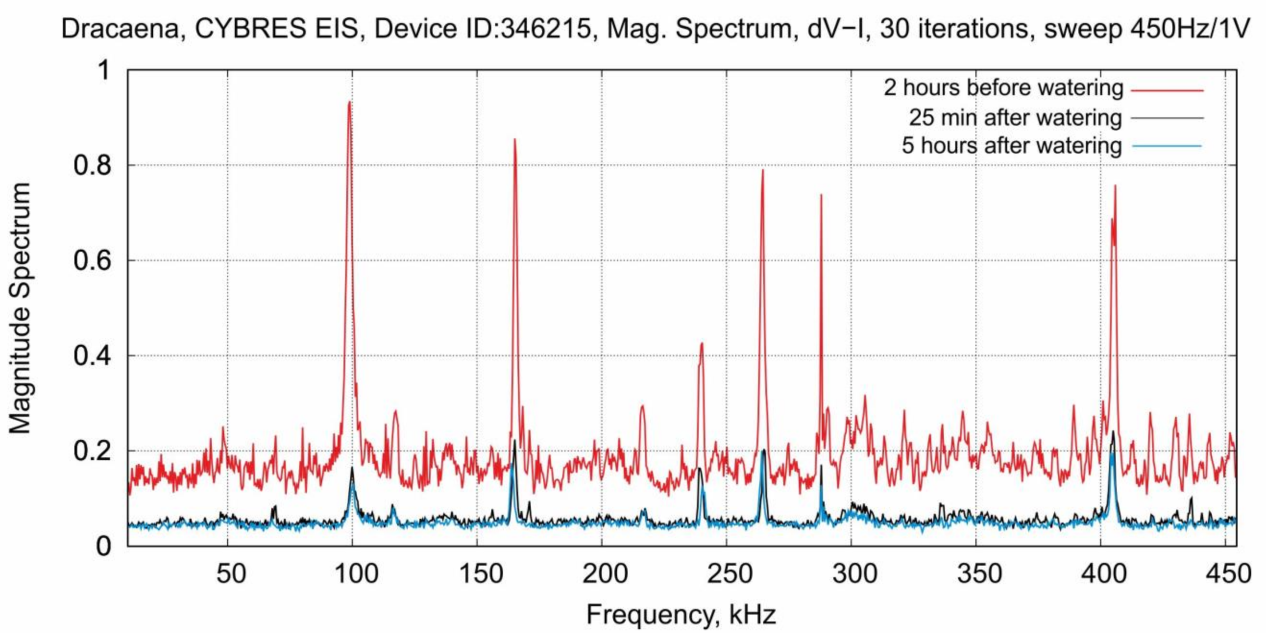


sap flow sensor
(based on thermal balance method)

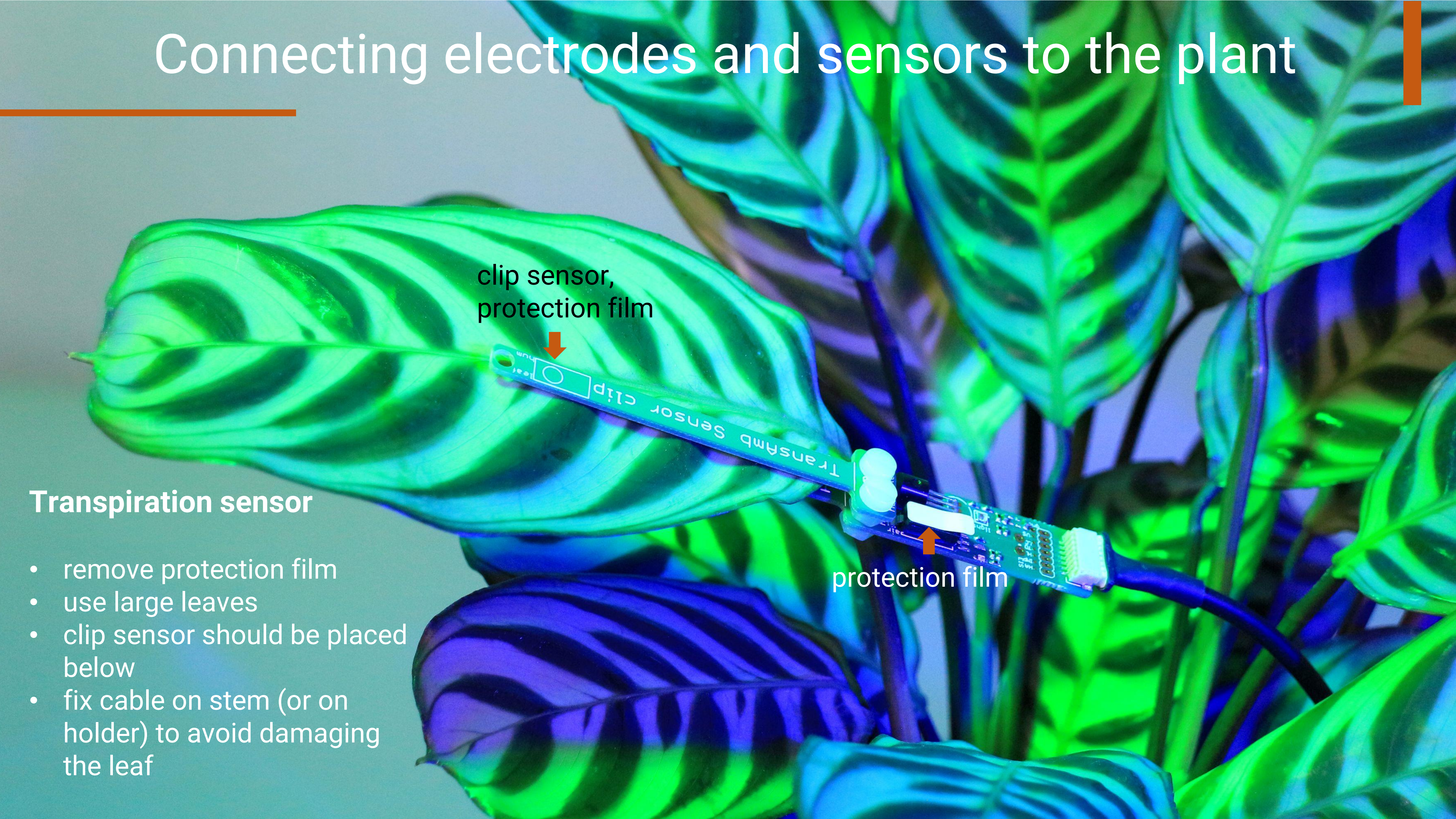
- stem diameter ~1-3 cm
- use thermal covering
- use in short-pulse mode, avoid long-term continuous usage
- make use of plant topology

Electrochemical sap flow sensor
(based on tissue impedance measurements)


Calathea, CYBRES EIS, Device ID:346252, Mag. Spectrum, dV−I, 30 iterations, sweep 450Hz/1V


Dracaena, CYBRES EIS, Device ID:346215, Mag. Spectrum, dV−I, 30 iterations, sweep 450Hz/1V

Connecting electrodes and sensors to the plant



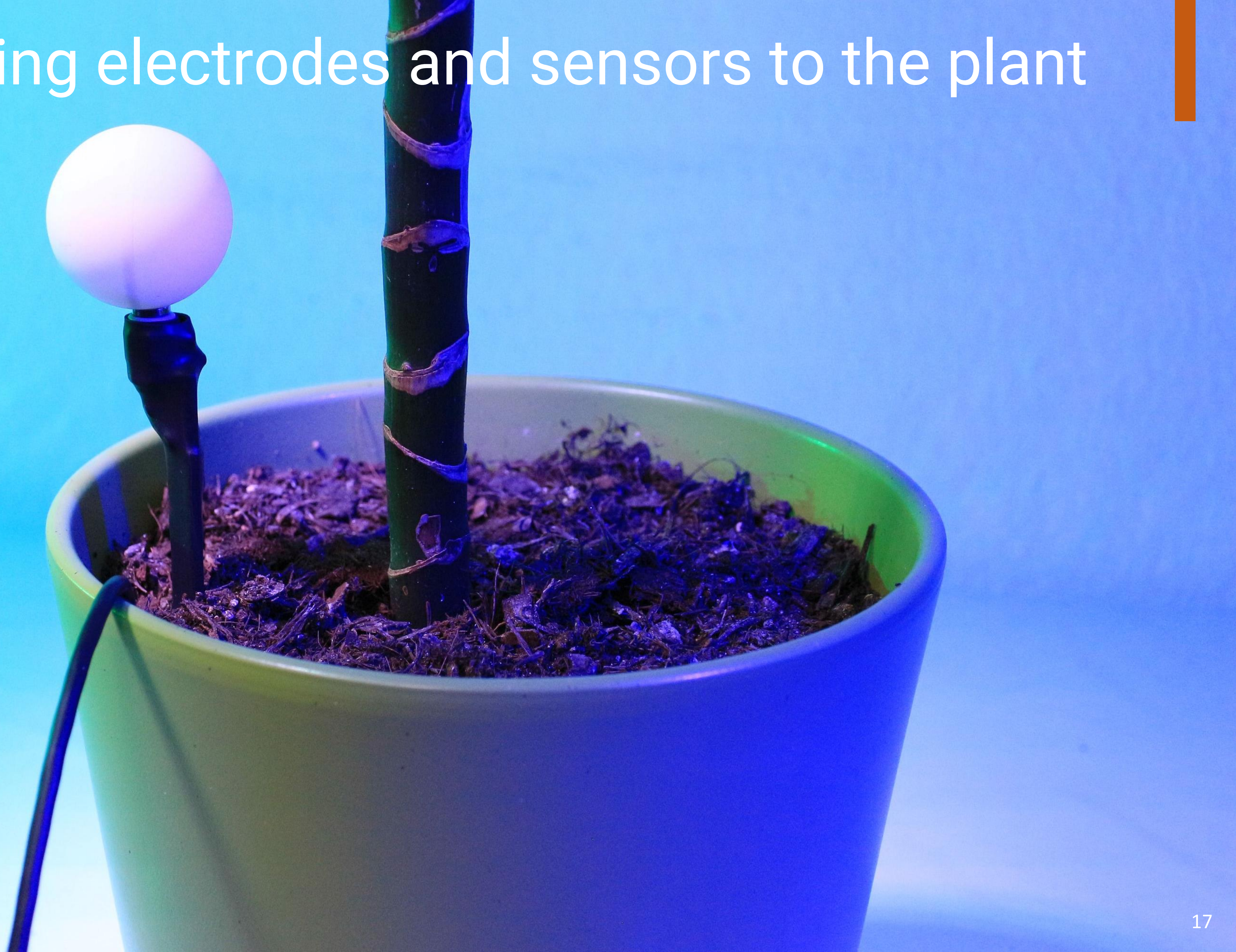
clip sensor, protection film

protection film

Transpiration sensor

- remove protection film
- use large leaves
- clip sensor should be placed below
- fix cable on stem (or on holder) to avoid damaging the leaf

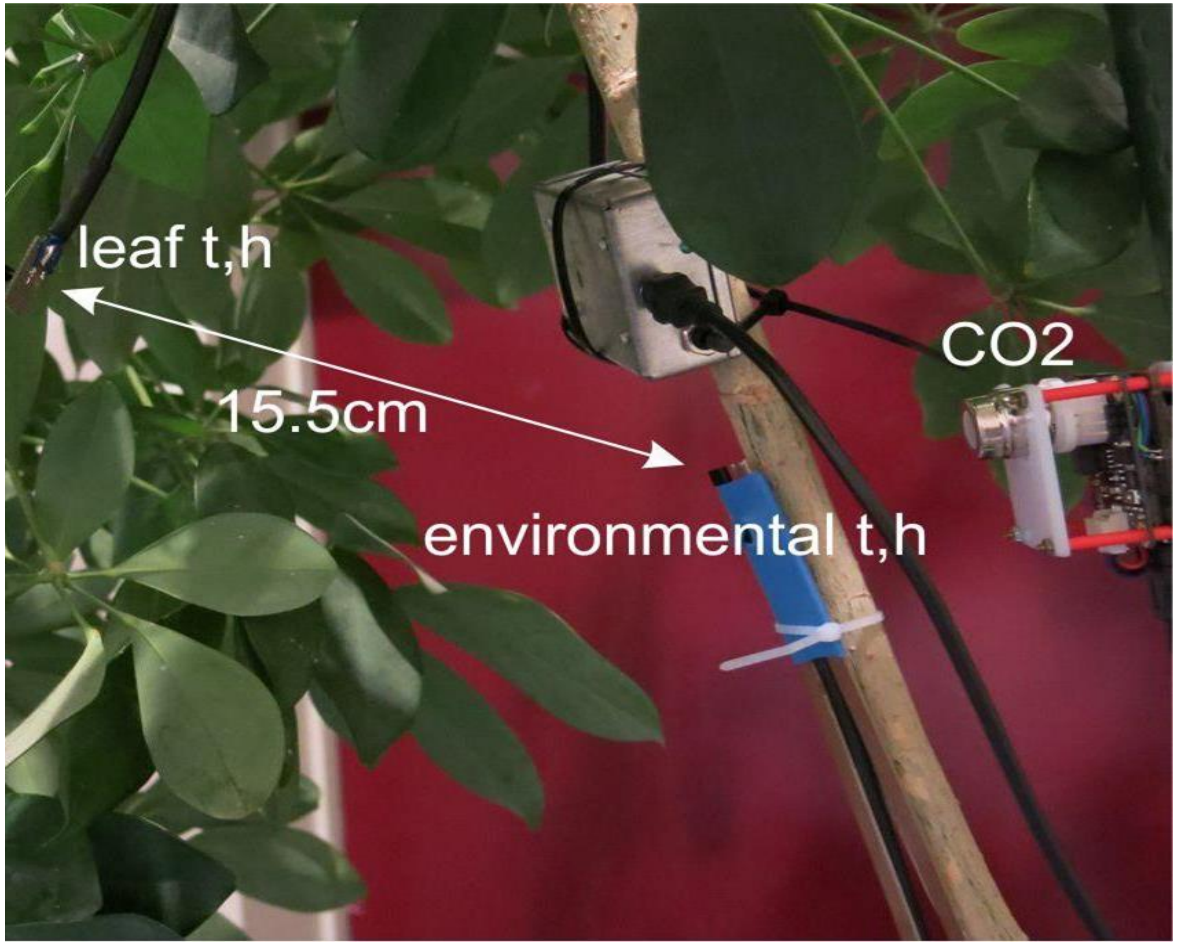
Connecting electrodes and sensors to the plant

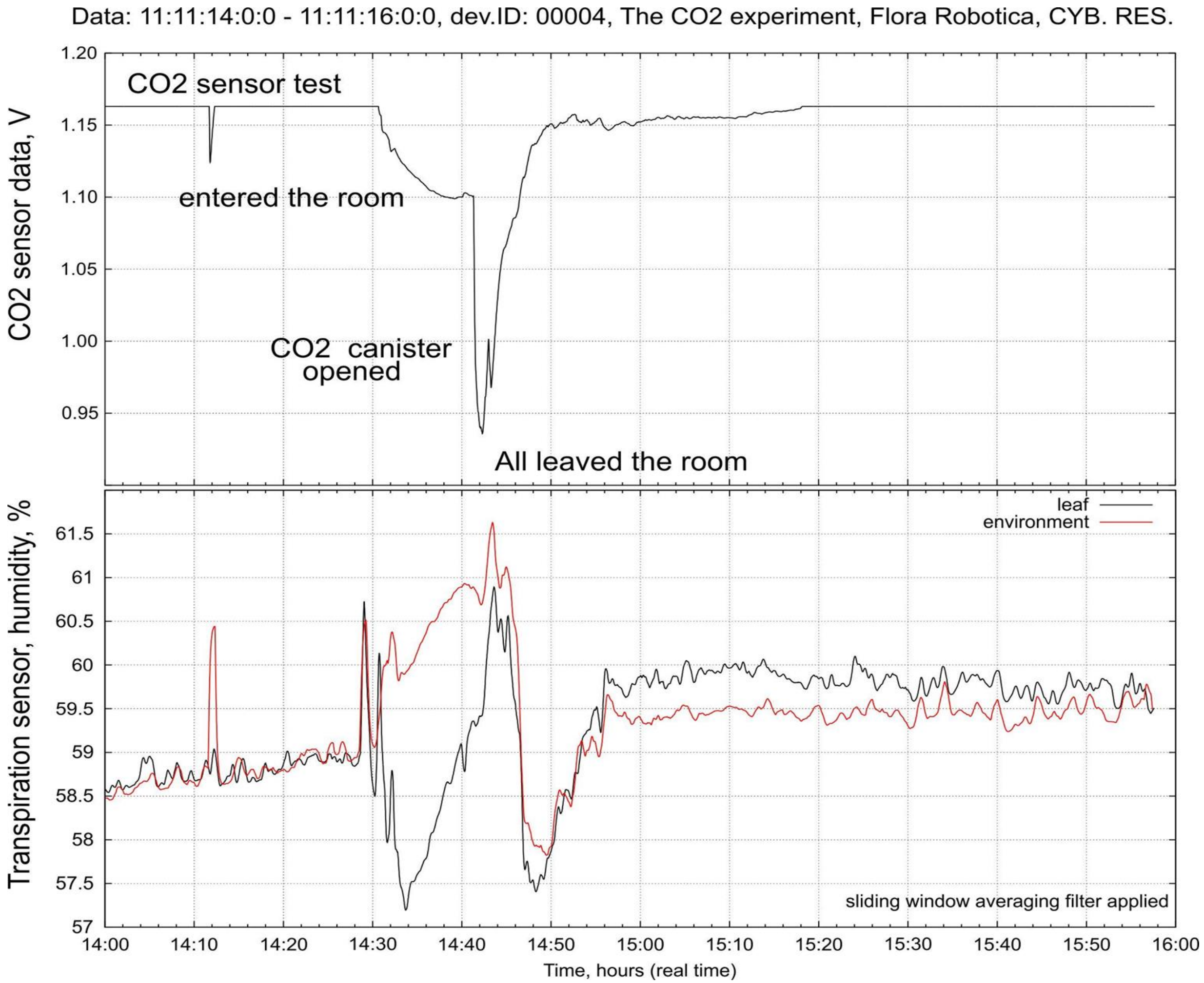


Soil sensor &
RGB Light Actuator

- water resistant, surface can be eroded
- avoid damaging of roots
- set low frequency of update -> capacitive sensor interacts with biopotentials
- sensor reading depends on the position, for calibration use relative values

Additional (e.g. CO_2) I^2C sensors





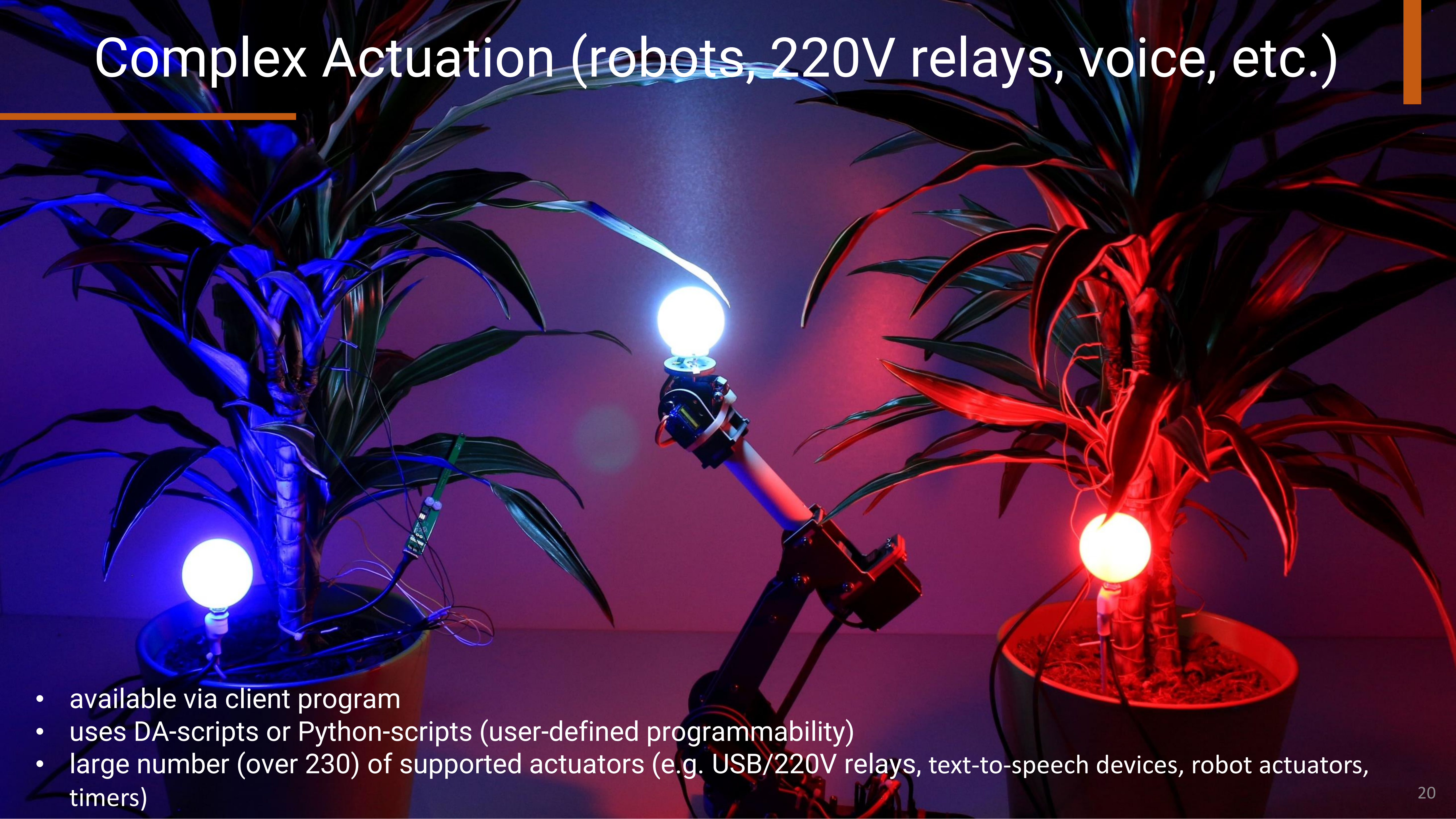
Use analog (voltage output), I2C bus, UART (with/without bridges), SPI bus (internal connection required) sensors
Typically, firmware update (sensor driver in firmware) is required

RGB Light Actuators

RGB Light Actuation

- internal MOSFETs (3.3V, 10 Ohm resistors)
- directly accessible via ASCII commands
- switching high-current LEDs causes measurement artifacts

Complex Actuation (robots, 220V relays, voice, etc.)

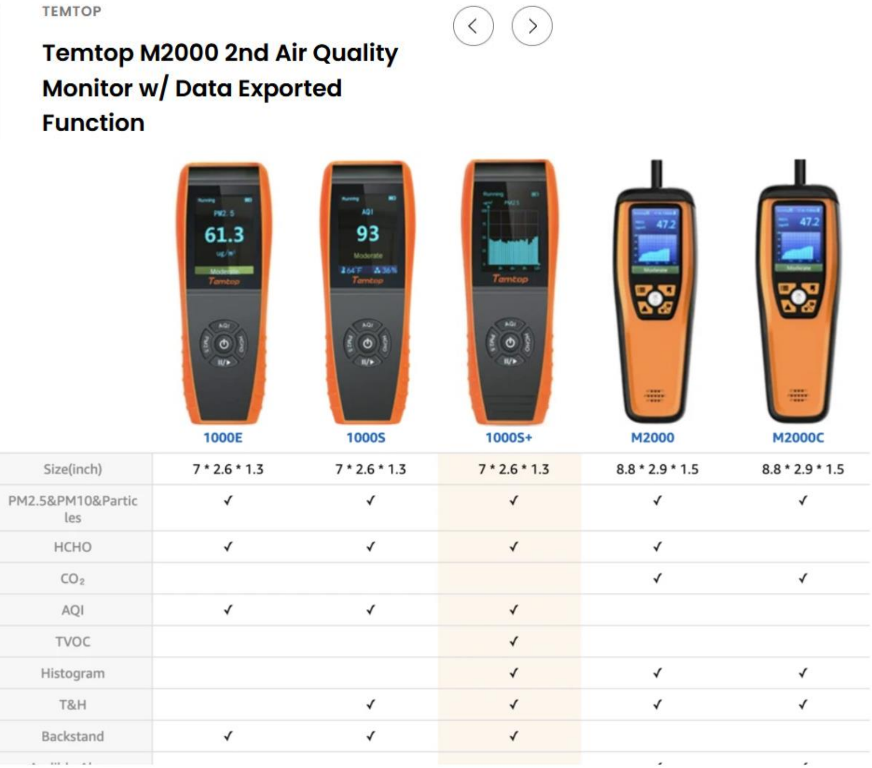


- available via client program
- uses DA-scripts or Python-scripts (user-defined programmability)
- large number (over 230) of supported actuators (e.g. USB/220V relays, text-to-speech devices, robot actuators, timers)

Outdoor Setup

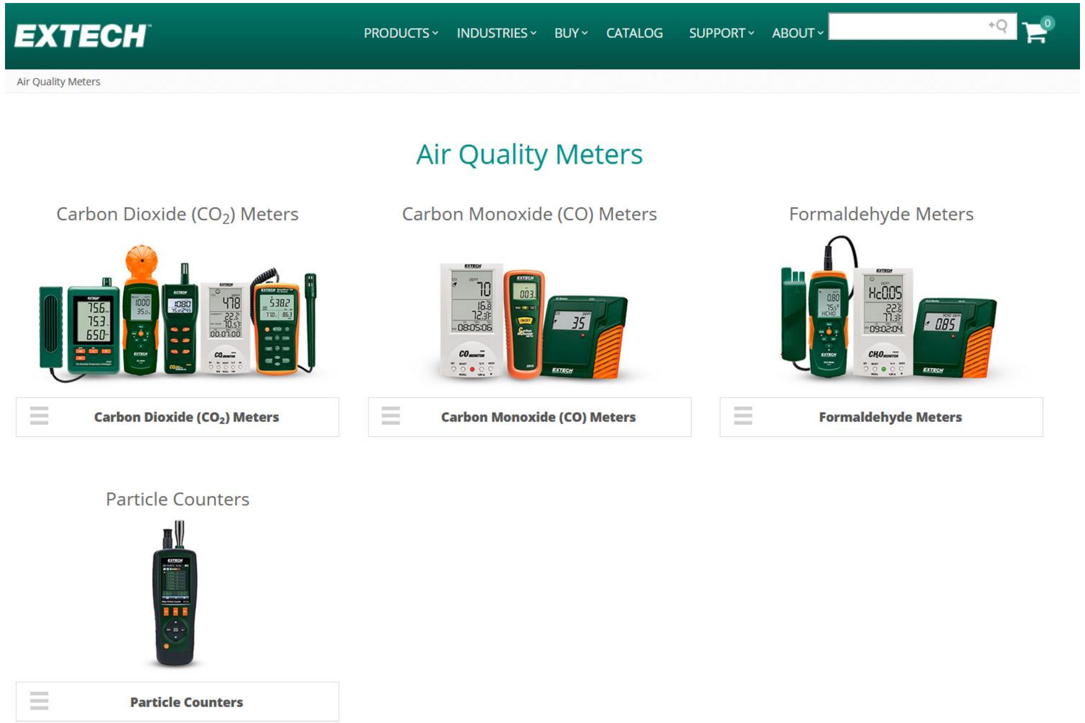
- Powering (PoE, solar)
- Packaging (IP class)
- Communication (PoE, WiFi, GSM)
- Different sensors (for outdoor plants)

Environmental sensors (device level)


TEMTOP

Temtop M2000 2nd Air Quality Monitor w/ Data Exported Function

	1000E	1000S	1000S+	M2000	M2000C
Size(inch)	7 * 2.6 * 1.3	7 * 2.6 * 1.3	7 * 2.6 * 1.3	8.8 * 2.9 * 1.5	8.8 * 2.9 * 1.5
PM2.5&PM10&Particles	✓	✓	✓	✓	✓
HCHO	✓	✓	✓	✓	
CO_2				✓	✓
AQI	✓	✓	✓		
TVOC			✓		
Histogram			✓	✓	✓
T&H		✓	✓	✓	✓
Backstand	✓	✓	✓		



Air Quality Meters

Carbon Dioxide (CO_2) Meters

Carbon Monoxide (CO) Meters

Formaldehyde Meters

Carbon Dioxide (CO_2) Meters

Carbon Monoxide (CO) Meters

Formaldehyde Meters

Particle Counters

Particle Counters

- see for overview e.g. https://wiki.ezvid.com/best-air-quality-monitors
- professional single-sensor devices: e.g. EXTECH (i.e. 7 devices for 7 sensing parameters)
- combined devices, 7-in-1, 9-in-1, range up to 500€: e.g. Temtop LKC-1000S+, Temtop M2000 2nd, IQAir AirVisual Pro
- commonly referred issues with combined devices: low repeatability (probably low accuracy), **external data logger functionality (e.g. via USB) in continuous mode is not provided**

Environmental sensors (sensor level)

SENSIRION
THE SENSOR COMPANY

Datasheet SGP30
Indoor Air Quality Sensor for TVOC and CO2eq Measurements

1)

- Multi-pixel gas sensor for indoor air quality applications
- Outstanding long-term stability
- I²C interface with TVOC and CO₂eq output signals
- Very small 6-pin DFN package: 2.45 x 2.45 x 0.9 mm³
- Low power consumption: 48 mA at 1.8V
- Tape and reel packaged, reflow solderable

accuracy ~ ± 15%

Data Sheet SFA30
Formaldehyde Sensor Module for HVAC and Indoor Air Quality Applications

2)

Target applications

- Real-time reading of HCHO gas concentration in parts per billion
- Air Conditioners and Air Exchangers
- Air Purifiers
- Indoor Air Quality Monitors

Key features

- Low cross-sensitivity to ethanol
- Long-term stability and 6 years' service life time
- Patented electrochemical cell with anti-dry technology
- I²C/UART interface with lifetime-calibrated output
- Fully temperature and humidity compensated via Sensirion RHT sensor

accuracy ~ ± 20%

SCD4x
Breaking the size barrier in CO₂ sensing

3a)

accuracy ± 9%-10% at 1000ppm

Features

- Photoacoustic sensor technology PASens®
- Smallest form factor: 10.1 x 10.1 x 6.5 mm³
- Surface-mount device for effective assembly
- Large output range: 0 ppm – 40'000 ppm
- Large supply voltage range: 2.4 – 5.5 V
- High accuracy: ±(40 ppm + 5 %)
- Digital interface I²C with digital output signal
- Integrated temperature and humidity sensor
- Adjustable current-consumption down to < 0.4 mA avg. @ 5 V, 1 meas. / 5 minutes

SENSIRION
THE SENSOR COMPANY

3b)

Datasheet Sensirion SCD30 Sensor Module
CO₂, humidity, and temperature sensor

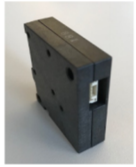
- NDIR CO₂ sensor technology
- Integrated temperature and humidity sensor
- Best performance-to-price ratio
- Dual-channel detection for superior stability
- Small form factor: 35 mm x 23 mm x 7 mm
- Measurement range: 400 ppm – 10.000 ppm
- Accuracy: ±(30 ppm + 3%)
- Current consumption: 19 mA @ 1 meas. per 2 s.
- Fully calibrated and linearized
- Digital interface UART or I²C

accuracy ±6% at 1000ppm

Panasonic

SN-GCJA5 Particulate Matter Laser Sensor

- On board Laser Diode provides Particulate Matter detection for indoor air quality (±10%, from low to high concentrations ~ 1,000 µgm3)
- Output mass-density value of PM1.0, Pm2.5 and PM10 (µgm3)
- Minimum detectable particle: 0.3µm
- Very small footprint: 37×37×12mm
- Weight: 13g
- Extended lifetime optimized by S/W control
- Optimized air pathway design to minimize dust accumulation
- High S/N



4a)

accuracy ~ ± 10%

SENSIRION
THE SENSOR COMPANY

4b)

Datasheet SPS30
Particulate Matter Sensor for Air Quality Monitoring and Control

- Unique long-term stability
- Advanced particle size binning
- Superior precision in mass concentration and number concentration sensing
- Small, ultra-slim package
- Fully calibrated digital output

accuracy ~ ± 10%

SPEC SENSORS

3SP_O3_20 C Package 110-407
March 2019

5,6) O3 and NO2

15x15 O3 Sensor 20 ppm C Package 110-407

SPEC SENSORS

DGS-NO2 968-043
August 2017

Digital Gas Sensor – Nitrogen Dioxide

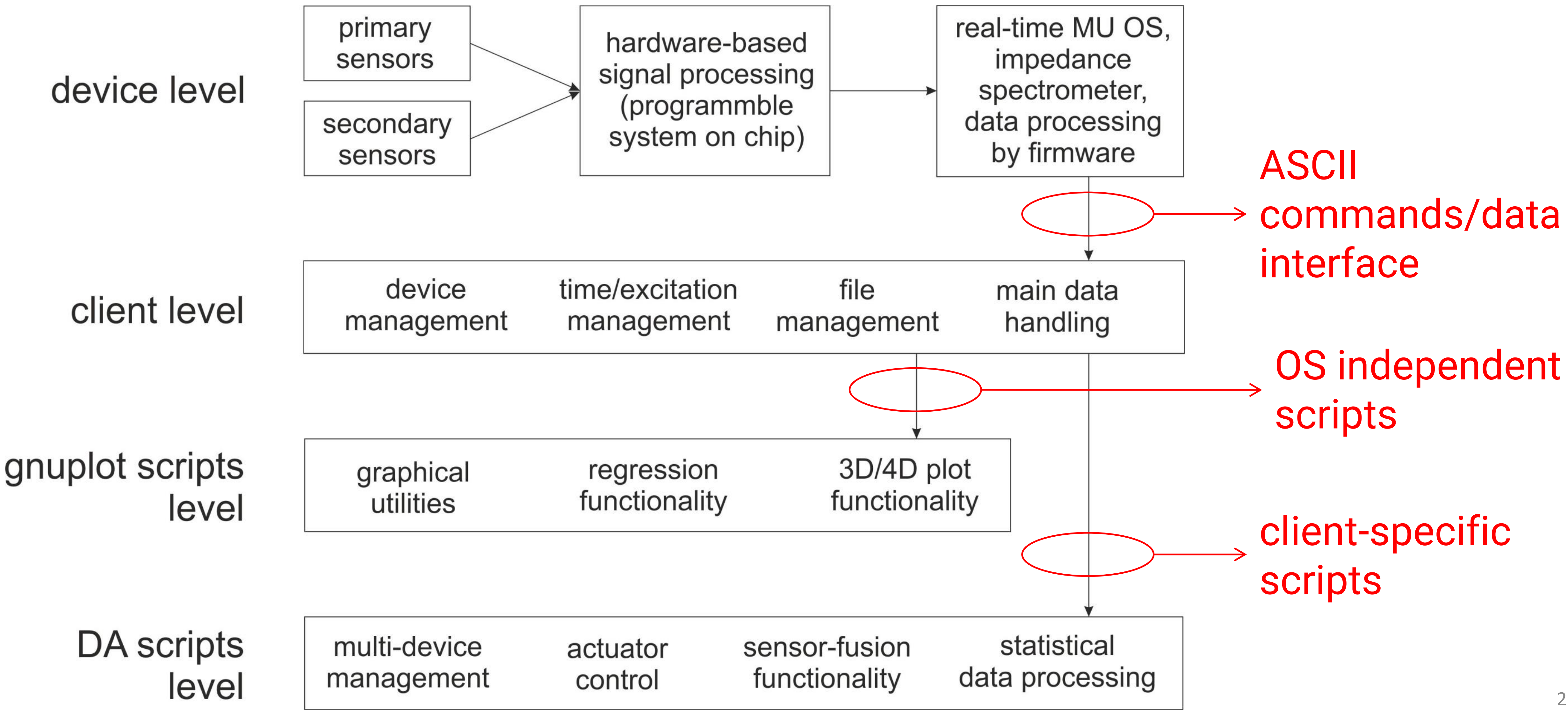
- It makes sense to integrate environmental sensors on the sensor level
- class: <100€ per sensor (expensive!), I2C interface (easy to integrate)

2. Software, ASCII communication and commands

Operating System (OS) Dependency

OS	Access to device, client programs and scripts	Win10 mini PC	Analysis on client level	Plotting engine	User-defined programs
Windows	All components are prepared, full access	yes	full access	screen, web, jpeg, eps	programmable within prepared framework, DA/Python scripts
Linux	• Access to device via ASCII interface	no	no	no	yes, any
	• Access to mini PC via TCP/IP communication	yes	full access	screen, web, jpeg, eps	yes, any
Android, iOS	access to data and plots from mobile devices via Remote Desktop	yes	full access	screen, web, jpeg, eps	programmable within prepared framework, DA/Python scripts

Software structure



device level

primary sensors

secondary sensors

hardware-based signal processing (programmble system on chip)

real-time MU OS, impedance spectrometer, data processing by firmware

ASCII commands/data interface

client level

device management

time/excitation management

file management

main data handling

OS independent scripts

gnuplot scripts level

graphical utilities

regression functionality

3D/4D plot functionality

client-specific scripts

DA scripts level

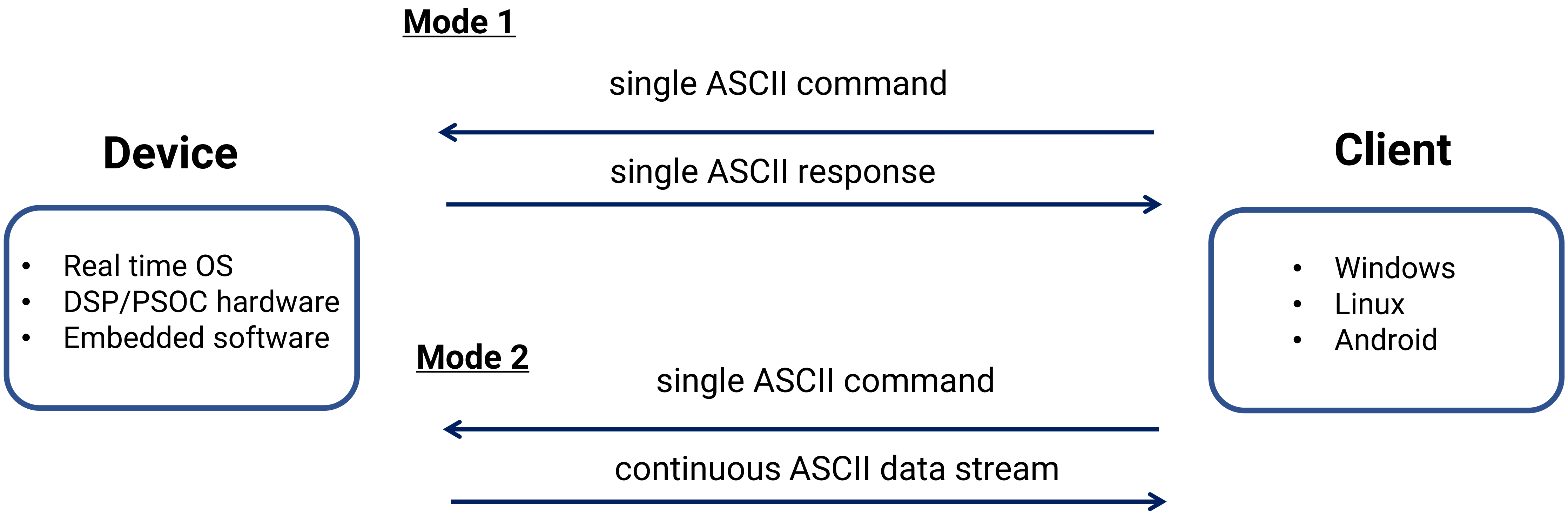
multi-device management

actuator control

sensor-fusion functionality

statistical data processing

Communication with device: general principles



Device

- Real time OS
- DSP/PSOC hardware
- Embedded software

Mode 1

single ASCII command

single ASCII response

Mode 2

single ASCII command

continuous ASCII data stream

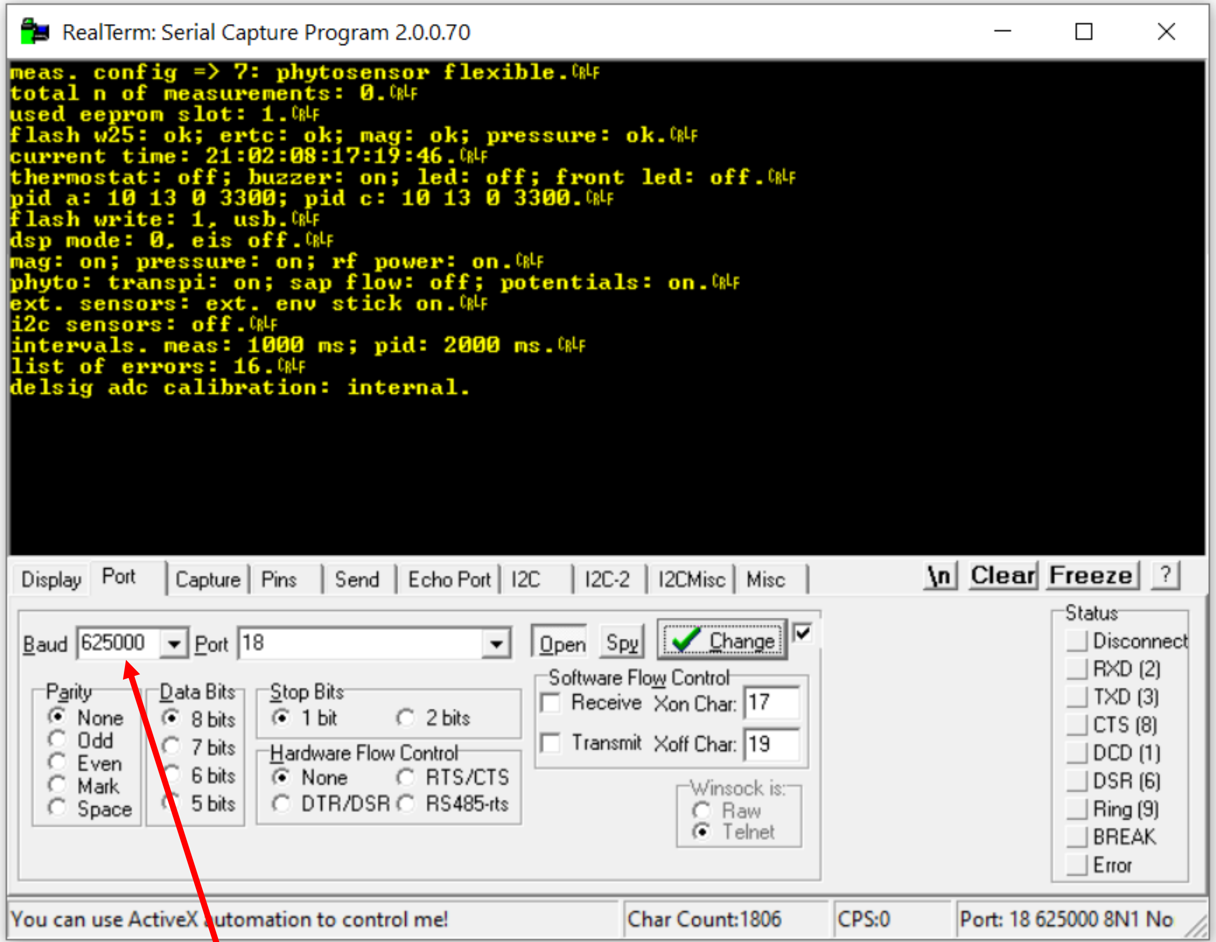
Client

- Windows
- Linux
- Android

Communication on the client side is a standard COM port operation:
open port -> write data -> read data -> close port

Example of ASCII Communication

(from Windows, Linux, Android)



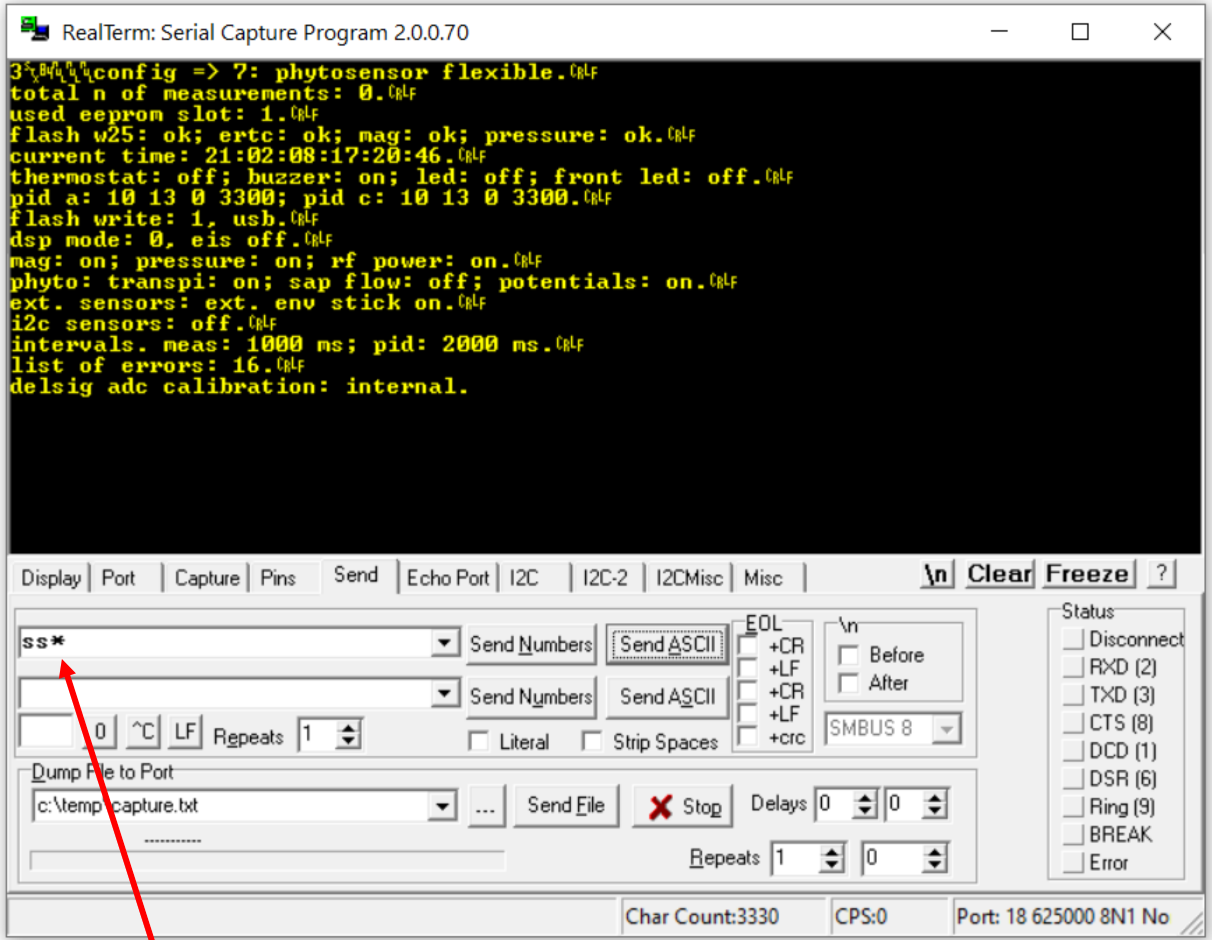
RealTerm: Serial Capture Program 2.0.0.70

```
meas. config => 7: phytosensor flexible.CRLF
total n of measurements: 0.CRLF
used eeprom slot: 1.CRLF
flash w25: ok; ertc: ok; mag: ok; pressure: ok.CRLF
current time: 21:02:08:17:19:46.CRLF
thermostat: off; buzzer: on; led: off; front led: off.CRLF
pid a: 10 13 0 3300; pid c: 10 13 0 3300.CRLF
flash write: 1, usb.CRLF
dsp mode: 0, eis off.CRLF
mag: on; pressure: on; rf power: on.CRLF
phyto: transpi: on; sap flow: off; potentials: on.CRLF
ext. sensors: ext. env stick on.CRLF
i2c sensors: off.CRLF
intervals. meas: 1000 ms; pid: 2000 ms.CRLF
list of errors: 16.CRLF
delsig adc calibration: internal.
```

Baud: 625000
Port: 18
Parity: ● None
Data Bits: ● 8 bits
Stop Bits: ● 1 bit
Hardware Flow Control: ● None
Software Flow Control: ☐ Receive Xon Char: 17; ☐ Transmit Xoff Char: 19
Winsock is: ● Telnet

You can use ActiveX automation to control me! | Char Count:1806 | CPS:0 | Port: 18 625000 8N1 No

standard operating baudrate: see init/init.ini (625000)
(emulated via USB!)



RealTerm: Serial Capture Program 2.0.0.70

```
3[illegible]config => 7: phytosensor flexible.CRLF
total n of measurements: 0.CRLF
used eeprom slot: 1.CRLF
flash w25: ok; ertc: ok; mag: ok; pressure: ok.CRLF
current time: 21:02:08:17:20:46.CRLF
thermostat: off; buzzer: on; led: off; front led: off.CRLF
pid a: 10 13 0 3300; pid c: 10 13 0 3300.CRLF
flash write: 1, usb.CRLF
dsp mode: 0, eis off.CRLF
mag: on; pressure: on; rf power: on.CRLF
phyto: transpi: on; sap flow: off; potentials: on.CRLF
ext. sensors: ext. env stick on.CRLF
i2c sensors: off.CRLF
intervals. meas: 1000 ms; pid: 2000 ms.CRLF
list of errors: 16.CRLF
delsig adc calibration: internal.
```

ss*

Repeats: 1
Dump File to Port: c:\temp\capture.txt
Delays: 0 0
Repeats: 1 0

Char Count:3330 | CPS:0 | Port: 18 625000 8N1 No

ASCII commands

Device Commands

see User Manual, p.63, section 5.8 “Communication with the EIS operating system”

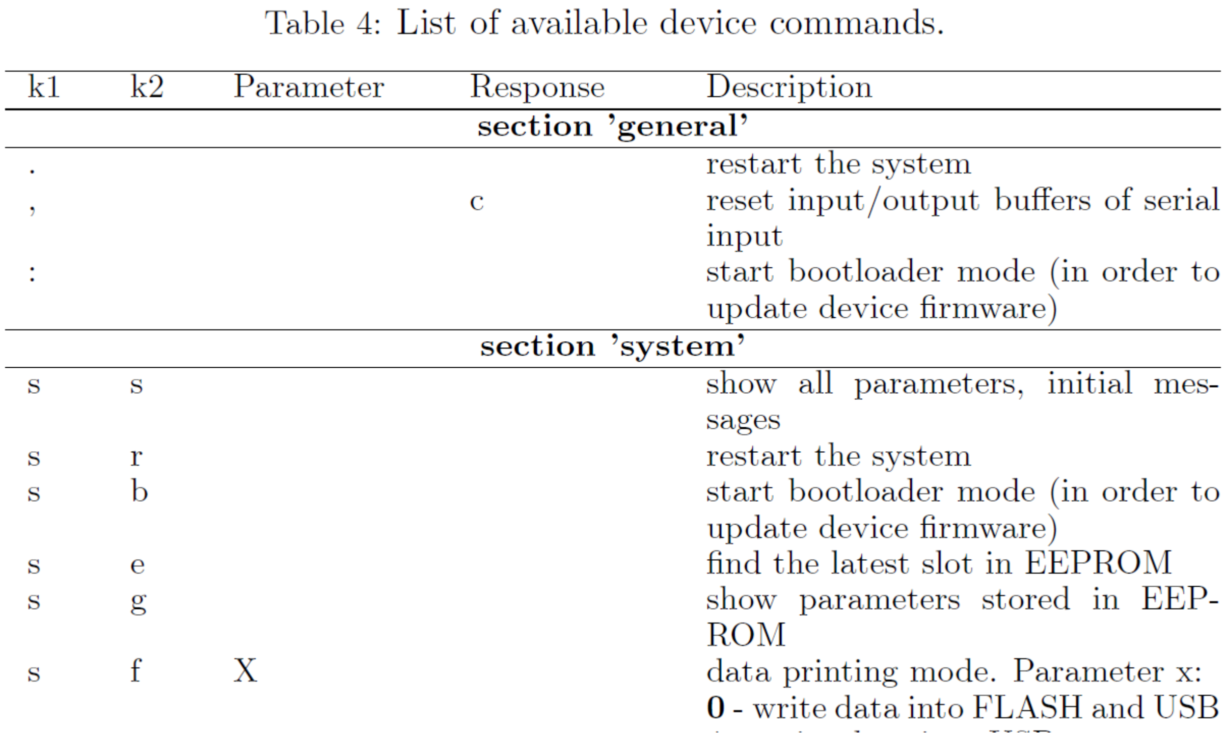


Table 4: List of available device commands.

k1	k2	Parameter	Response	Description
		section ’general’		
.				restart the system
,			c	reset input/output buffers of serial input
:				start bootloader mode (in order to update device firmware)
		section ’system’		
s	s			show all parameters, initial messages
s	r			restart the system
s	b			start bootloader mode (in order to update device firmware)
s	e			find the latest slot in EEPROM
s	g			show parameters stored in EEPROM
s	f	X		data printing mode. Parameter x: **0** - write data into FLASH and USB

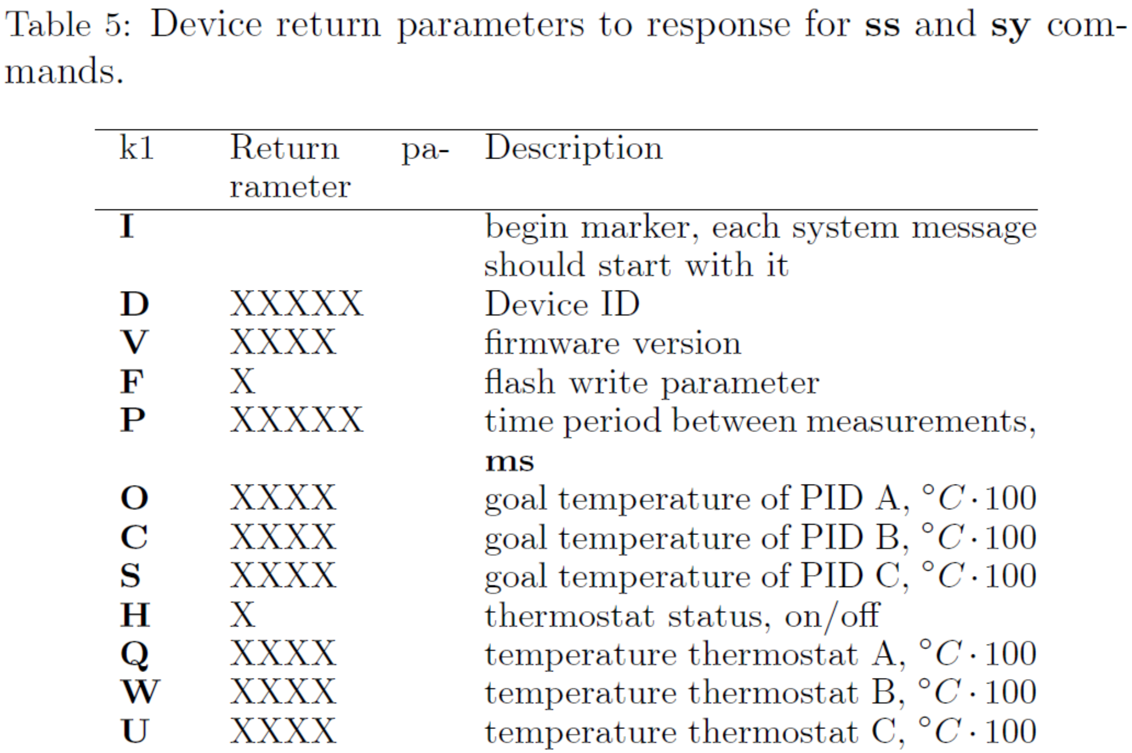


Table 5: Device return parameters to response for **ss** and **sy** commands.

k1	Return parameter	Description
I		begin marker, each system message should start with it
D	XXXXX	Device ID
V	XXXX	firmware version
F	X	flash write parameter
P	XXXXX	time period between measurements, **ms**
O	XXXX	goal temperature of PID A, $^{\circ}C \cdot 100$
C	XXXX	goal temperature of PID B, $^{\circ}C \cdot 100$
S	XXXX	goal temperature of PID C, $^{\circ}C \cdot 100$
H	X	thermostat status, on/off
Q	XXXX	temperature thermostat A, $^{\circ}C \cdot 100$
W	XXXX	temperature thermostat B, $^{\circ}C \cdot 100$
U	XXXX	temperature thermostat C, $^{\circ}C \cdot 100$

end marker

Format of commands: k1k2xxxx*

parameters

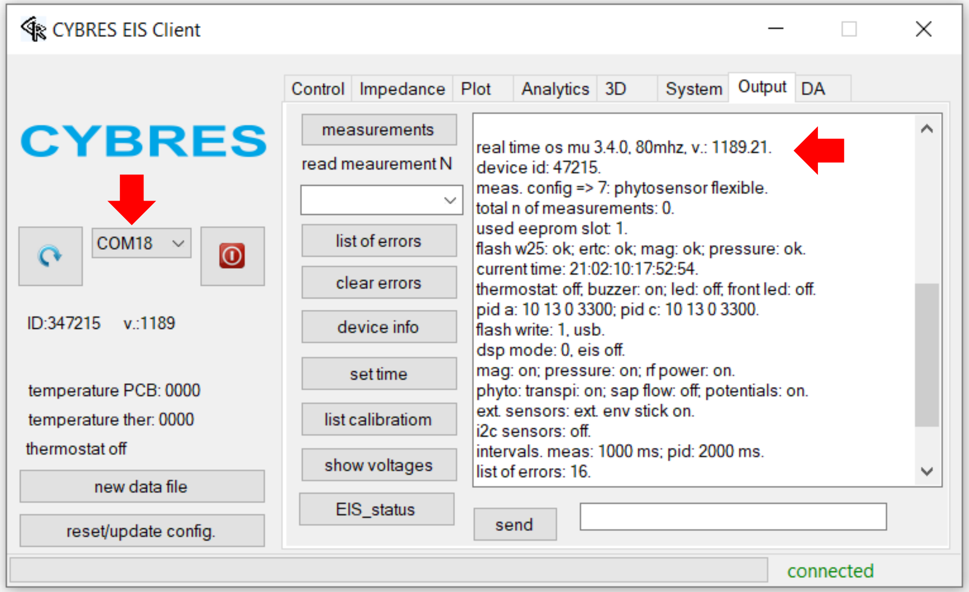
3. Software Client Program, parameters of measurements and data structures

Client Program

- Installation for Win 10: typically no drives are required
- Install the redistributable package for visual C++ 2012 and Gnuplot (all files are in the directory 'drivers'), see “User Manual”, p. 49
- Connect to “COM port” of the device

For the first time only, check:

- the firmware version
- configuration
- enable/disable additional sensors
- setup the period between measurements, e.g. 10 secs.



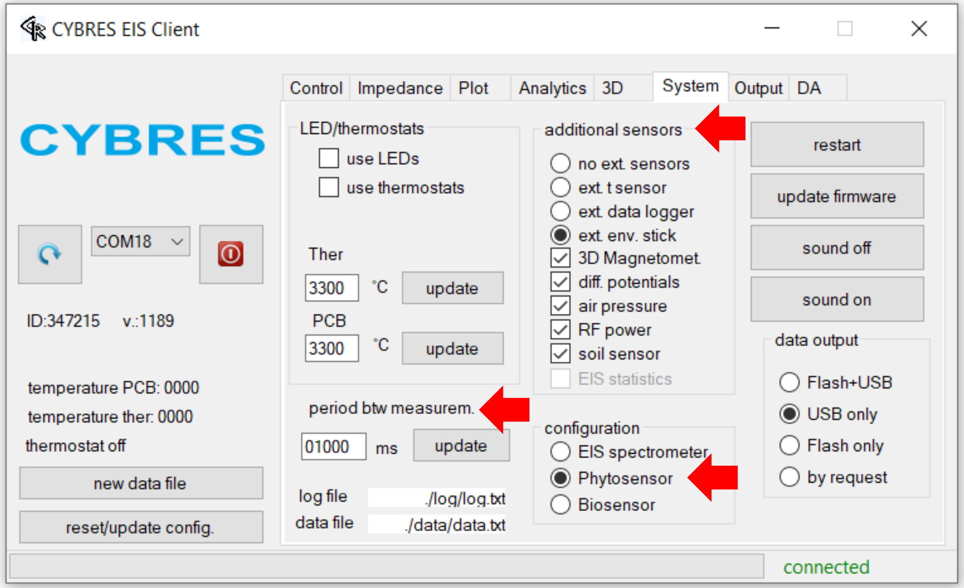
COM18

ID:347215 v.:1189

temperature PCB: 0000
temperature ther: 0000
thermostat off

```
real time os mu 3.4.0, 80mhz, v.: 1189.21.
device id: 47215.
meas. config => 7: phytosensor flexible.
total n of measurements: 0.
used eeprom slot: 1.
flash w25: ok; ertc: ok; mag: ok; pressure: ok.
current time: 21:02:10:17:52:54.
thermostat: off; buzzer: on; led: off; front led: off.
pid a: 10 13 0 3300; pid c: 10 13 0 3300.
flash write: 1, usb.
dsp mode: 0, eis off.
mag: on; pressure: on; rf power: on.
phyto: transpi: on; sap flow: off; potentials: on.
ext. sensors: ext. env stick on.
i2c sensors: off.
intervals. meas: 1000 ms; pid: 2000 ms.
list of errors: 16.
```

connected



COM18

ID:347215 v.:1189

temperature PCB: 0000
temperature ther: 0000
thermostat off

LED/thermostats
☐ use LEDs
☐ use thermostats

Ther 3300 °C
PCB 3300 °C

period btw measurem. 01000 ms

log file ./log/log.txt
data file ./data/data.txt

additional sensors
○ no ext. sensors
○ ext. t sensor
○ ext. data logger
● ext. env. stick
☑ 3D Magnetomet.
☑ diff. potentials
☑ air pressure
☑ RF power
☑ soil sensor
☐ EIS statistics

configuration
○ EIS spectrometer
● Phytosensor
○ Biosensor

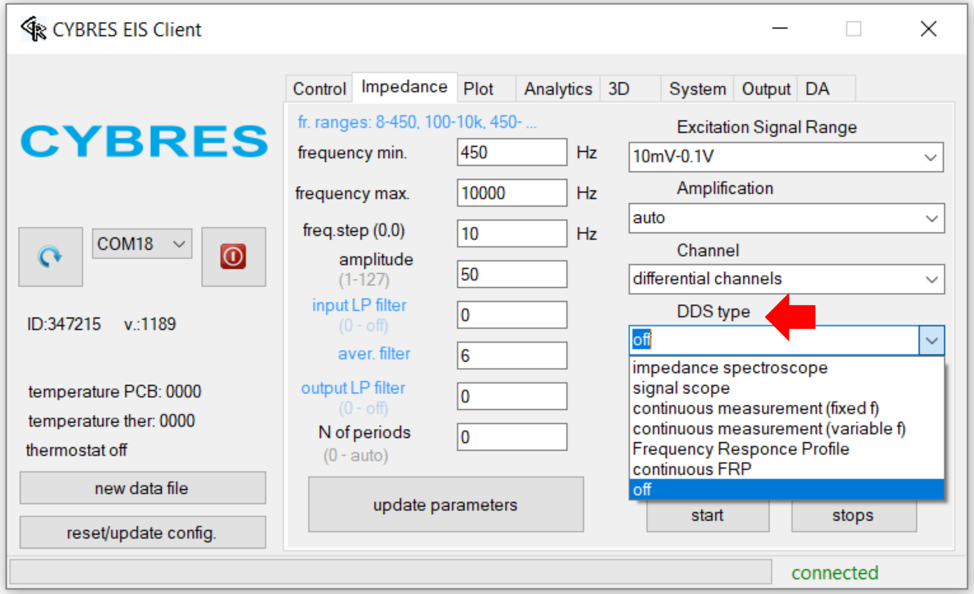
data output
○ Flash+USB
● USB only
○ Flash only
○ by request

connected

Configuration of measurement parameters

- “DDS type” specifies Impedance Spectroscopy module (Tissue Impedance, Ionic Interfaces and Electrical Stimulation): off if not used

- use primarily the lowest signal excision range (0.01 V)



fr. ranges: 8-450, 100-10k, 450- ...
frequency min. 450 Hz
frequency max. 10000 Hz
freq.step (0,0) 10 Hz
amplitude (1-127) 50
input LP filter (0 - off) 0
aver. filter 6
output LP filter (0 - off) 0
N of periods (0 - auto) 0

Excitation Signal Range: 10mV-0.1V
Amplification: auto
Channel: differential channels
DDS type: off

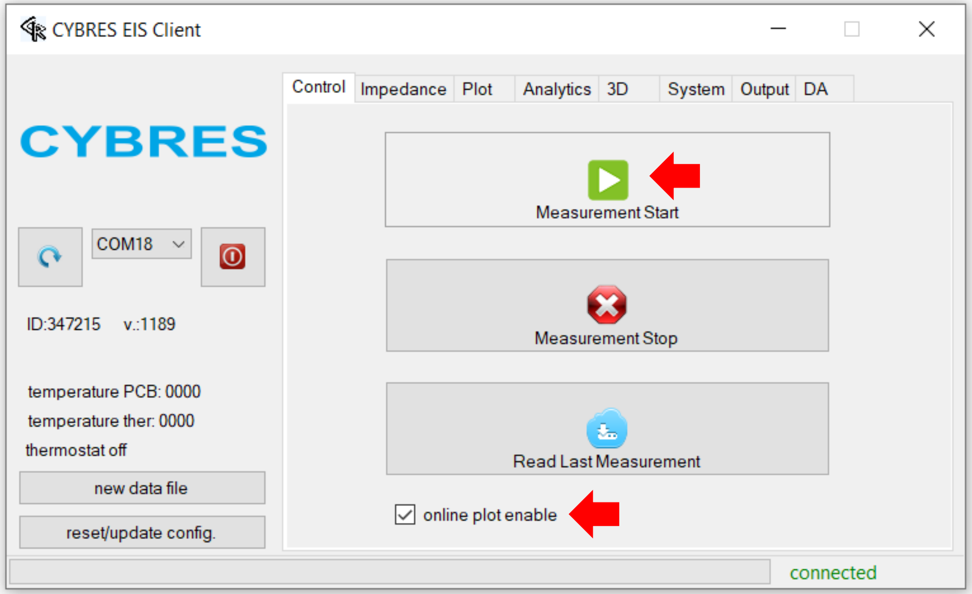
ID:347215 v.:1189

temperature PCB: 0000
temperature ther: 0000
thermostat off

connected

- To start measurements, press “Measurements Start”

- Enable online plot



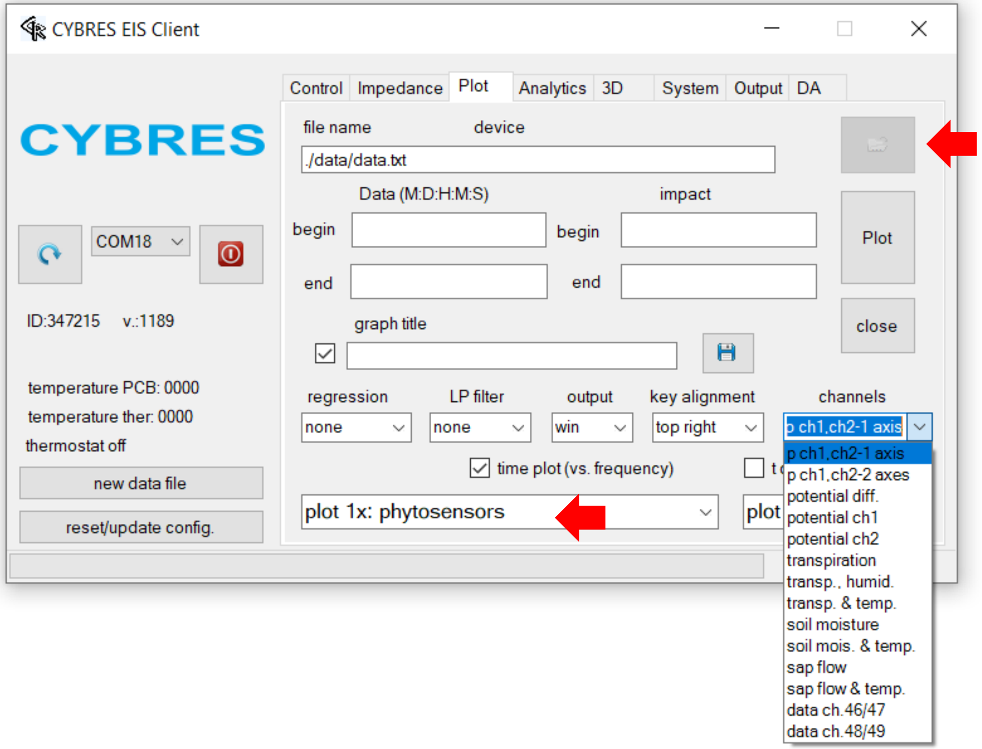
☑ online plot enable

ID:347215 v.:1189

temperature PCB: 0000
temperature ther: 0000
thermostat off

connected

Configuration of measurement parameters



file name: ./data/data.txt

device:

Data (M:D:H:M:S) begin: end:

impact begin: end:

ID:347215 v.:1189

temperature PCB: 0000

temperature ther: 0000

thermostat off

☑ graph title:

regression: none

LP filter: none

output: win

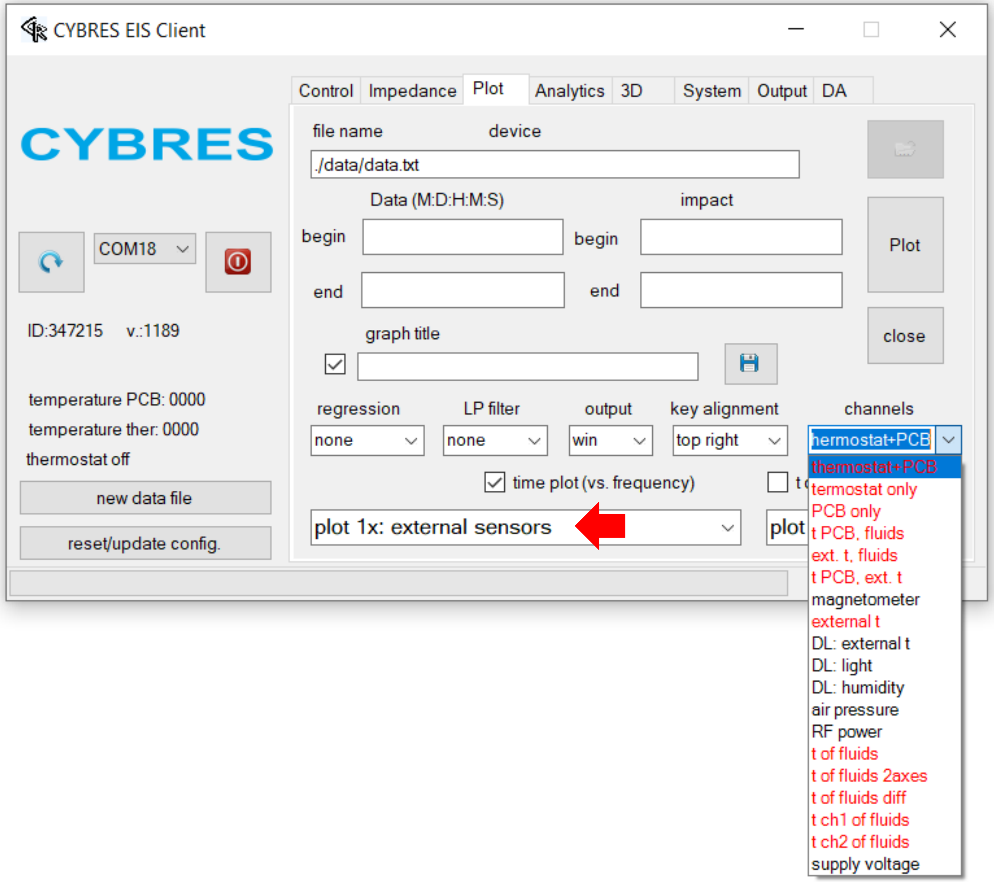
key alignment: top right

channels: p ch1,ch2-1 axis

☑ time plot (vs. frequency)

plot 1x: phytosensors

open the file



file name: ./data/data.txt

device:

Data (M:D:H:M:S) begin: end:

impact begin: end:

ID:347215 v.:1189

temperature PCB: 0000

temperature ther: 0000

thermostat off

☑ graph title:

regression: none

LP filter: none

output: win

key alignment: top right

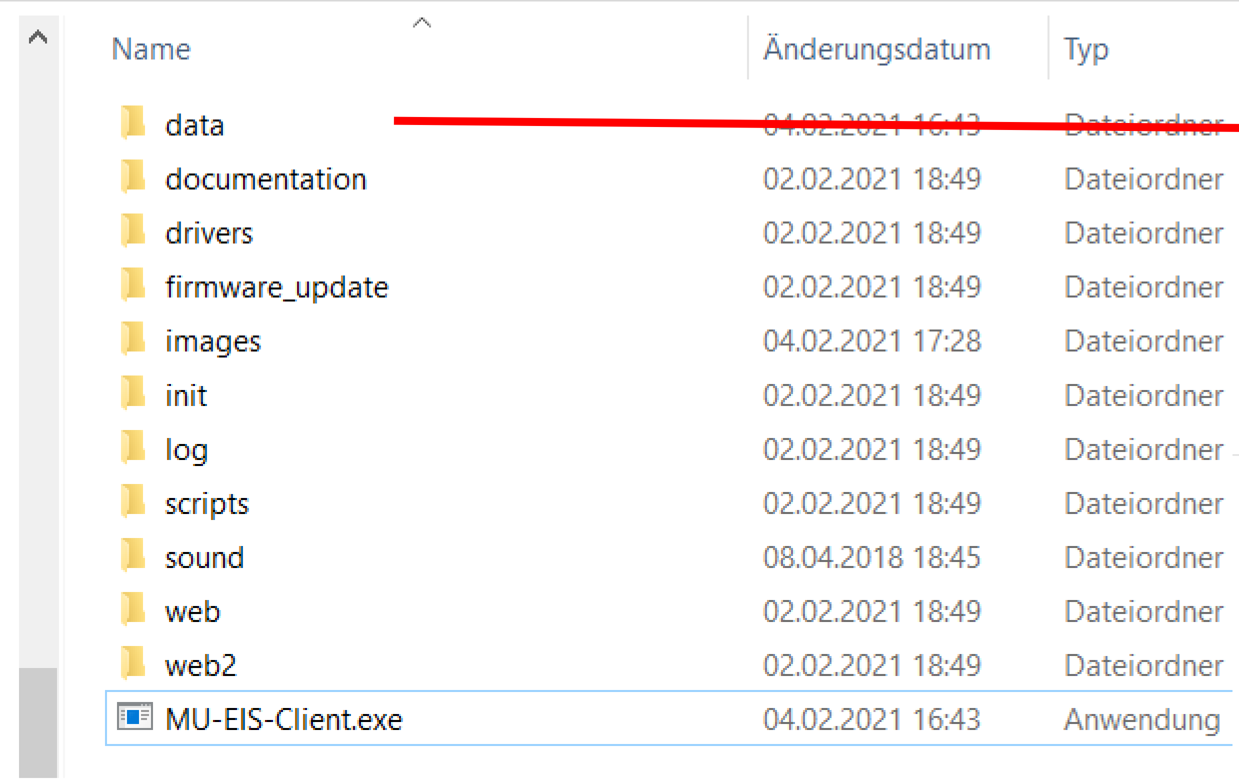
channels: thermostat+PCB

☑ time plot (vs. frequency)

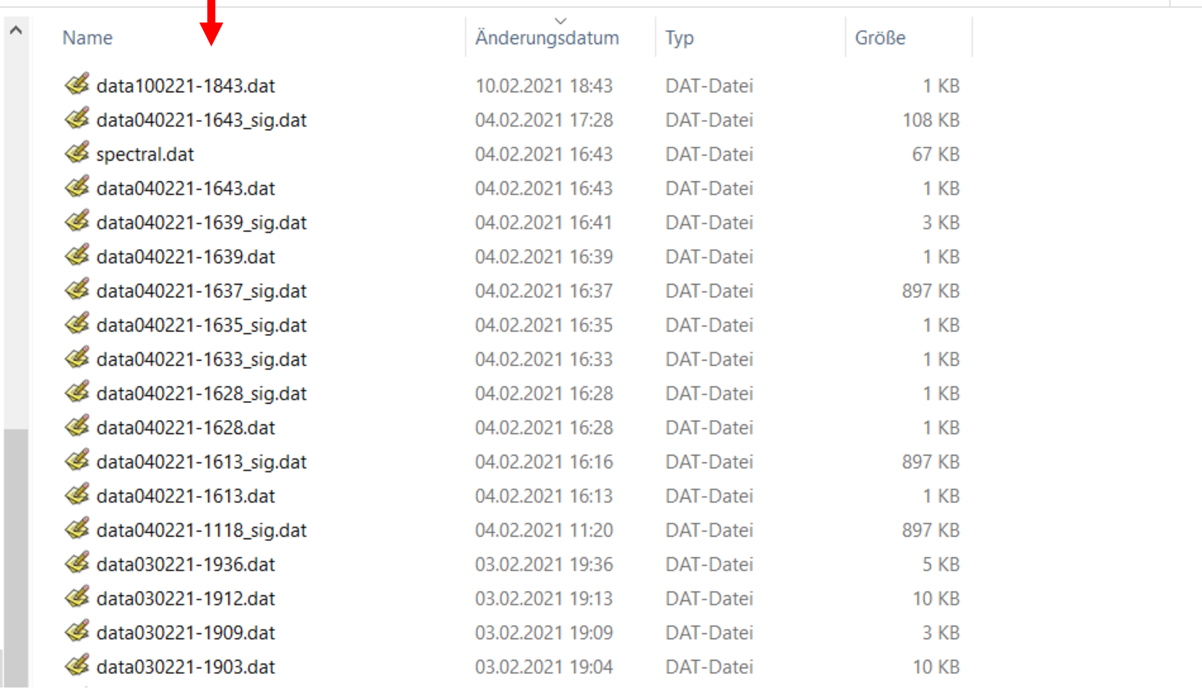
plot 1x: external sensors

- for plot specific data use the option “phytosensors” and “external sensors”
- to plot already stored data (from previous measurements), 1) disconnect from device; 2) open the file

Configuration of measurement parameters



Name	Änderungsdatum	Typ	Größe
data	04.02.2021 16:43	Dateiordner	
documentation	02.02.2021 18:49	Dateiordner	
drivers	02.02.2021 18:49	Dateiordner	
firmware_update	02.02.2021 18:49	Dateiordner	
images	04.02.2021 17:28	Dateiordner	
init	02.02.2021 18:49	Dateiordner	
log	02.02.2021 18:49	Dateiordner	
scripts	02.02.2021 18:49	Dateiordner	
sound	08.04.2018 18:45	Dateiordner	
web	02.02.2021 18:49	Dateiordner	
web2	02.02.2021 18:49	Dateiordner	
MU-EIS-Client.exe	04.02.2021 16:43	Anwendung	



Name	Änderungsdatum	Typ	Größe
data100221-1843.dat	10.02.2021 18:43	DAT-Datei	1 KB
data040221-1643_sig.dat	04.02.2021 17:28	DAT-Datei	108 KB
spectral.dat	04.02.2021 16:43	DAT-Datei	67 KB
data040221-1643.dat	04.02.2021 16:43	DAT-Datei	1 KB
data040221-1639_sig.dat	04.02.2021 16:41	DAT-Datei	3 KB
data040221-1639.dat	04.02.2021 16:39	DAT-Datei	1 KB
data040221-1637_sig.dat	04.02.2021 16:37	DAT-Datei	897 KB
data040221-1635_sig.dat	04.02.2021 16:35	DAT-Datei	1 KB
data040221-1633_sig.dat	04.02.2021 16:33	DAT-Datei	1 KB
data040221-1628_sig.dat	04.02.2021 16:28	DAT-Datei	1 KB
data040221-1628.dat	04.02.2021 16:28	DAT-Datei	1 KB
data040221-1613_sig.dat	04.02.2021 16:16	DAT-Datei	897 KB
data040221-1613.dat	04.02.2021 16:13	DAT-Datei	1 KB
data040221-1118_sig.dat	04.02.2021 11:20	DAT-Datei	897 KB
data030221-1936.dat	03.02.2021 19:36	DAT-Datei	5 KB
data030221-1912.dat	03.02.2021 19:13	DAT-Datei	10 KB
data030221-1909.dat	03.02.2021 19:09	DAT-Datei	3 KB
data030221-1903.dat	03.02.2021 19:04	DAT-Datei	10 KB

- data files are indexed by day-month-year-time

Data Structures (depends on DSP mode)

DSP/DDS mode	Usage	Description
All types of “Continuous Measurement”	Typical for phytosensor measurement mode	80 fixed data fields, see User Manual, Sec. 6.8, page 77
Signal Scope & Spectral analysis	Analysis of ionic interfaces	Several outputs, fixed data fields, see User Manual, Sec. 6.9, page 80
3D/4D mode, “continuous measurement with variable f”	Vernadsky scale, Impedance Spectroscopy	block-wise data structure, see User Manual, Sec. 6.10, page 80
Frequency analysis	Impedance Spectroscopy, frequency-response analysis	similar to “continuous mode”, the first field is replaces by frequency

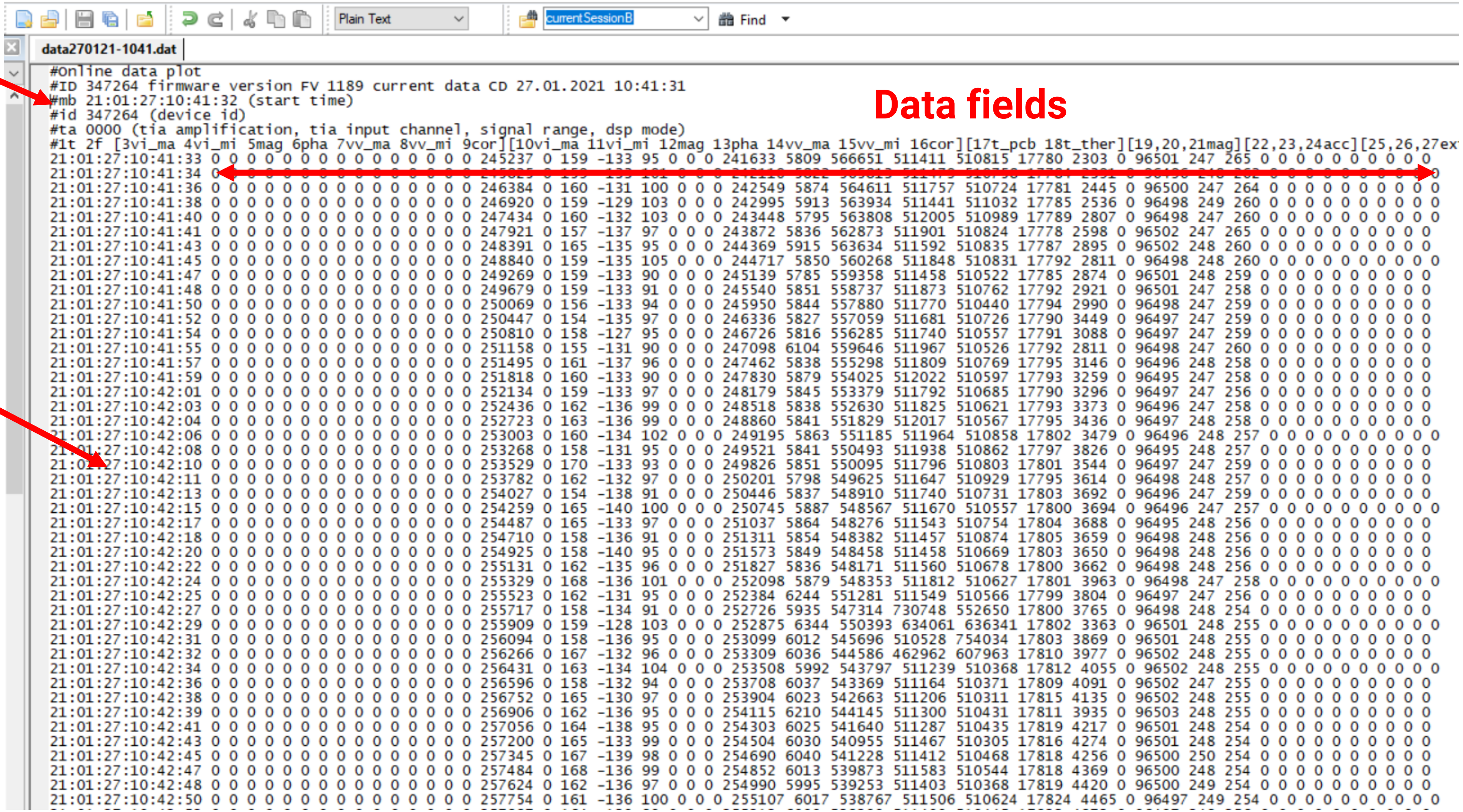
Data Structures

(example for “continuous measurement”)

configuration

time stamp

Device sends data in such format

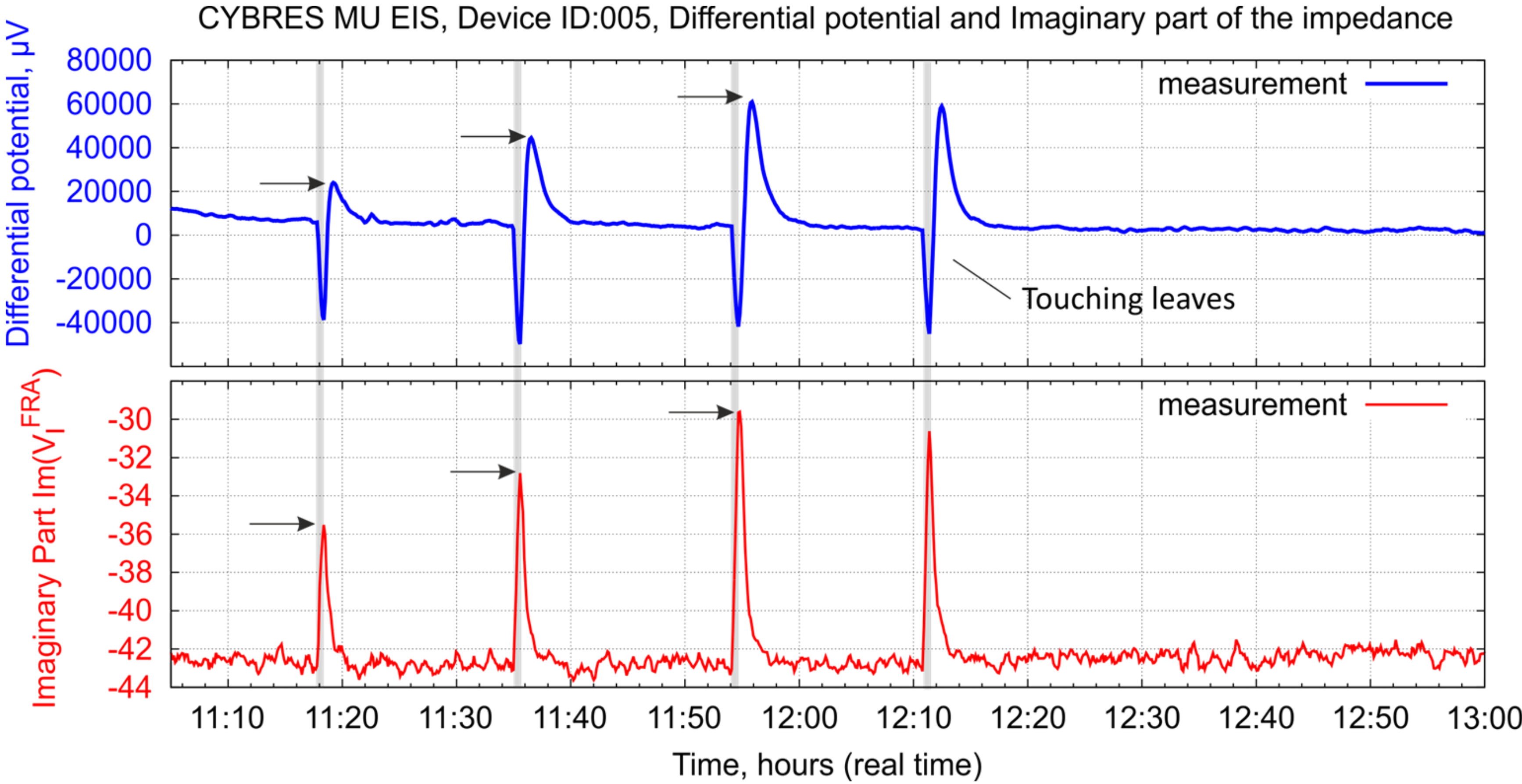


Data fields

```
#Online data plot
#ID 347264 firmware version FV 1189 current data CD 27.01.2021 10:41:31
#mb 21:01:27:10:41:32 (start time)
#id 347264 (device id)
#ta 0000 (tia amplification, tia input channel, signal range, dsp mode)
#1t 2f [3vi_ma 4vi_mi 5mag 6pha 7vv_ma 8vv_mi 9cor][10vi_ma 11vi_mi 12mag 13pha 14vv_ma 15vv_mi 16cor][17t_pcb 18t_ther][19,20,21mag][22,23,24acc][25,26,27ex
21:01:27:10:41:33 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 245237 0 159 -133 95 0 0 0 241633 5809 566651 511411 510815 17780 2303 0 96501 247 265 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:34 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 245825 0 159 -133 101 0 0 0 242110 5822 565813 511479 510758 17784 2391 0 96496 248 262 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:36 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 246384 0 160 -131 100 0 0 0 242549 5874 564611 511757 510724 17781 2445 0 96500 247 264 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:38 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 246920 0 159 -129 103 0 0 0 242995 5913 563934 511441 511032 17785 2536 0 96498 249 260 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:40 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 247434 0 160 -132 103 0 0 0 243448 5795 563808 512005 510989 17789 2807 0 96498 247 260 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:41 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 247921 0 157 -137 97 0 0 0 243872 5836 562873 511901 510824 17778 2598 0 96502 247 265 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:43 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 248391 0 165 -135 95 0 0 0 244369 5915 563634 511592 510835 17787 2895 0 96502 248 260 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:45 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 248840 0 159 -135 105 0 0 0 244717 5850 560268 511848 510831 17792 2811 0 96498 248 260 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:47 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 249269 0 159 -133 90 0 0 0 245139 5785 559358 511458 510522 17785 2874 0 96501 248 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:48 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 249679 0 159 -133 91 0 0 0 245540 5851 558737 511873 510762 17792 2921 0 96501 247 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:50 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 250069 0 156 -133 94 0 0 0 245950 5844 557880 511770 510440 17794 2990 0 96498 247 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:52 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 250447 0 154 -135 97 0 0 0 246336 5827 557059 511681 510726 17790 3449 0 96497 247 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:54 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 250810 0 158 -127 95 0 0 0 246726 5816 556285 511740 510557 17791 3088 0 96497 247 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:55 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 251158 0 155 -131 90 0 0 0 247098 6104 559646 511967 510526 17792 2811 0 96498 247 260 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:57 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 251495 0 161 -137 96 0 0 0 247462 5838 555298 511809 510769 17795 3146 0 96496 248 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:41:59 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 251818 0 160 -133 90 0 0 0 247830 5879 554025 512022 510597 17793 3259 0 96495 247 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:01 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 252134 0 159 -133 97 0 0 0 248179 5845 553379 511792 510685 17790 3296 0 96497 247 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:03 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 252436 0 162 -136 99 0 0 0 248518 5838 552630 511825 510621 17793 3373 0 96496 247 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:04 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 252723 0 163 -136 99 0 0 0 248860 5841 551829 512017 510567 17795 3436 0 96497 248 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:06 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 253003 0 160 -134 102 0 0 0 249195 5863 551185 511964 510858 17802 3479 0 96496 248 257 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:08 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 253268 0 158 -131 95 0 0 0 249521 5841 550493 511938 510862 17797 3826 0 96495 248 257 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:10 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 253529 0 170 -133 93 0 0 0 249826 5851 550095 511796 510803 17801 3544 0 96497 247 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:11 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 253782 0 162 -132 97 0 0 0 250201 5798 549625 511647 510929 17795 3614 0 96498 248 257 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:13 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 254027 0 154 -138 91 0 0 0 250446 5837 548910 511740 510731 17803 3692 0 96496 247 259 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:15 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 254259 0 165 -140 100 0 0 0 250745 5887 548567 511670 510557 17800 3694 0 96496 247 257 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:17 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 254487 0 165 -133 97 0 0 0 251037 5864 548276 511543 510754 17804 3688 0 96495 248 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:18 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 254710 0 158 -136 91 0 0 0 251311 5854 548382 511457 510874 17805 3659 0 96498 248 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 254925 0 158 -140 95 0 0 0 251573 5849 548458 511458 510669 17803 3650 0 96498 248 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:22 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 255131 0 162 -135 96 0 0 0 251827 5836 548171 511560 510678 17800 3662 0 96498 248 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:24 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 255329 0 168 -136 101 0 0 0 252098 5879 548353 511812 510627 17801 3963 0 96498 247 258 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:25 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 255523 0 162 -131 95 0 0 0 252384 6244 551281 511549 510566 17799 3804 0 96497 247 256 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:27 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 255717 0 158 -134 91 0 0 0 252726 5935 547314 730748 552650 17800 3765 0 96498 248 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:29 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 255909 0 159 -128 103 0 0 0 252875 6344 550393 634061 636341 17802 3363 0 96501 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:31 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256094 0 158 -136 95 0 0 0 253099 6012 545696 510528 754034 17803 3869 0 96501 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:32 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256266 0 167 -132 96 0 0 0 253309 6036 544586 462962 607963 17810 3977 0 96502 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:34 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256431 0 163 -134 104 0 0 0 253508 5992 543797 511239 510368 17812 4055 0 96502 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:36 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256596 0 158 -132 94 0 0 0 253708 6037 543369 511164 510371 17809 4091 0 96502 247 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:38 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256752 0 165 -130 97 0 0 0 253904 6023 542663 511206 510311 17815 4135 0 96502 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:39 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 256906 0 162 -136 95 0 0 0 254115 6210 544145 511300 510431 17811 3935 0 96503 248 255 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:41 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257056 0 164 -138 95 0 0 0 254303 6025 541640 511287 510435 17819 4217 0 96501 248 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:43 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257200 0 165 -133 99 0 0 0 254504 6030 540955 511467 510305 17816 4274 0 96501 248 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:45 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257345 0 167 -139 98 0 0 0 254690 6040 541228 511412 510468 17818 4256 0 96500 250 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:47 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257484 0 168 -136 99 0 0 0 254852 6013 539873 511583 510544 17818 4369 0 96500 248 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:48 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257624 0 162 -136 97 0 0 0 254990 5995 539253 511403 510368 17819 4420 0 96500 249 254 0 0 0 0 0 0 0 0 0 0
21:01:27:10:42:50 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 257754 0 161 -136 100 0 0 0 255107 6017 538767 511506 510624 17824 4465 0 96497 249 254 0 0 0 0 0 0 0 0 0 0
```

4. Examples of measurements, data analysis and bio-hybrid feedback

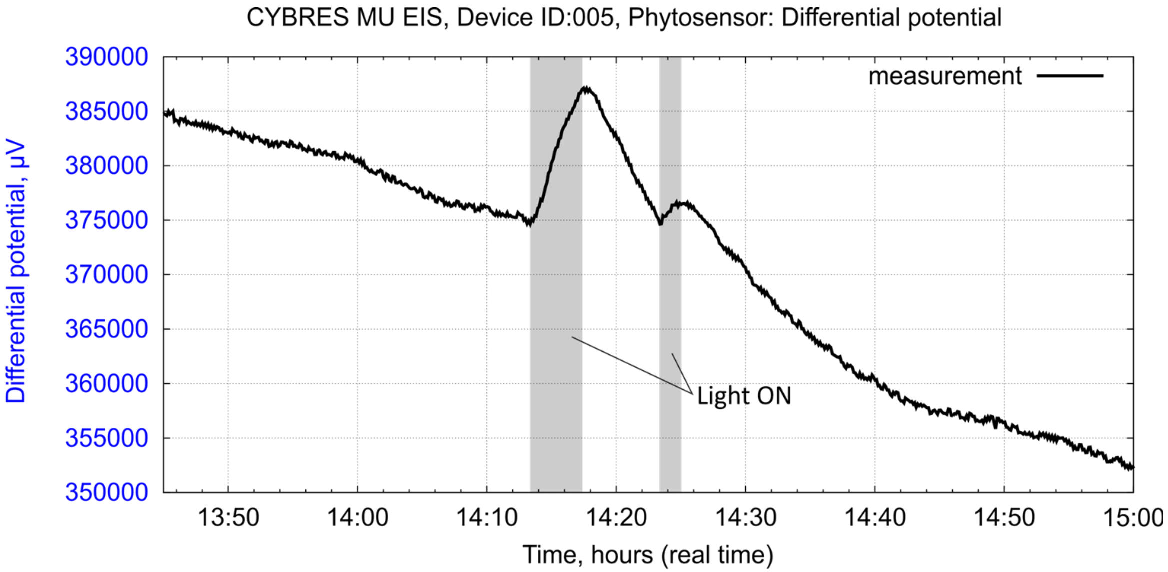
Electrophysiology: mechanical (electrostatic) stimuli

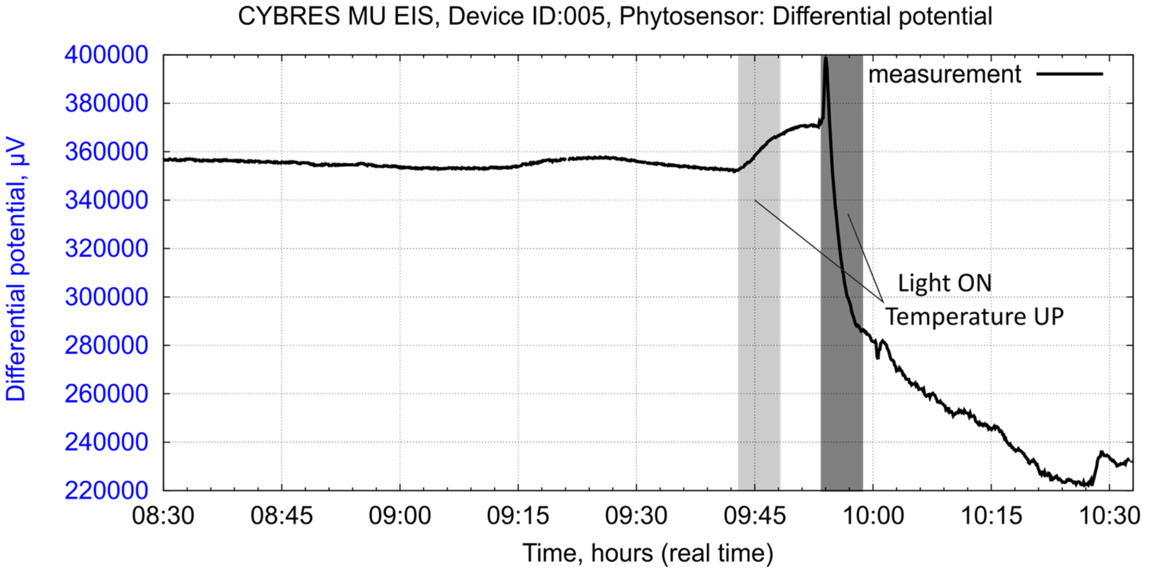


- Fast reaction (in seconds) at specific plant species
- It can be used in complex scenarios, even for multiple plants (see next slides)

Electrophysiology: light & heat

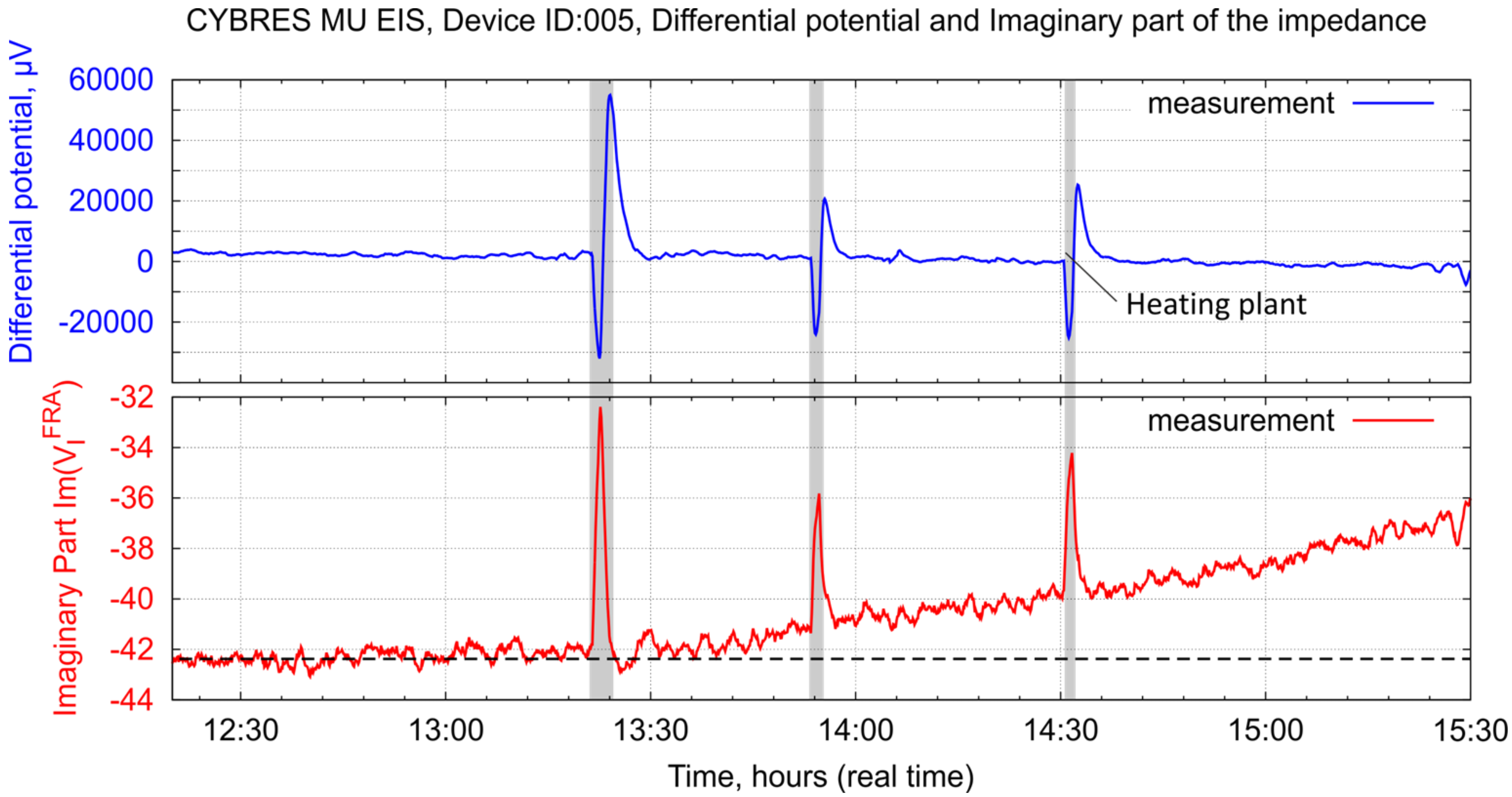
- Non-specific electro-physiological reaction on different stimuli
- physiological & environmental data are required for analysis





Electrophysiology (tissue impedance)

heat and mechanical distortion

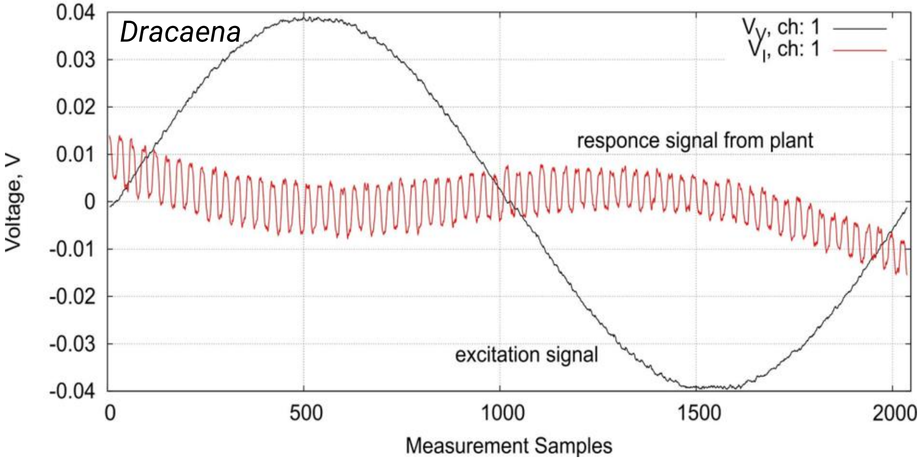


Reaction on external stimuli also by tissue impedance

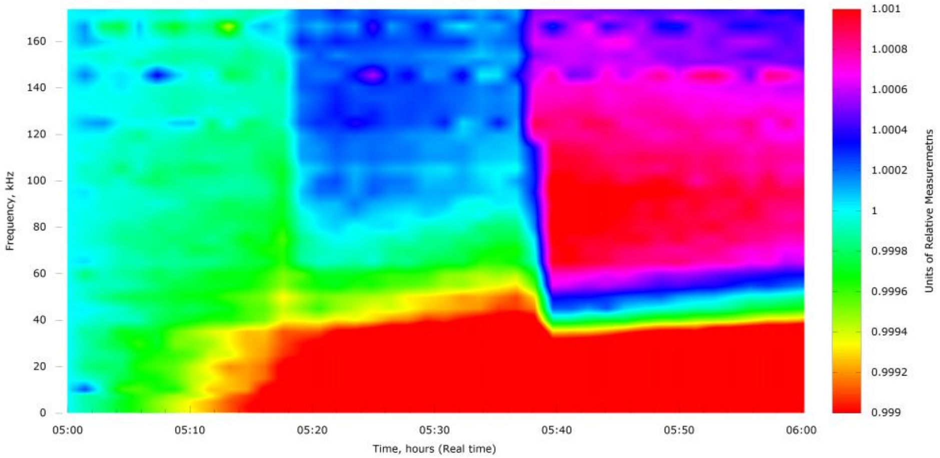
Tissue impedance spectroscopy

periodic response, frequency shift, frequency-temporal dynamics

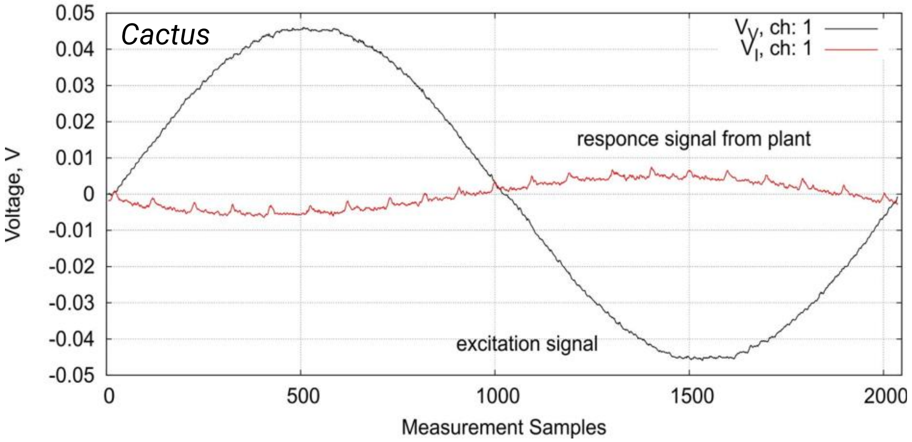
CYBRES MU EIS, Device ID:0005, Signal Scope mode, V_V, V_I signals, 500Hz, tissue conductivity



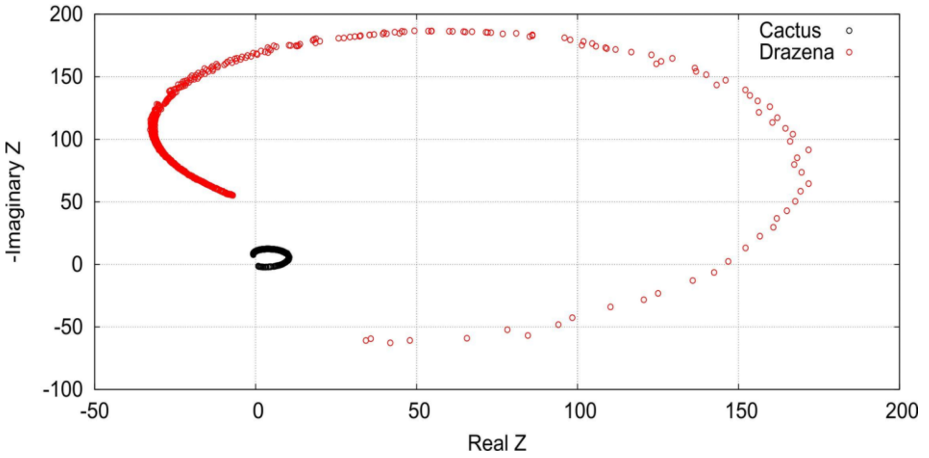
CYBRES EIS, Device ID:322016, Heat map of RMS conductivity, ch.1 (Vernadsky Scale of Relative Measurements)



CYBRES MU EIS, Device ID:0005, Signal Scope mode, V_V, V_I signals, 500Hz, tissue conductivity



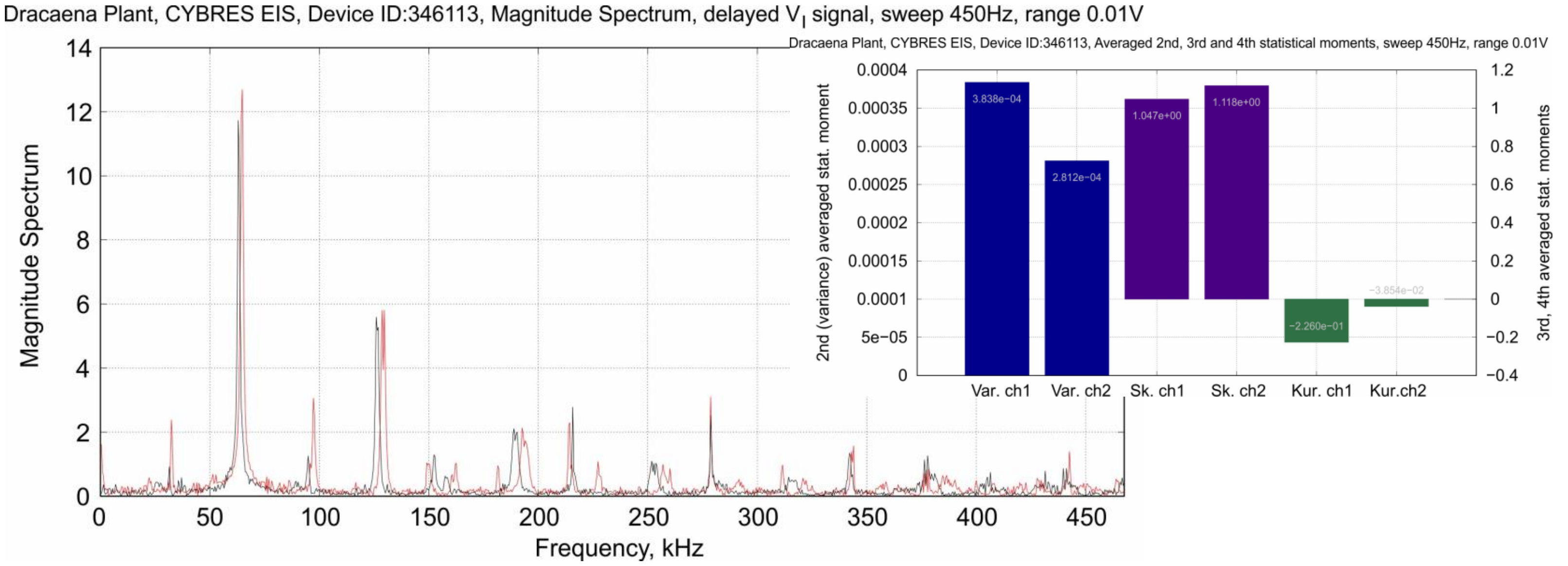
CYBRES MU EIS, Device ID:00006, Nyquist Plot



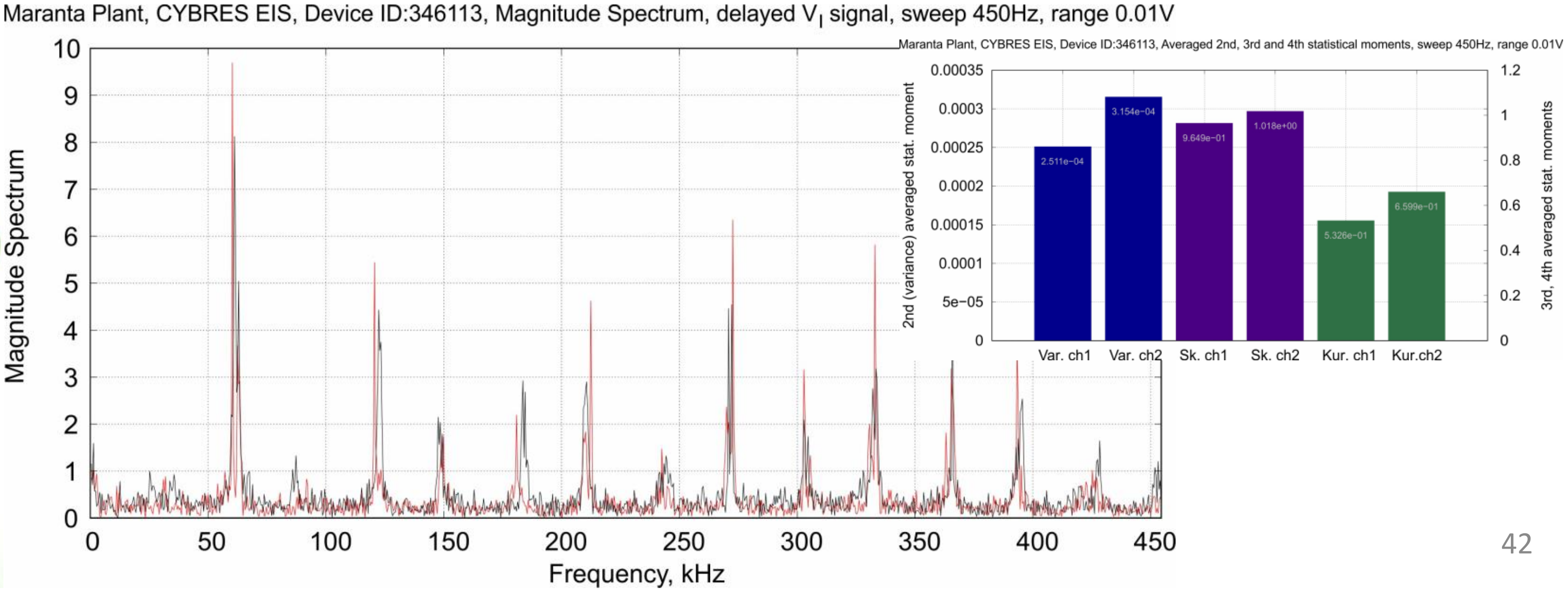
Replication experiments on published data about tissue responses

Tissue impedance spectroscopy

Ionic interfaces

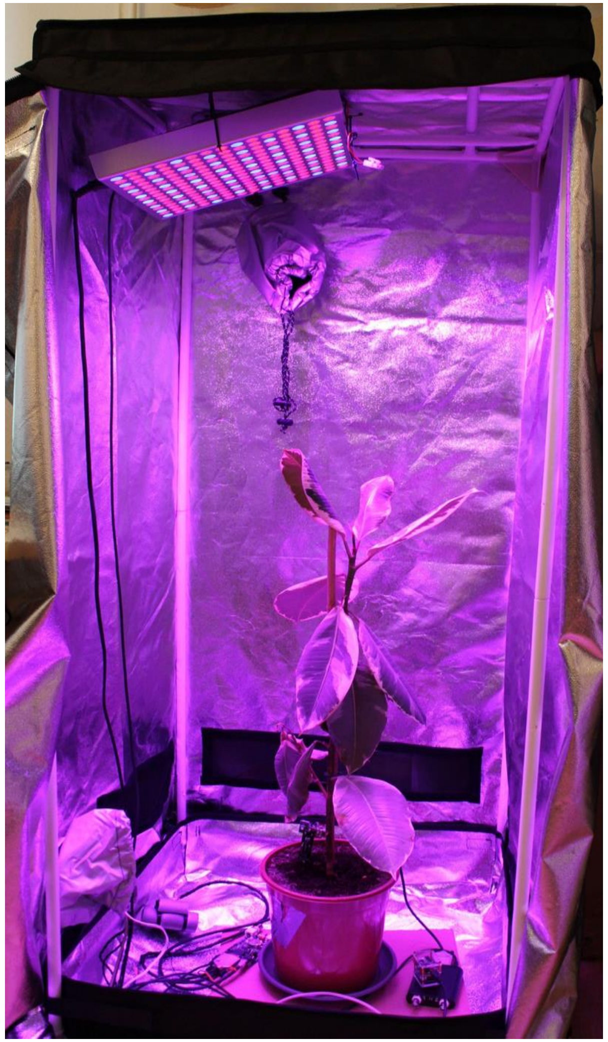


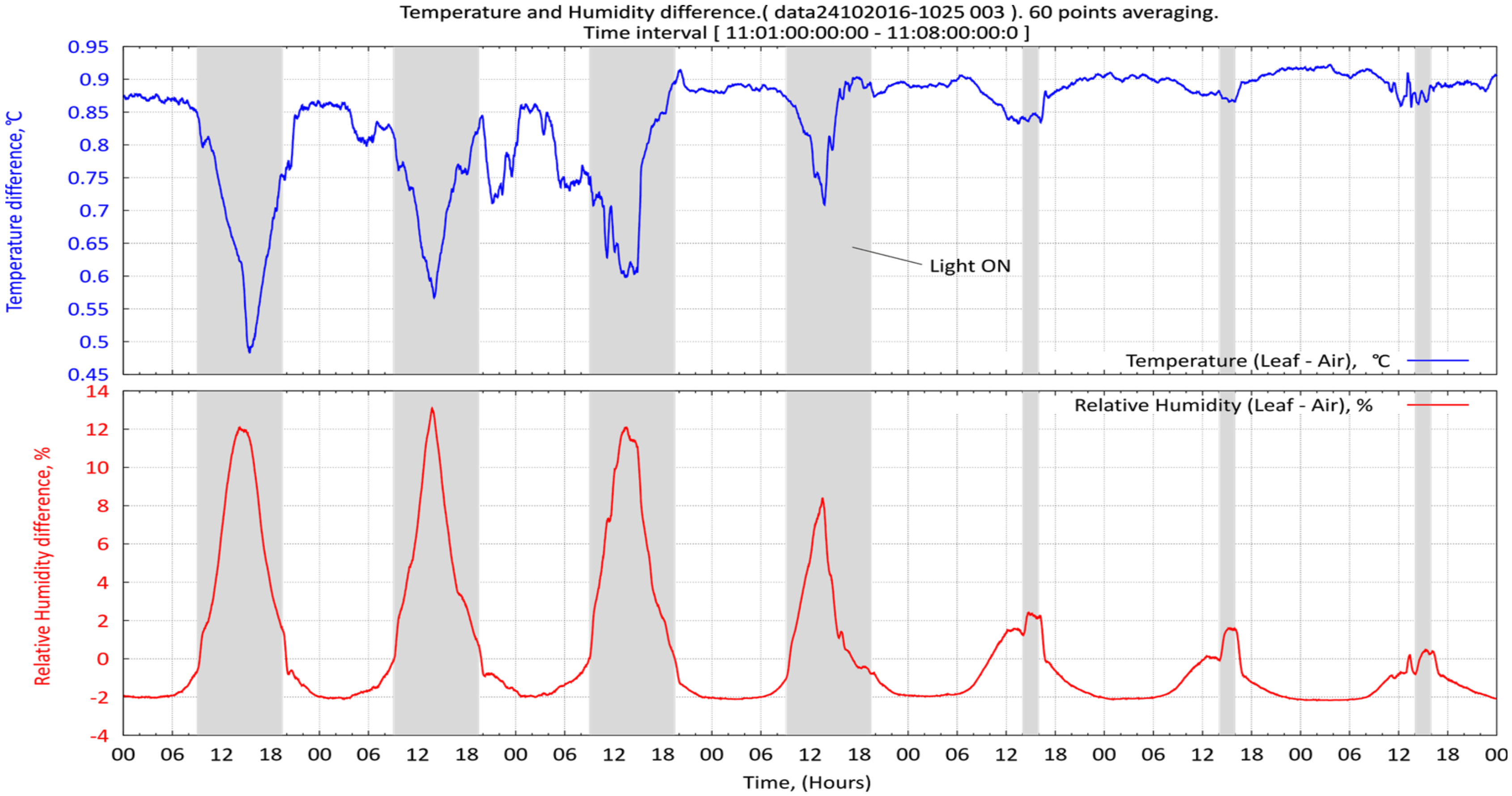
Dracaena Plant, CYBRES EIS, Device ID:346113, Magnitude Spectrum, delayed V_I signal, sweep 450Hz, range 0.01V



Maranta Plant, CYBRES EIS, Device ID:346113, Magnitude Spectrum, delayed V_I signal, sweep 450Hz, range 0.01V

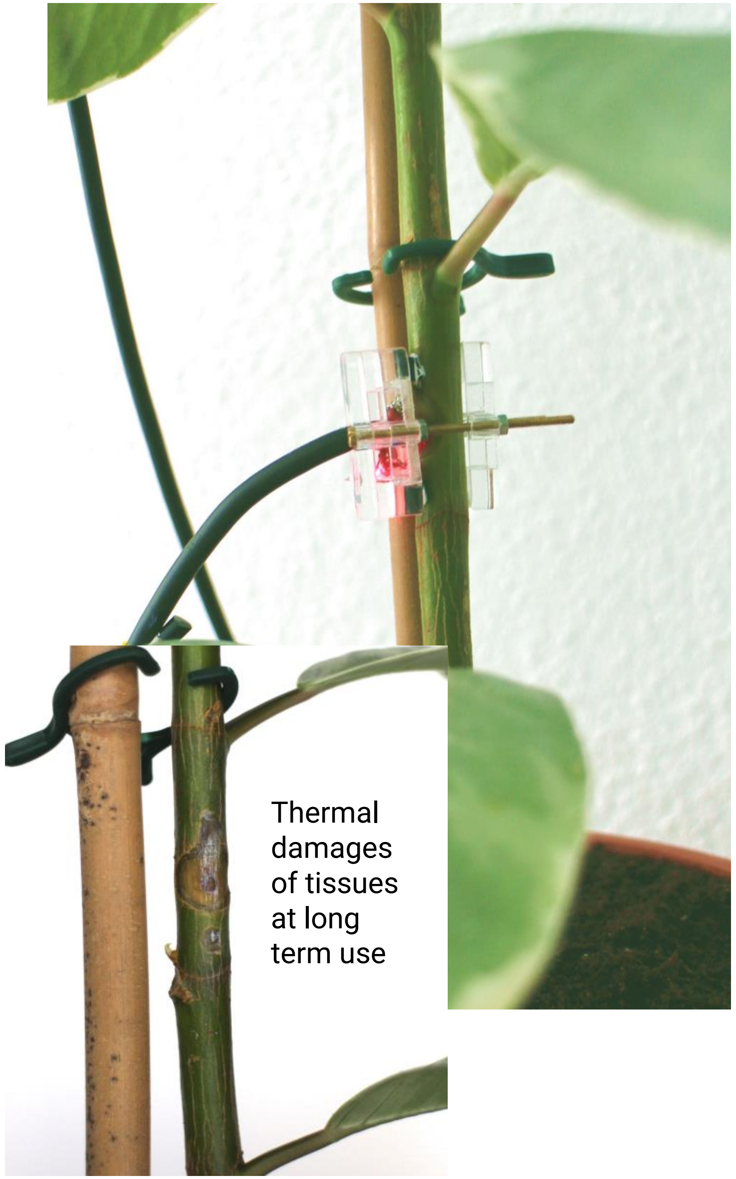
Transpiration measurements



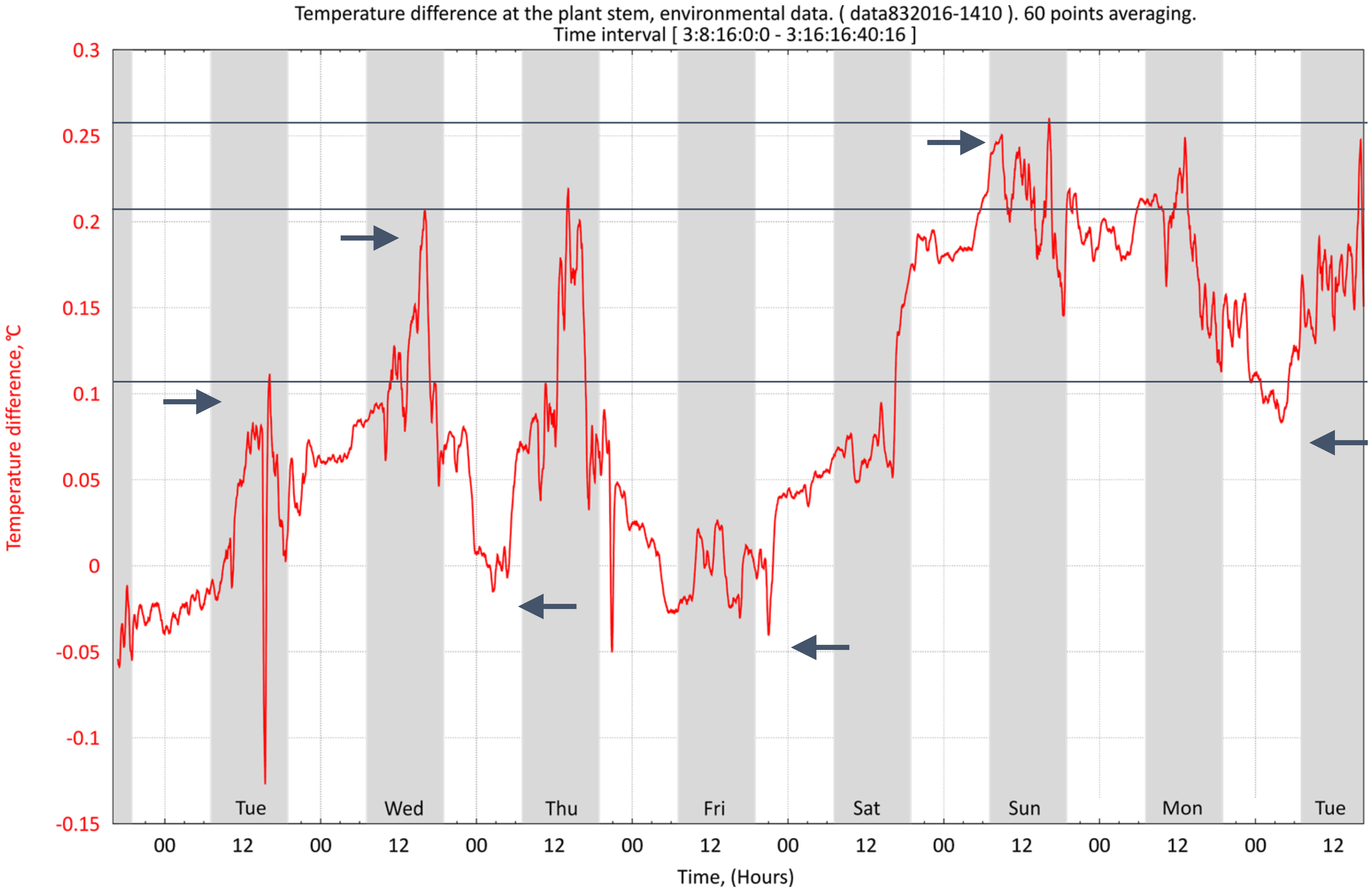


- transpiration is the inevitable consequence of gas exchange in the leaf
- transpiration is affected by light intensity, air movement, temperature and humidity

Stem water (sap) flow sensor (thermobalance method)



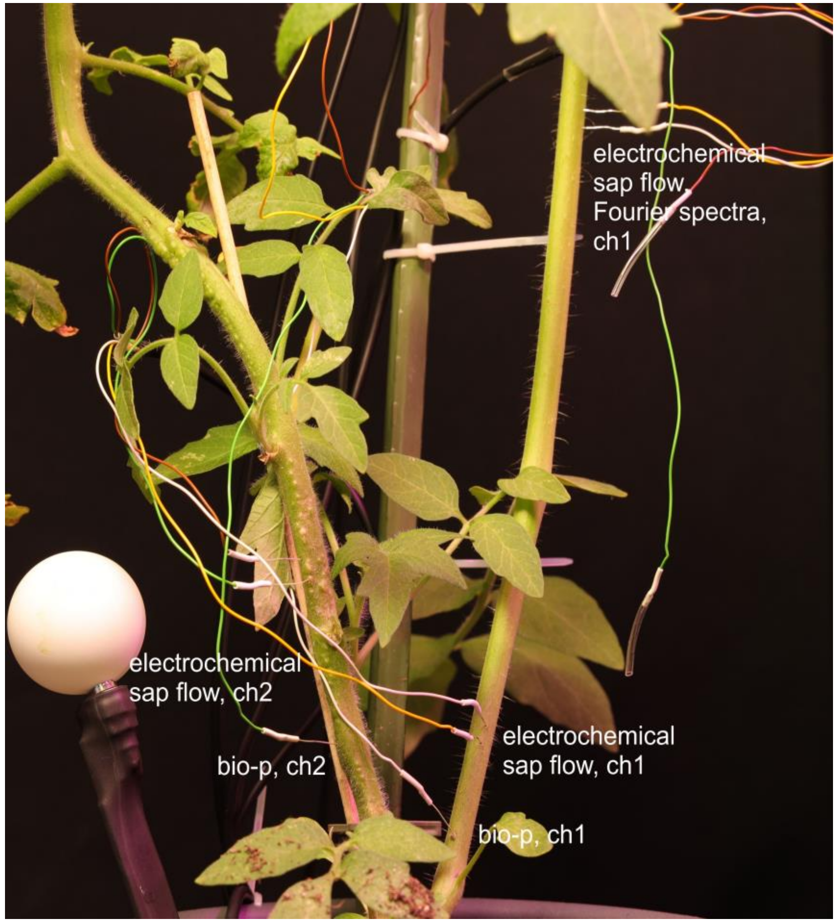
Thermal damages of tissues at long term use

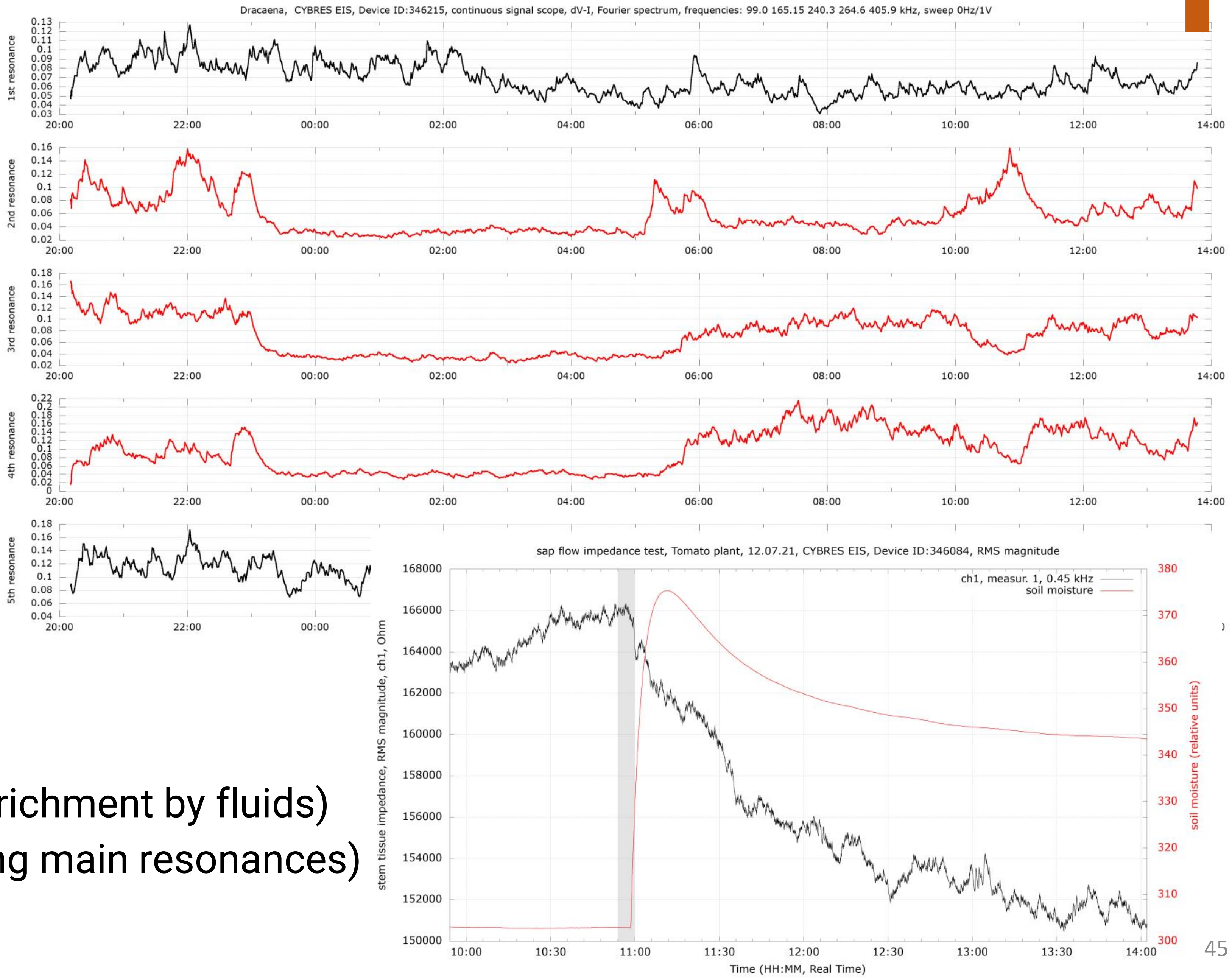


Temperature difference at the plant stem, environmental data. (data832016-1410). 60 points averaging. Time interval [3:8:16:0:0 - 3:16:16:40:16]

- increasing of water flow indicates a normal growth
- temperature effects

Electrochemical sap flow sensor: tracking main resonances

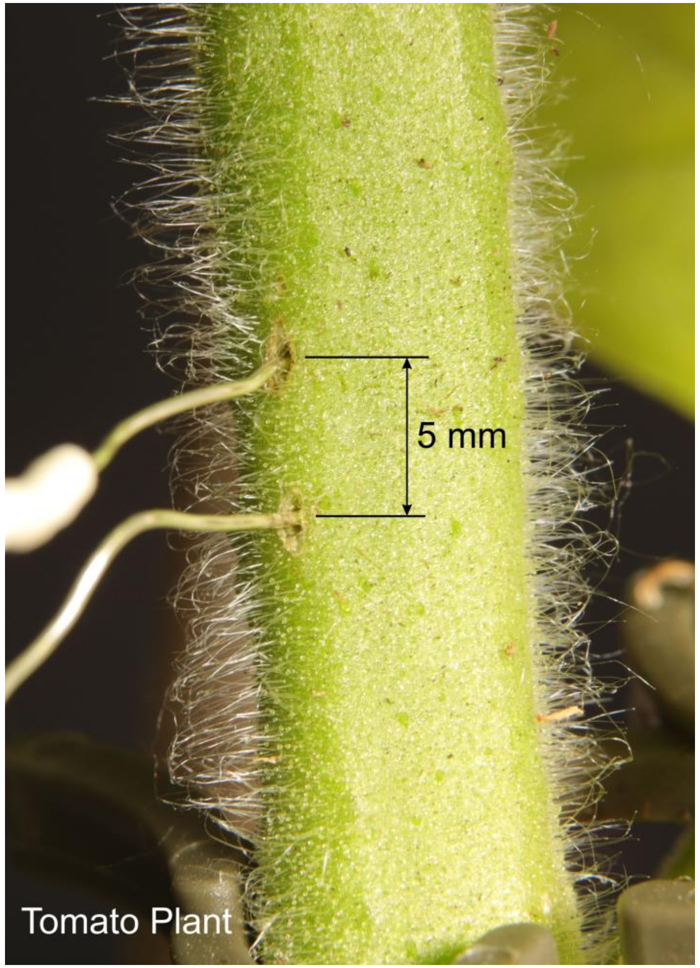



Dracaena, CYBRES EIS, Device ID:346215, continuous signal scope, dV-I, Fourier spectrum, frequencies: 99.0 165.15 240.3 264.6 405.9 kHz, sweep 0Hz/1V

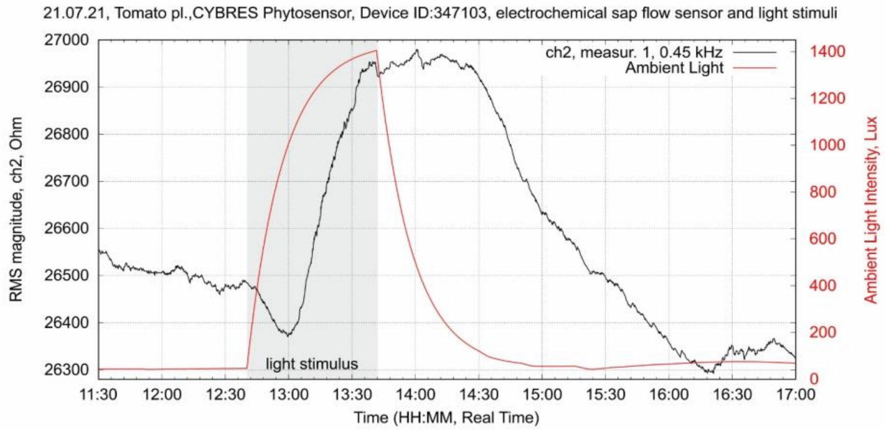
sap flow impedance test, Tomato plant, 12.07.21, CYBRES EIS, Device ID:346084, RMS magnitude

- tissue impedance approach (enrichment by fluids)
- Fourier spectra approach (tracing main resonances)

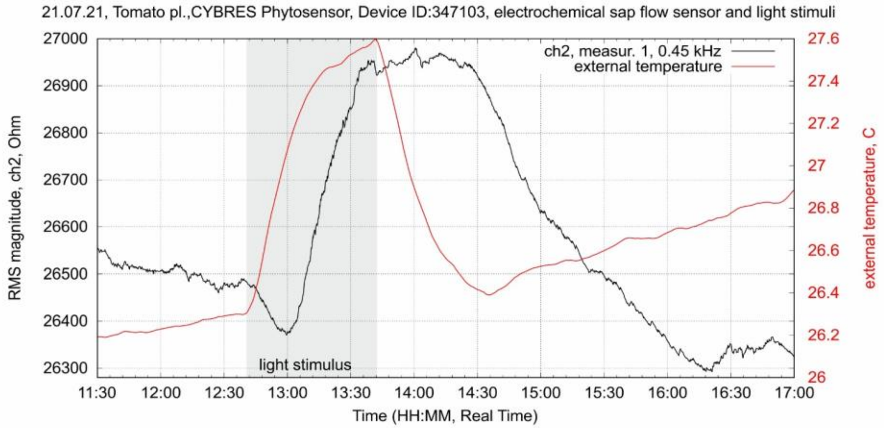
Electrochemical sap flow sensor



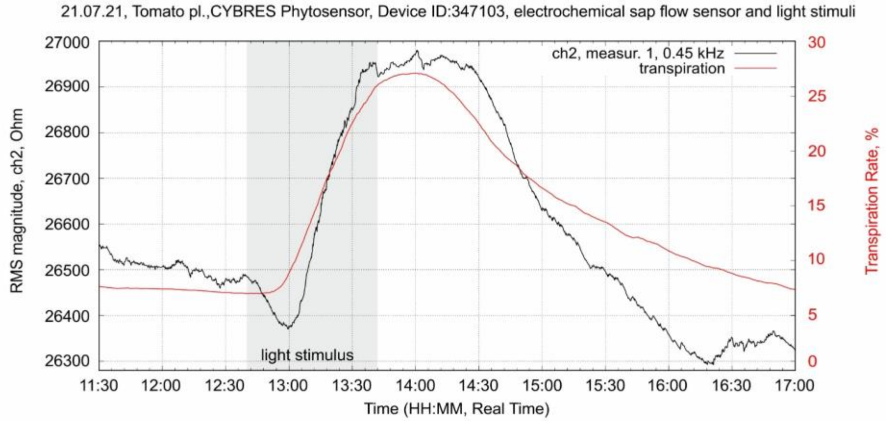
Light



Temperature

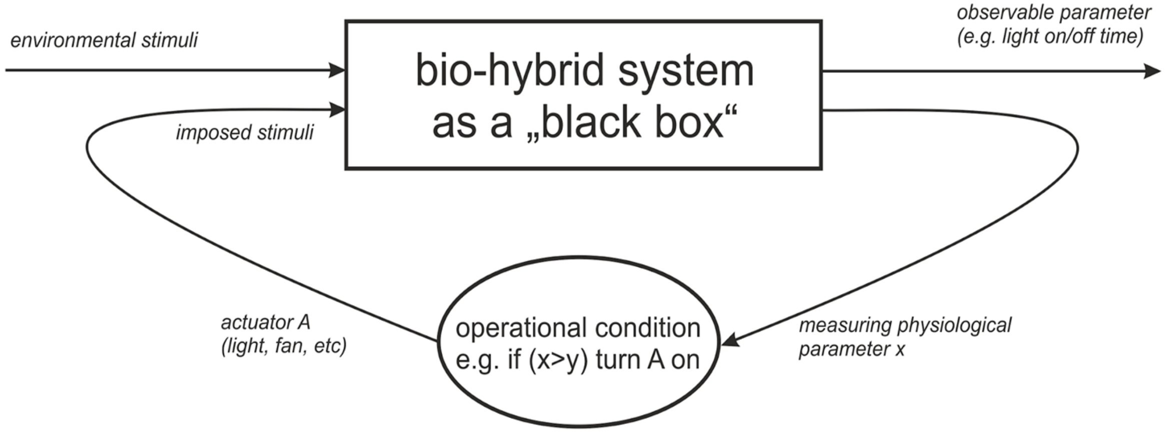


Transpiration



Good correlations with physiological reactions of plant organisms

Stimuli-Reward Learning in Plants



environmental stimuli

imposed stimuli

bio-hybrid system
as a „black box“

observable parameter
(e.g. light on/off time)

actuator A
(light, fan, etc)

operational condition
e.g. if (x>y) turn A on

measuring physiological
parameter x

1. The bio-hybrid system is a “black box”, we do not know what is inside
2. We consider the “external observable parameter” as the output measure (e.g. light is a part of the bio-hybrid system, on/off time as an output parameter)
3. The feedback loop changes the observable output parameter
4. The environmental stimuli still affecting the system, thus we will observe a complex behaviour

Pavlov’s plants: new study shows plants can learn from experience

December 6, 2016 10.15pm GMT

Can plants really think? Shutterstock

www.nature.com/scientificreports

SCIENTIFIC REPORTS

TheScientist
EXPLORING LIFE, INSPIRING INNOVATION

The Scientist » February 2017 Issue » Notebook

Can Plants Learn to Associate Stimuli with Reward?

A group of pea plants has displayed a sensitivity to environmental cues that resembles associative learning in animals.

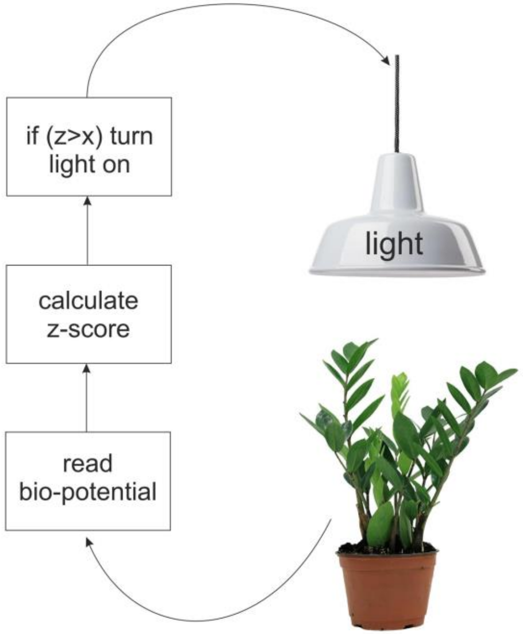
By Ben Andrew Henry | February 1, 2017

Learning by Association in Plants

Monica Gagliano[1], Vladyslav V. Vyazovskiy[2], Alexander A. Borbély[3], Mavra Grimonprez[1] & Martial Depczynski[4,5]

In complex and ever-changing environments, resources such as food are often scarce and unevenly distributed in space and time. Therefore, utilizing external cues to locate and remember high-quality sources allows more efficient foraging, thus increasing chances for survival. Associations between environmental cues and food are readily formed because of the tangible benefits they confer. While examples of the key role they play in shaping foraging behaviours are widespread in the animal world, the possibility that plants are also able to acquire learned associations to guide their foraging behaviour has never been demonstrated. Here we show that this type of learning occurs in the garden pea, *Pisum sativum*. By using a Y-maze task, we show that the position of a neutral cue, predicting the location of a light source, affected the direction of plant growth. This learned behaviour prevailed over innate phototropism. Notably, learning was successful only when it occurred during the subjective day, suggesting that behavioural performance is regulated by metabolic demands. Our results show that associative learning is an essential component of plant behaviour. We conclude that associative learning represents a universal adaptive mechanism shared by both animals and plants.

Stimuli-Reward Learning in Plants



if (z>x) turn light on

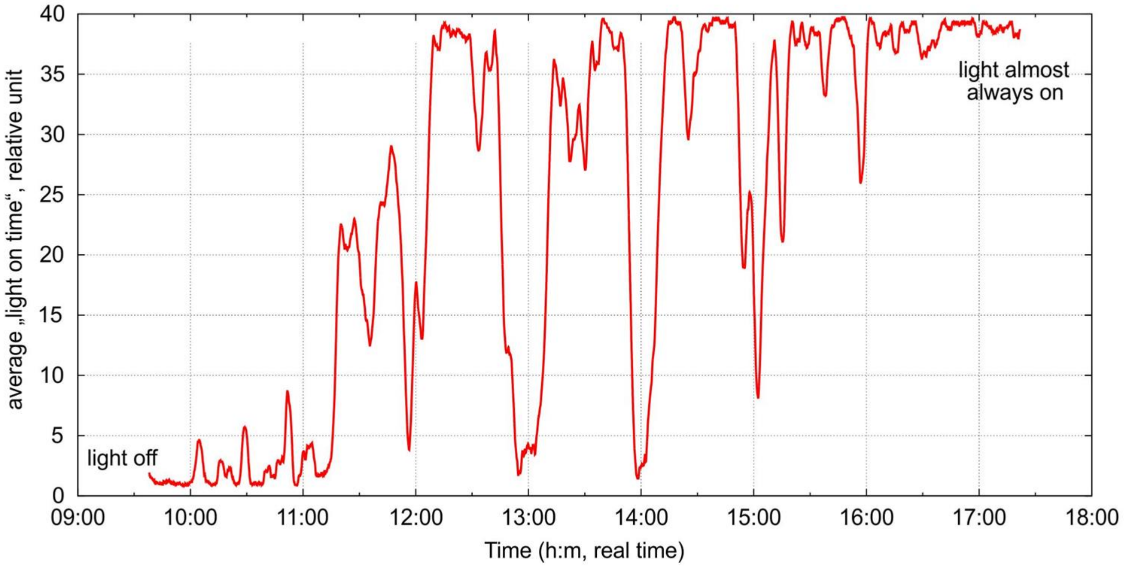
calculate z-score

read bio-potential

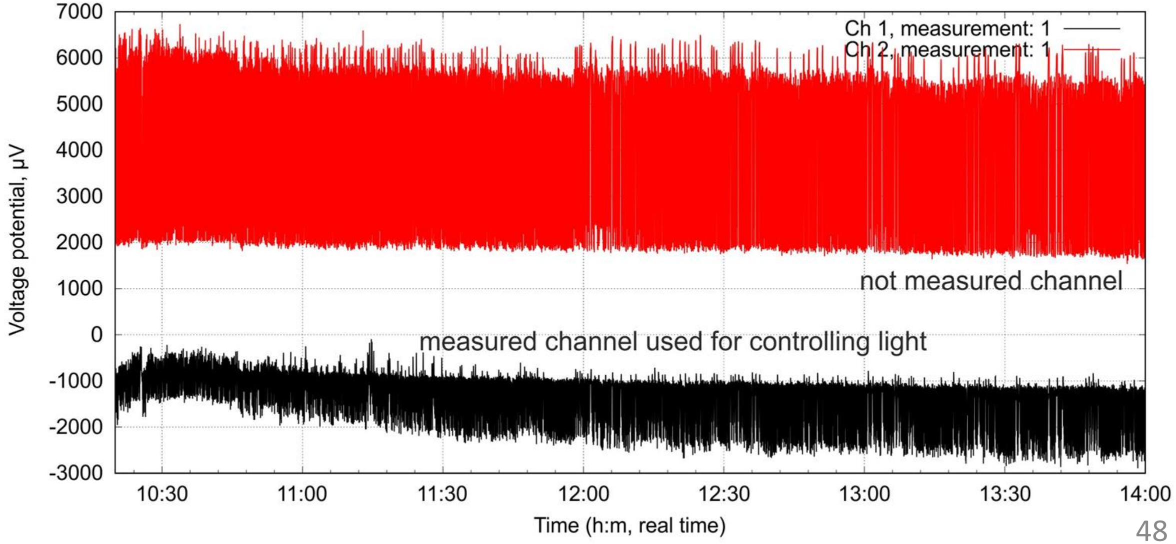
light

reinforced training within the z based feedback loop

Pavlov‘ Plant Experiment, Adaptation capability, CYBRES Phytosensor, Device ID:333029, average „ligh on time“



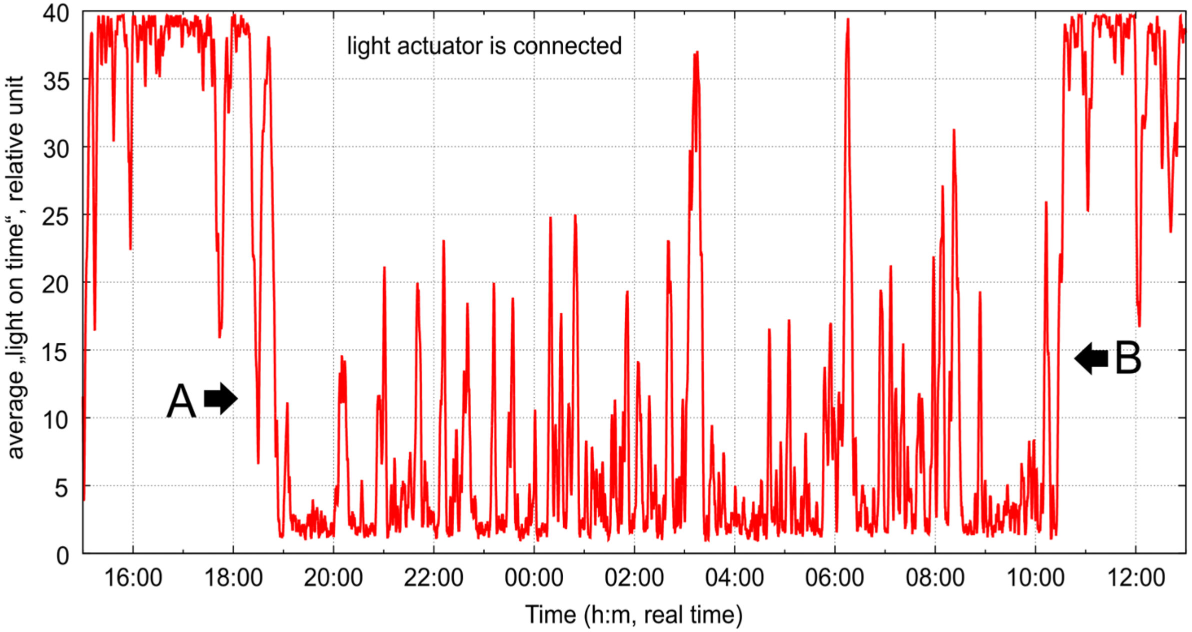
Pavlov‘ Plant Experiment, Adaptation capability, CYBRES Phytosensor, Device ID:333029, average ligh „on time“



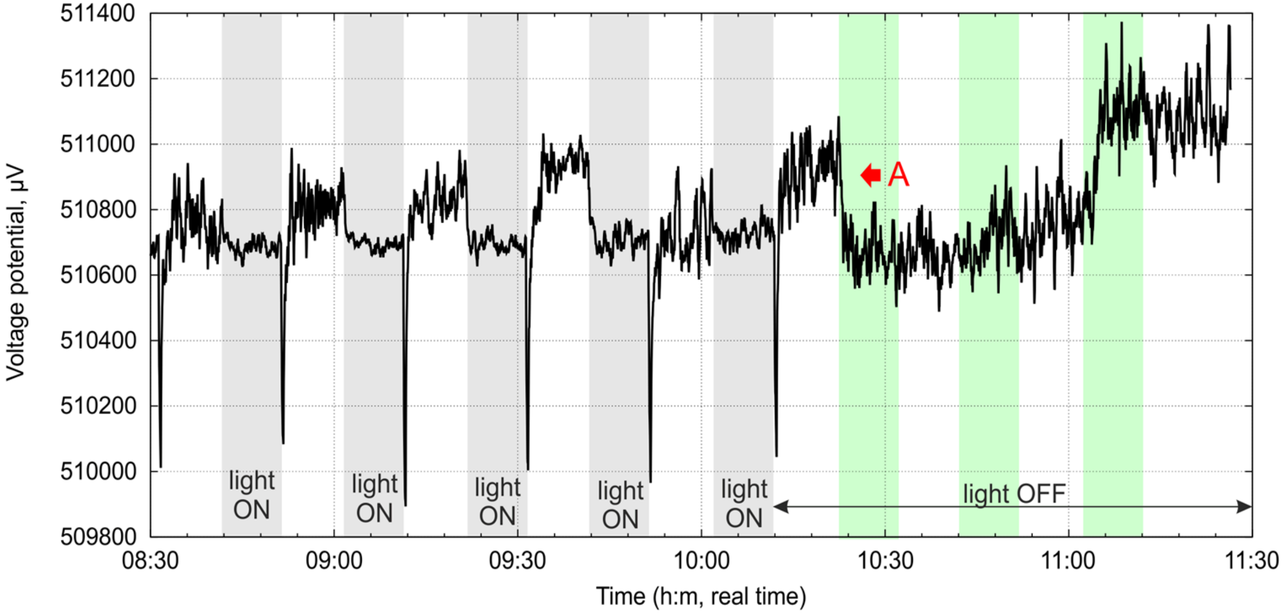
Stimuli-Reward Learning in Plants:

self-regulation of illumination time/adaptation for cyclical activities

Pavlov‘ Plant Experiment, Adaptation capability, CYBRES Phytosensor, Device ID:333029, average „ligh on time“



CYBRES Phytosensor, Device ID:333029, Biopotentials after periodical ON/OFF switching the light (time plot,ch.2)



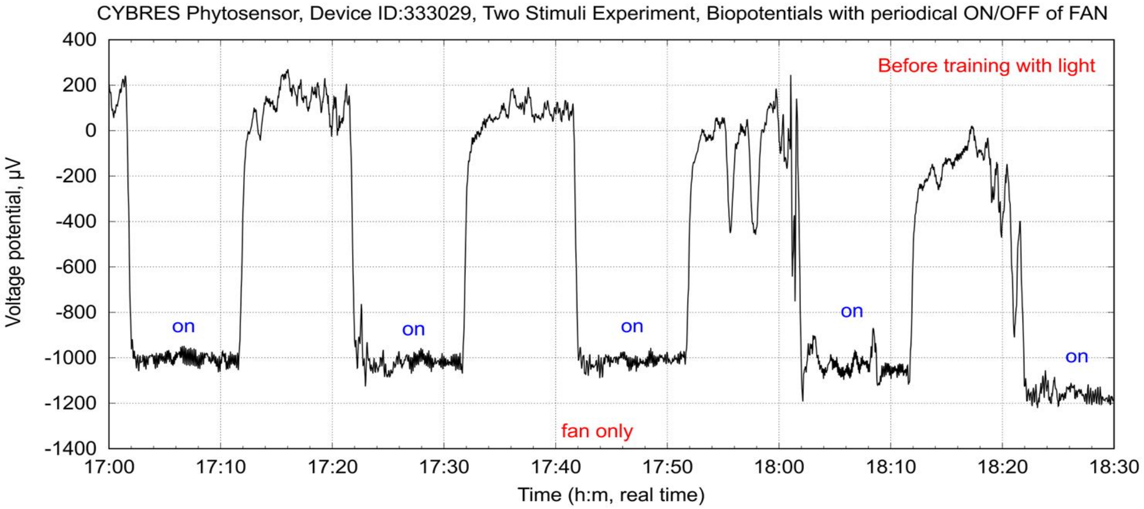
biopotentials within the z based feedback loop after a few days of training lead to turning OFF (the point ‘A’, evening) and turning ON (the point ‘B’, morning) the light **autonomously** -> one of indicators for adaptive physiological functionally

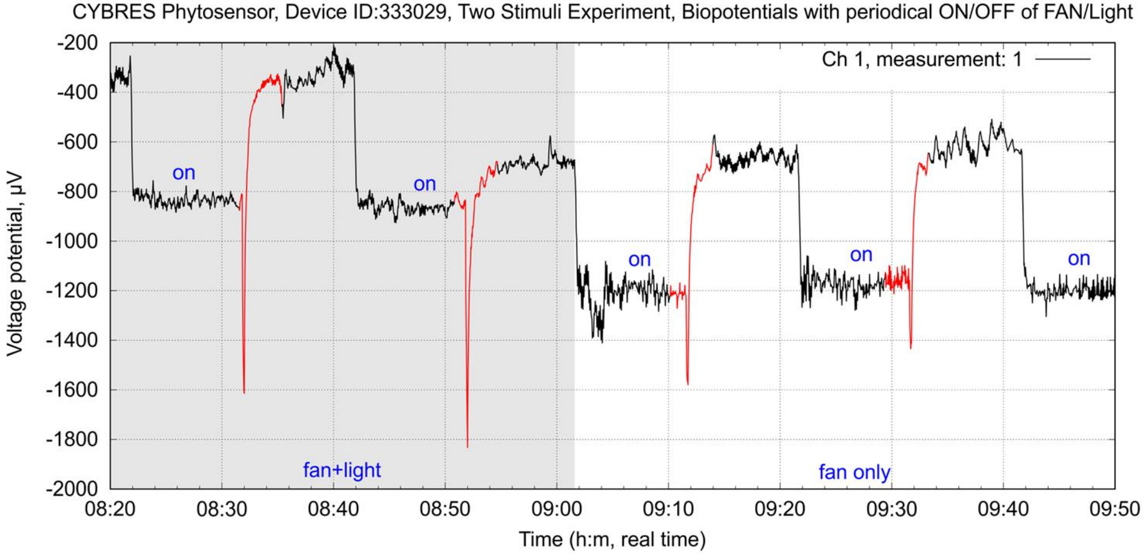
periodical excitation for 2 days with period 10 min “light ON/OFF”. In the “light ON phase” the DA module was deactivated, i.e. no further excitation by light. During the next expected “light ON phase” (almost exactly) the biopotential reacted in the same way as previously, but without external light stimulus (the red point A).

Stimuli-Reward Learning in Plants:

introducing the second stimulus (fan)

- replication of two stimuli experiment
- plant indeed can learn reworded reactions

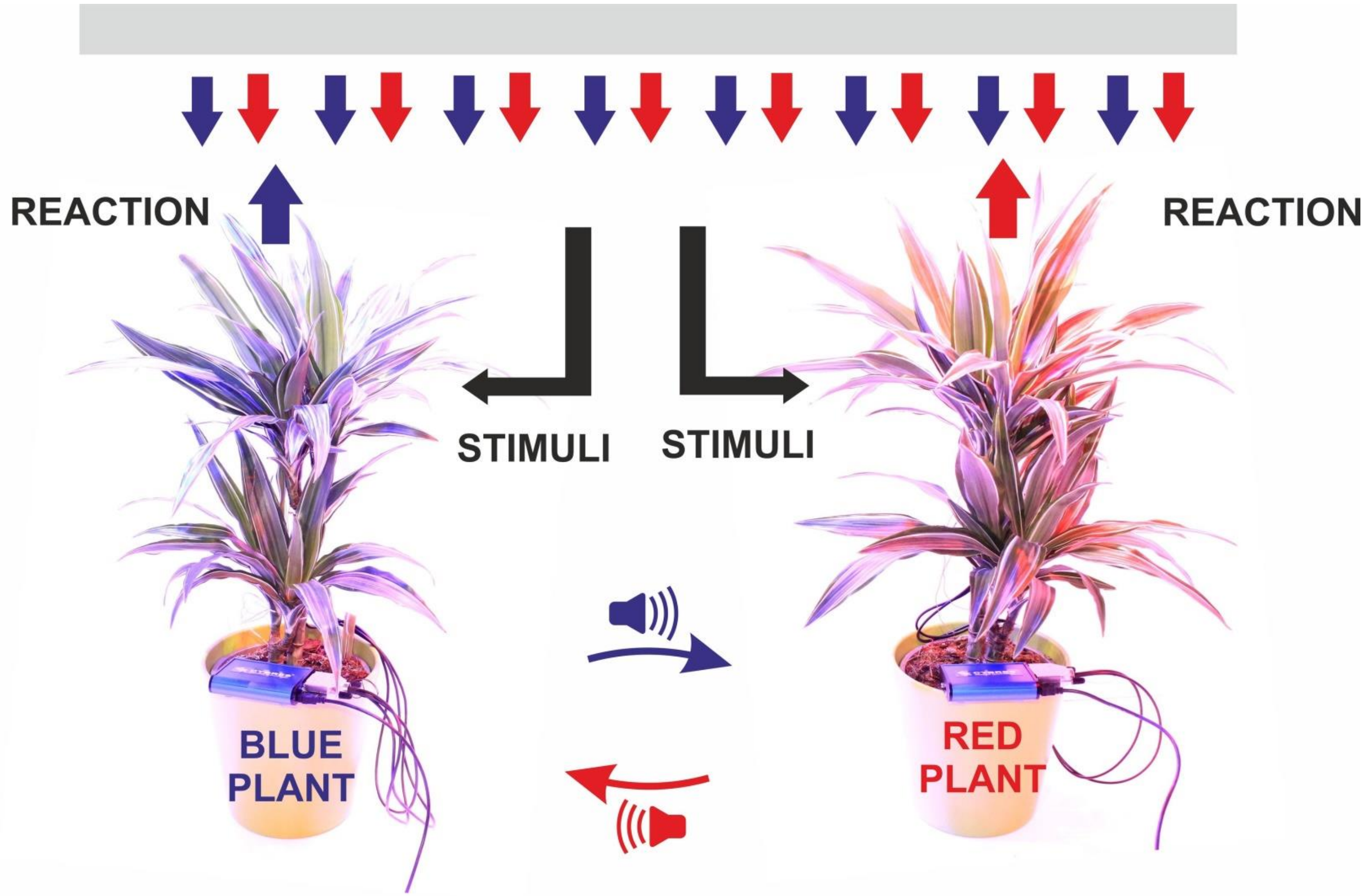

CYBRES Phytosensor, Device ID:333029, Two Stimuli Experiment, Biopotentials with periodical ON/OFF of FAN

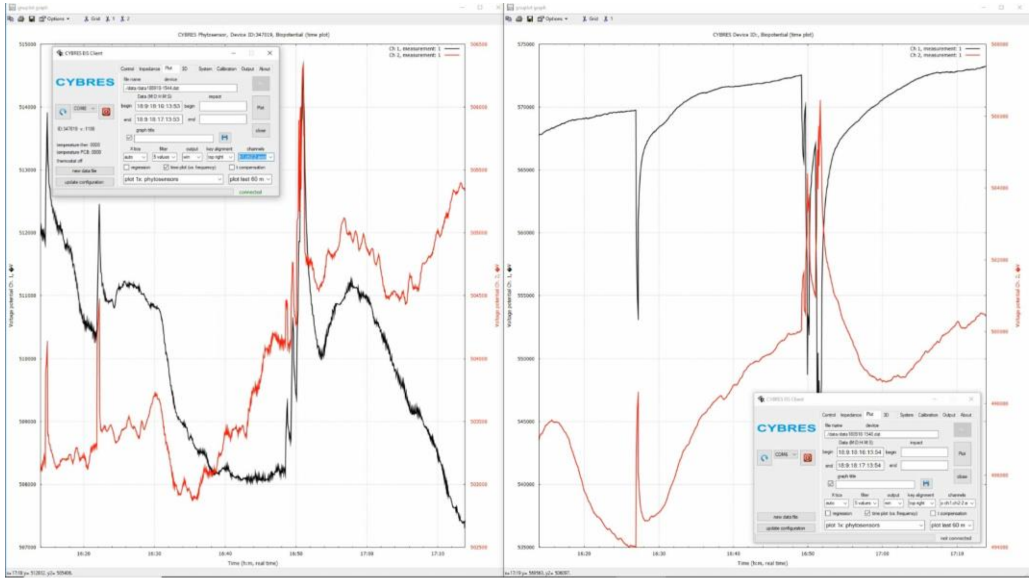

CYBRES Phytosensor, Device ID:333029, Two Stimuli Experiment, Biopotentials with periodical ON/OFF of FAN/Light

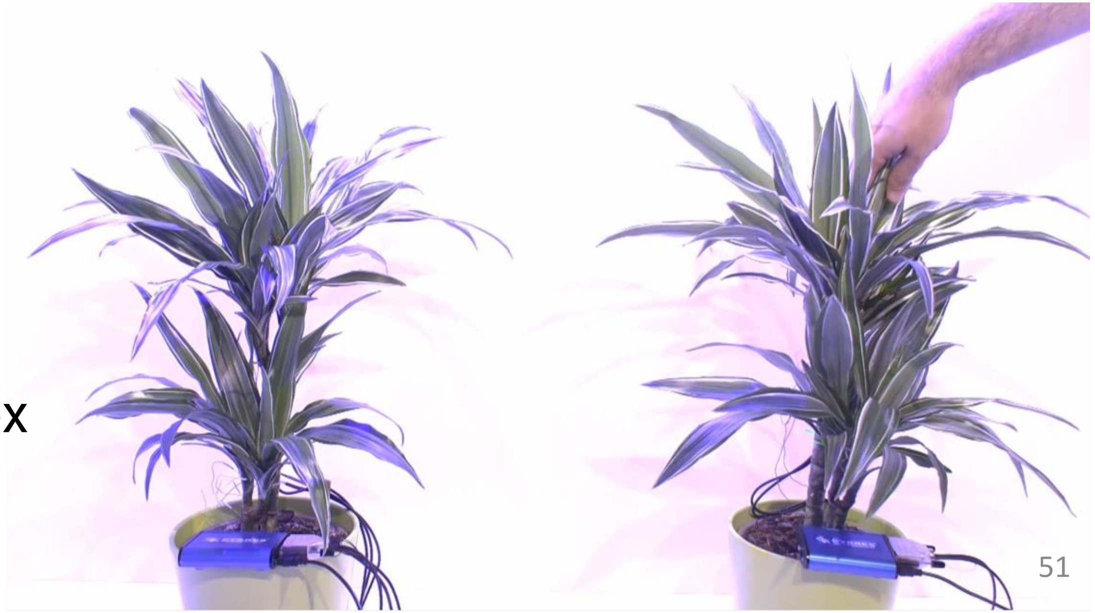
Phase 1 – only the fan is operating;
Phase 2 – light+fan are operating (12 hours);
Phase 3 – only the fan is operating

Communication & interactions between plants

(see video, “two plants”)







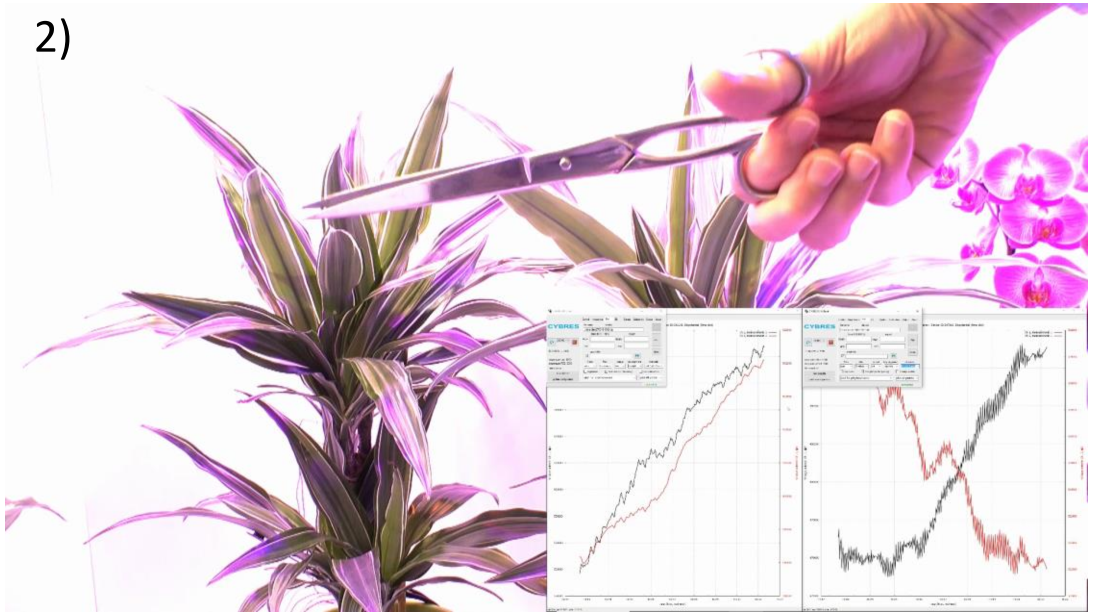
Feedback loops in bio-hybrid systems can generate complex interactions (communication) patterns between biological organisms

Collective electrophysiological reactions

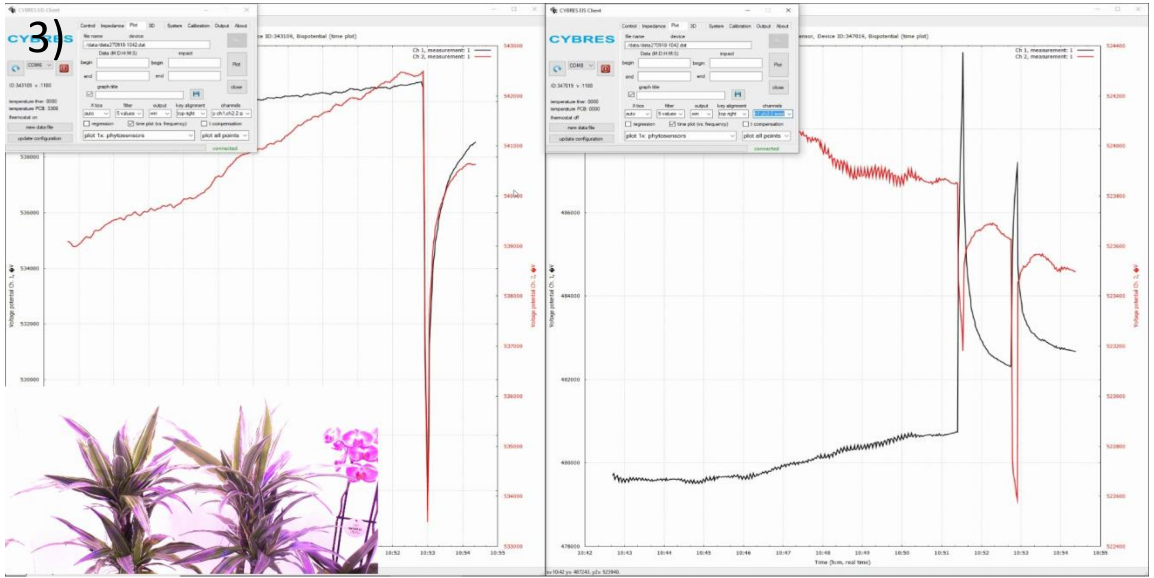
(complex scenarios for multiple plants, see video “cutting plant”)

1)

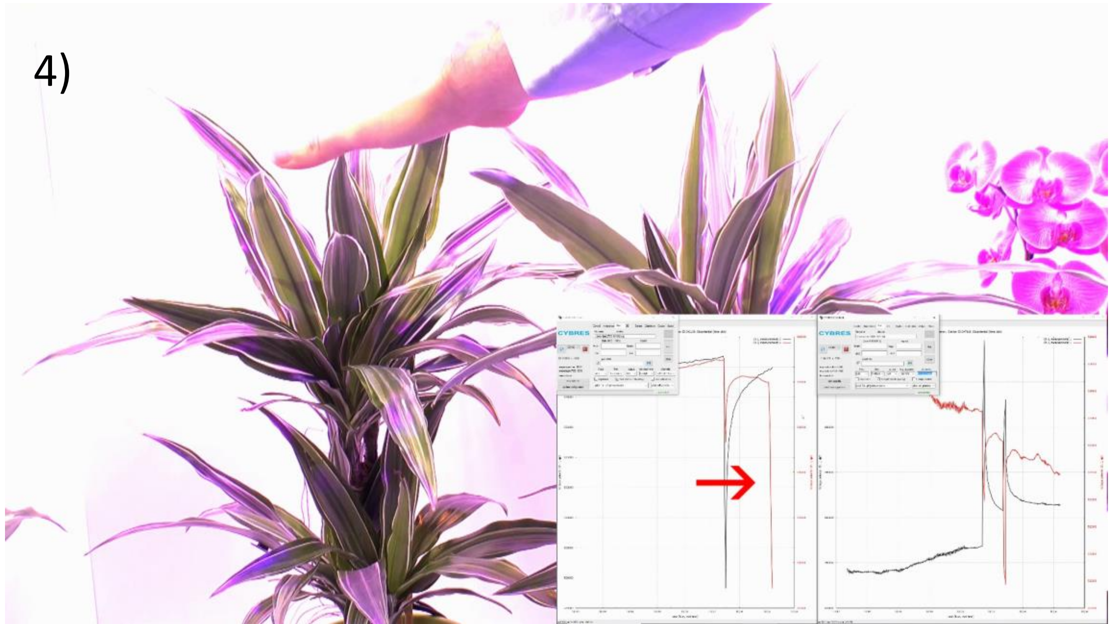
2)



3)



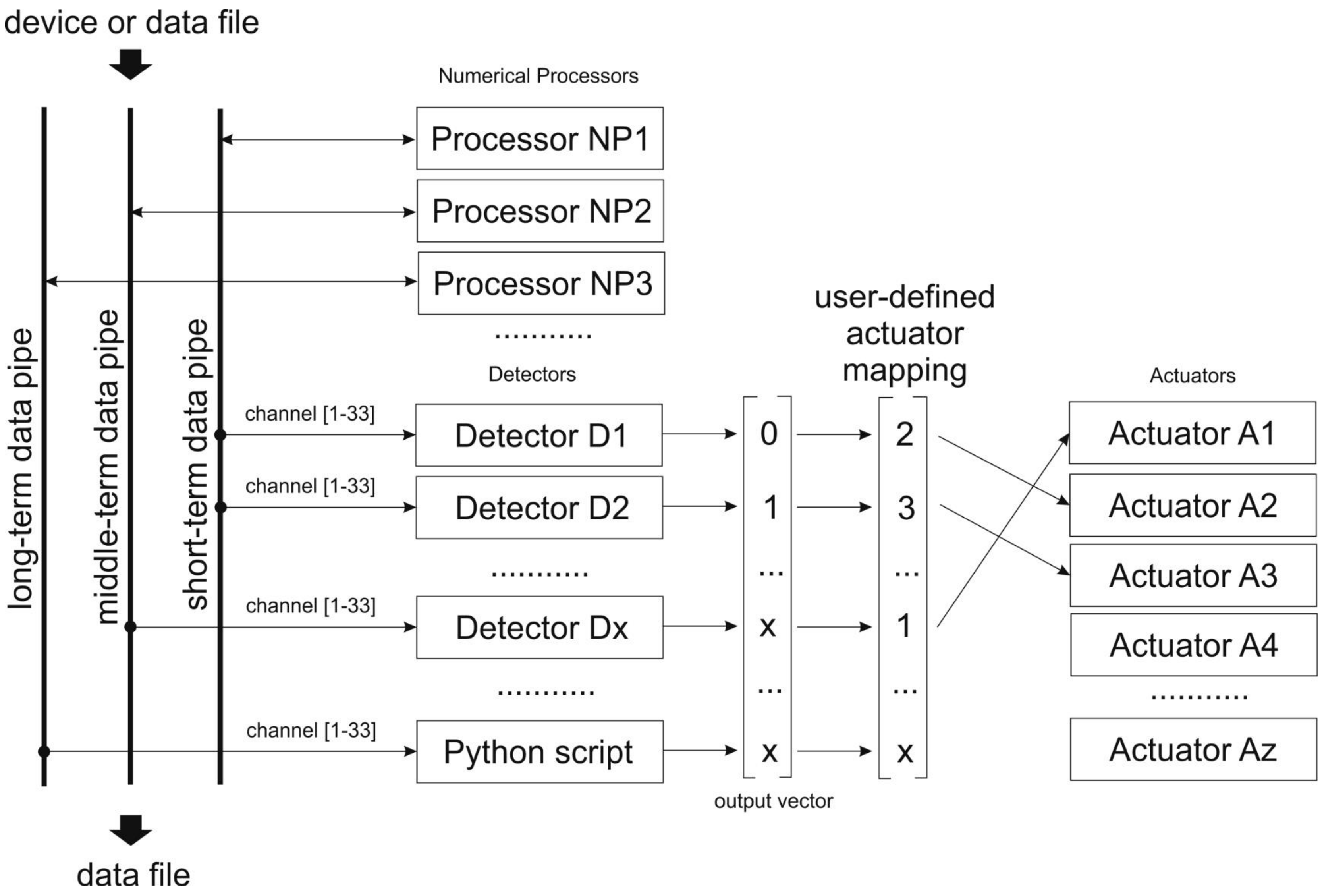
4)



5. User-defined programming

Operations over continuous data stream

- System can be programmed in simple way without knowledge of computer programming languages
- **Python script** can be used for user-defined programming
- **Concept I:** data pipes with different time dynamics (over seconds, over days, over weeks)
- **Concept II:** numerical processors (e.g. statistical analysis) can be enabled or disabled by users
- **Concept III:** detectors perform simple operations and trigger actuators

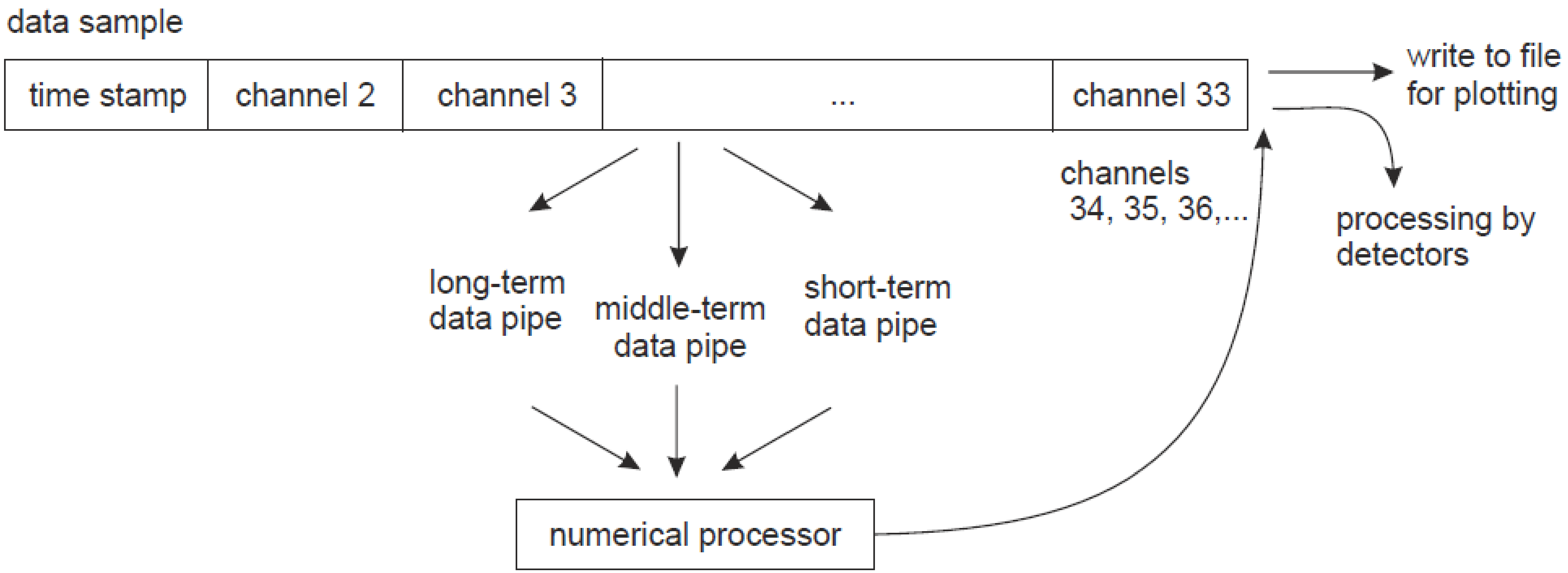


Real-time numerical processors

Each numerical processor takes data from the data pipe, performs calculations, and writes results back into the data pipe

Examples of numerical processors:

- Basic and advanced statistics
- Linear/Nonlinear regression analysis
- Fourier transformation/Spectral analysis
- Correlations
- Numerical analysis



DA scripts vs Python scripts

User-defined programs

DA (Detector-Actuator) script

+ native C++ implementation
+ fast execution
+ no programming skills required

- complex programs are difficult to write

Python script

+ flexible programming
+ large code base

- interpreter: slow execution
- required programming knowledge

DA scripts

- provide a flexible way to create a sensor-actuator system, e.g. to detect specific signals (signal patterns) in all sensor data and to react on these signals
- allow creating environmental feedback loops and homeostatic behavior, to develop complex demonstration scenarios and setups;
- enable performing fully automatic experiments
- to enable a real-time data analysis by numerical processors and creation of synthetic (virtual) sensors by performing a sensor fusion from different physical sensors
- currently implemented ~250 detectors and numerical processors (incl. probabilistic Bayesian networks, and toked driven Petri Nets
- currently implemented ~230 actuators (sound-, music-, speech-, light- actuation; turning on/off physical devices; electrical stimulation or sending internets messages, robot drivers)
- see User Manual, chapter 8 “DA module: real-time signal processing and actuation”, p. 100

Real-time detectors with DA script

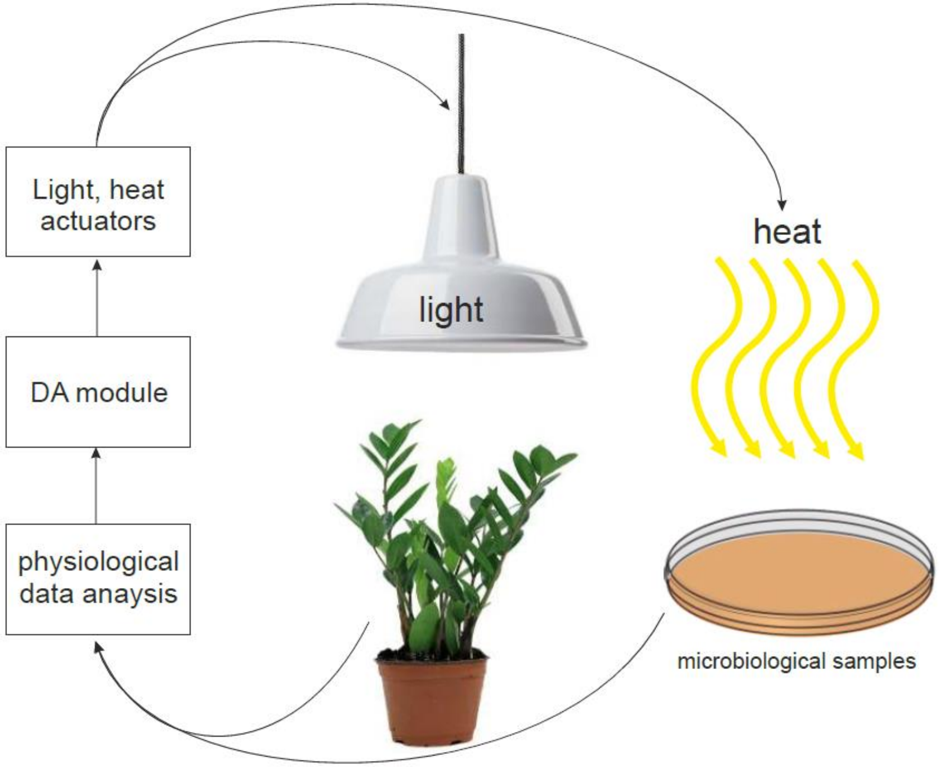
example with simple homeostatic feedback loop

Data channel 25 of external temperature

```
if (data[25][i]<26C) call A41; else call A42
```

LED on

LED off



DA script

```
I11=25;                # threshold-based detector D11, input channel 25
P11=260000 x;          # temperature threshold 26C

D11=41;                # define actuator 41 for "true" condition
D-11=42;               # define actuator 42 for "false" condition

A41=wk111*;            # define actuator 41 (ASCII commands for RGB LED on)
A42=wk000*;            # define actuator 42 (ASCII commands for RGB LED on)
```

Real-time detectors with DA script

simple example with text-to-speech TTS engine (talking plants)

The parameter 'textToSpeechLanguage' in the './ini/ini.ini' file determines the default language used by TTS engine

Data channel 28 of biopotentials ch1 (touch detection)

if data ([28][i]>12700) call A102 ← call TTS engine

threshold for touch detection

Flora – the talking plant

DA script

```
I11=28;                 # threshold-based detector D11, input channel 28
P11=12700 x;            # biopotential ch 1 threshold

D11=102;                # define actuator 102 for “true” condition

A102=I like you!;       # define actuator 102 (text for TTS engine)
```

Real-time detectors with DA script

example with two sensors

DA script

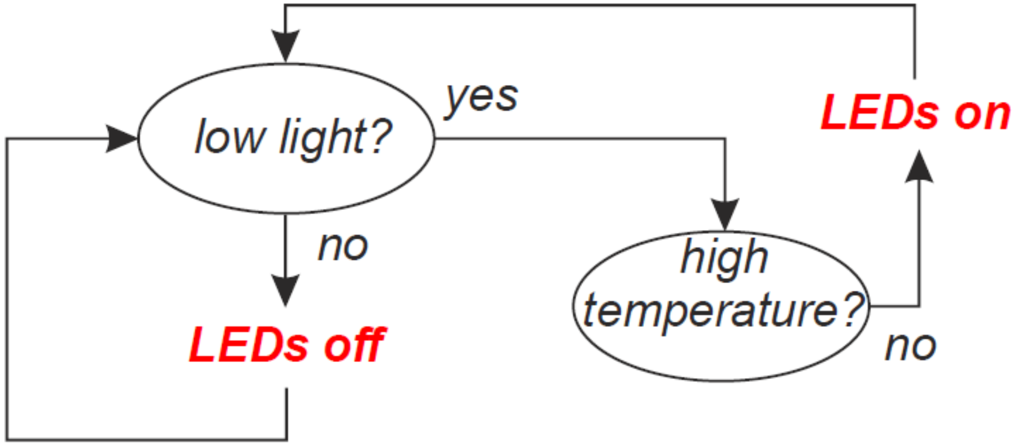
```
I11=26;               # threshold-based detector D11, input channel 26 (light)
P11=x 5000;           # light threshold 5000

D11=151;              # define "and"-actuator 151 for "true" condition
D-11=42;              # define actuator 42 for "false" condition

I12=25;               # threshold-based detector D12, input channel 25 (temperature)
P12=X 243000;         # temperature threshold 24.3C

D12=151;              # define actuator 151 for "true" condition

A151=41 11 -12;       # specify the 'and' actuator
A41=wk111*;           # define actuator 41 (ASCII commands for RGB LED on)
A42=wk000*;           # define actuator 42 (ASCII commands for RGB LED on)
```



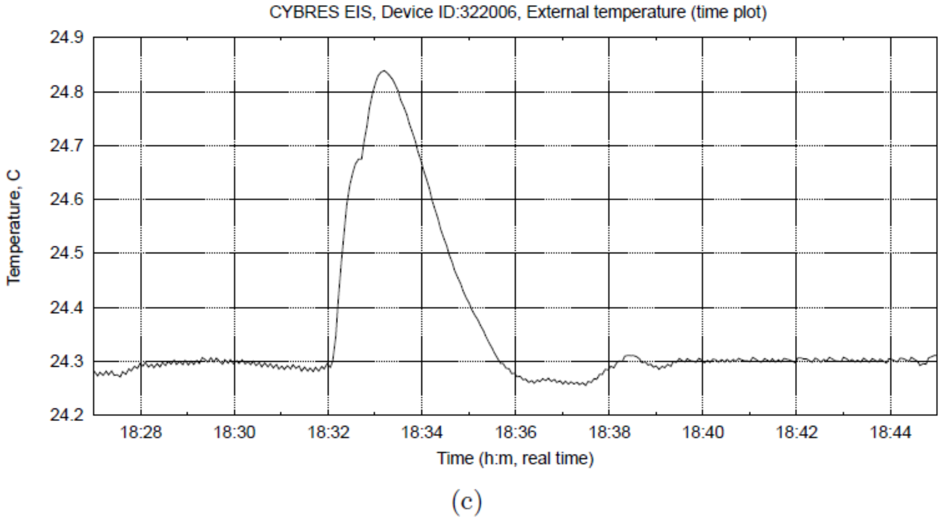
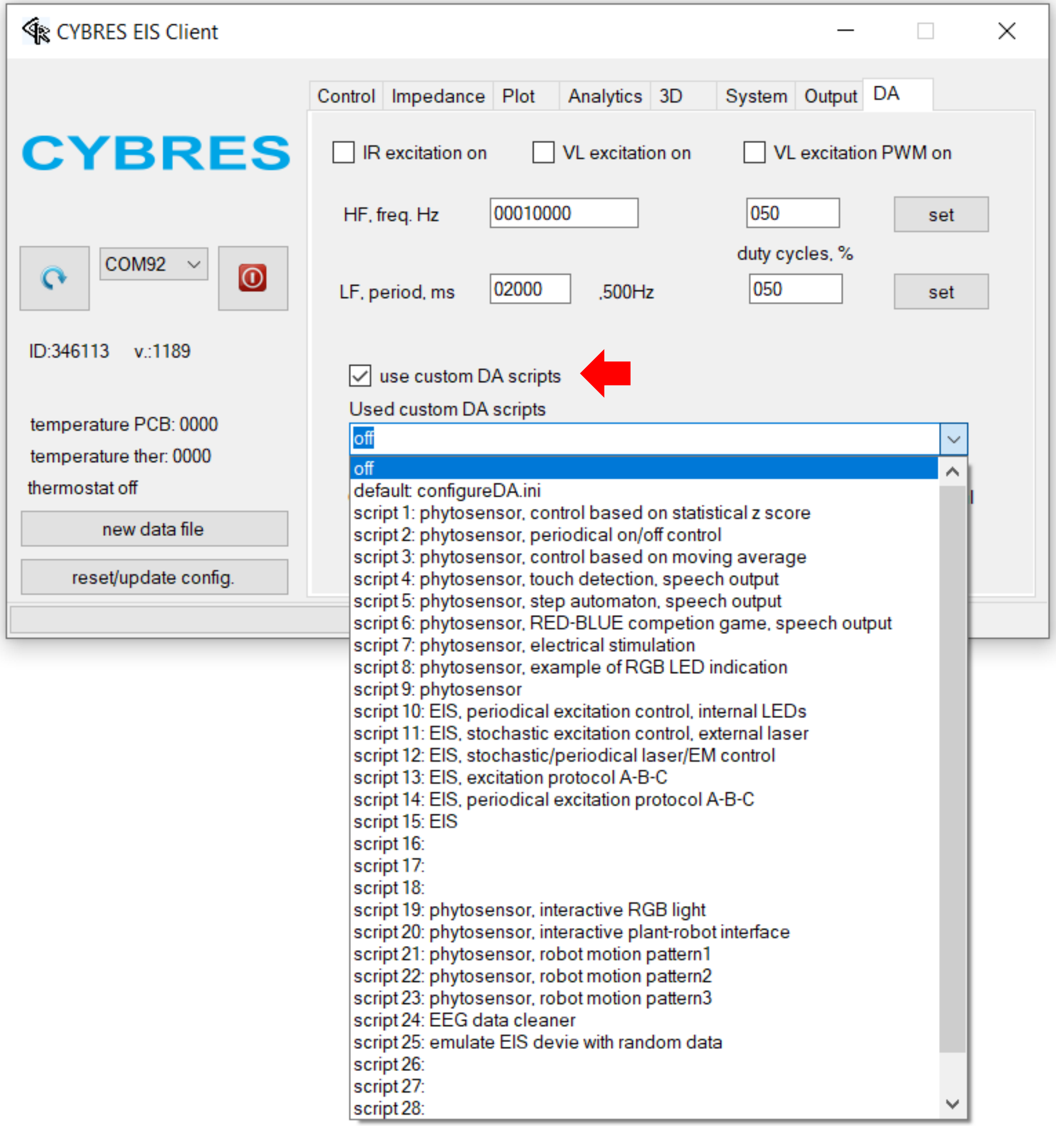


Figure 69: Example of homeostatic feedback loops, shown in the demonstration video, to create an oscillating behaviour of LED, controlled by light and temperature sensors to keep the temperature stable at defined value. (a) Block-diagram, (b) the network representation and (c) the temperature dynamics (perturbation is shown).

see demonstration in this video

How to use DA scripts

- think about scenario
- specify sensor data
- specify which actuators are necessary
- prepare DA script (or use prepared one)
- enable “use custom DA script”
  (files in directory /init/DA_library)
- select the script
- run experiment



ID:346113 v.:1189

temperature PCB: 0000
temperature ther: 0000
thermostat off

☐ IR excitation on ☐ VL excitation on ☐ VL excitation PWM on

HF, freq. Hz 00010000 050

duty cycles, %

LF, period, ms 02000 .500Hz 050

☑ use custom DA scripts

Used custom DA scripts

off

off
default: configureDA.ini
script 1: phytosensor, control based on statistical z score
script 2: phytosensor, periodical on/off control
script 3: phytosensor, control based on moving average
script 4: phytosensor, touch detection, speech output
script 5: phytosensor, step automaton, speech output
script 6: phytosensor, RED-BLUE competion game, speech output
script 7: phytosensor, electrical stimulation
script 8: phytosensor, example of RGB LED indication
script 9: phytosensor
script 10: EIS, periodical excitation control, internal LEDs
script 11: EIS, stochastic excitation control, external laser
script 12: EIS, stochastic/periodical laser/EM control
script 13: EIS, excitation protocol A-B-C
script 14: EIS, periodical excitation protocol A-B-C
script 15: EIS
script 16:
script 17:
script 18:
script 19: phytosensor, interactive RGB light
script 20: phytosensor, interactive plant-robot interface
script 21: phytosensor, robot motion pattern1
script 22: phytosensor, robot motion pattern2
script 23: phytosensor, robot motion pattern3
script 24: EEG data cleaner
script 25: emulate EIS devie with random data
script 26:
script 27:
script 28:

Available numerical processors, detectors, actuators

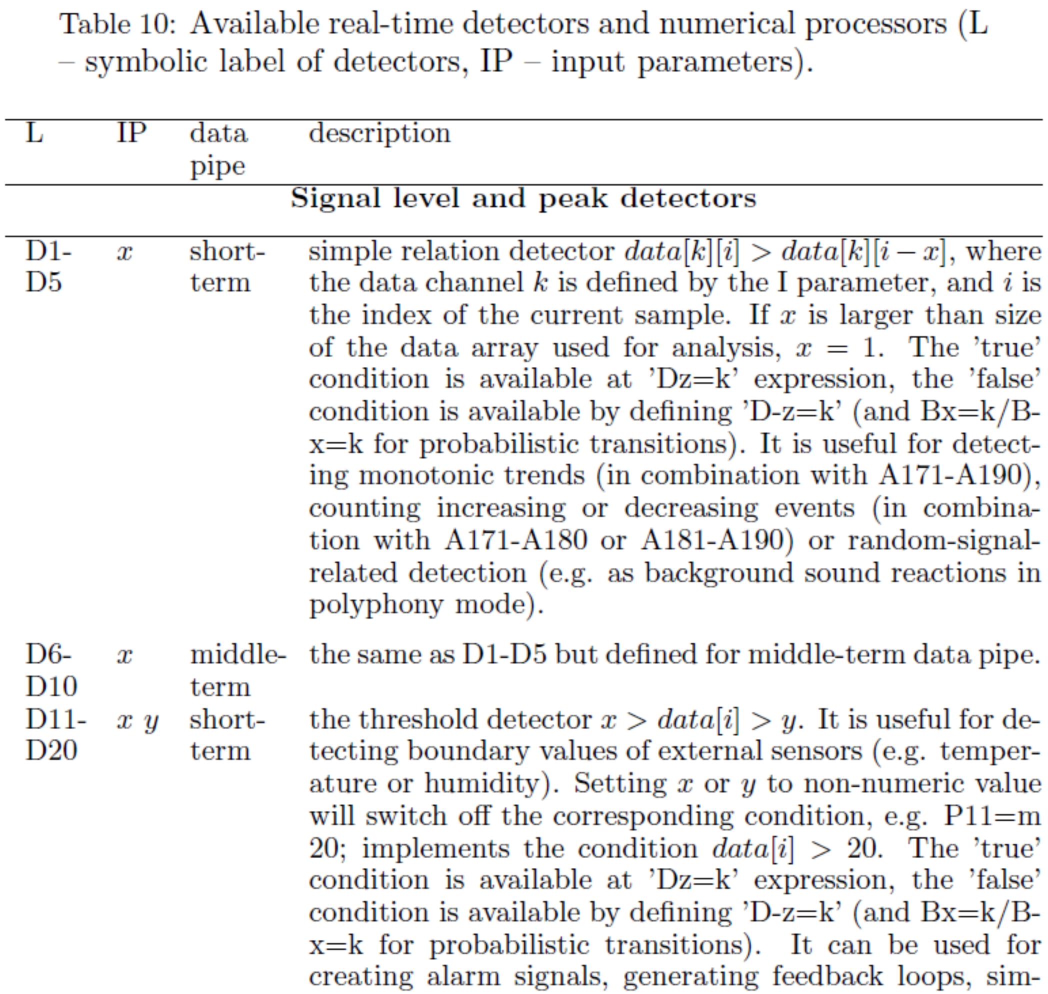


Table 10: Available real-time detectors and numerical processors (L – symbolic label of detectors, IP – input parameters).

L	IP	data pipe	description
			Signal level and peak detectors
D1-D5	x	short-term	simple relation detector $data[k][i] > data[k][i-x]$, where the data channel k is defined by the I parameter, and i is the index of the current sample. If x is larger than size of the data array used for analysis, $x = 1$. The 'true' condition is available at 'Dz=k' expression, the 'false' condition is available by defining 'D-z=k' (and Bx=k/B-x=k for probabilistic transitions). It is useful for detecting monotonic trends (in combination with A171-A190), counting increasing or decreasing events (in combination with A171-A180 or A181-A190) or random-signal-related detection (e.g. as background sound reactions in polyphony mode).
D6-D10	x	middle-term	the same as D1-D5 but defined for middle-term data pipe.
D11-D20	x y	short-term	the threshold detector $x > data[i] > y$. It is useful for detecting boundary values of external sensors (e.g. temperature or humidity). Setting x or y to non-numeric value will switch off the corresponding condition, e.g. P11=m 20; implements the condition $data[i] > 20$. The 'true' condition is available at 'Dz=k' expression, the 'false' condition is available by defining 'D-z=k' (and Bx=k/B-x=k for probabilistic transitions). It can be used for creating alarm signals, generating feedback loops, sim-

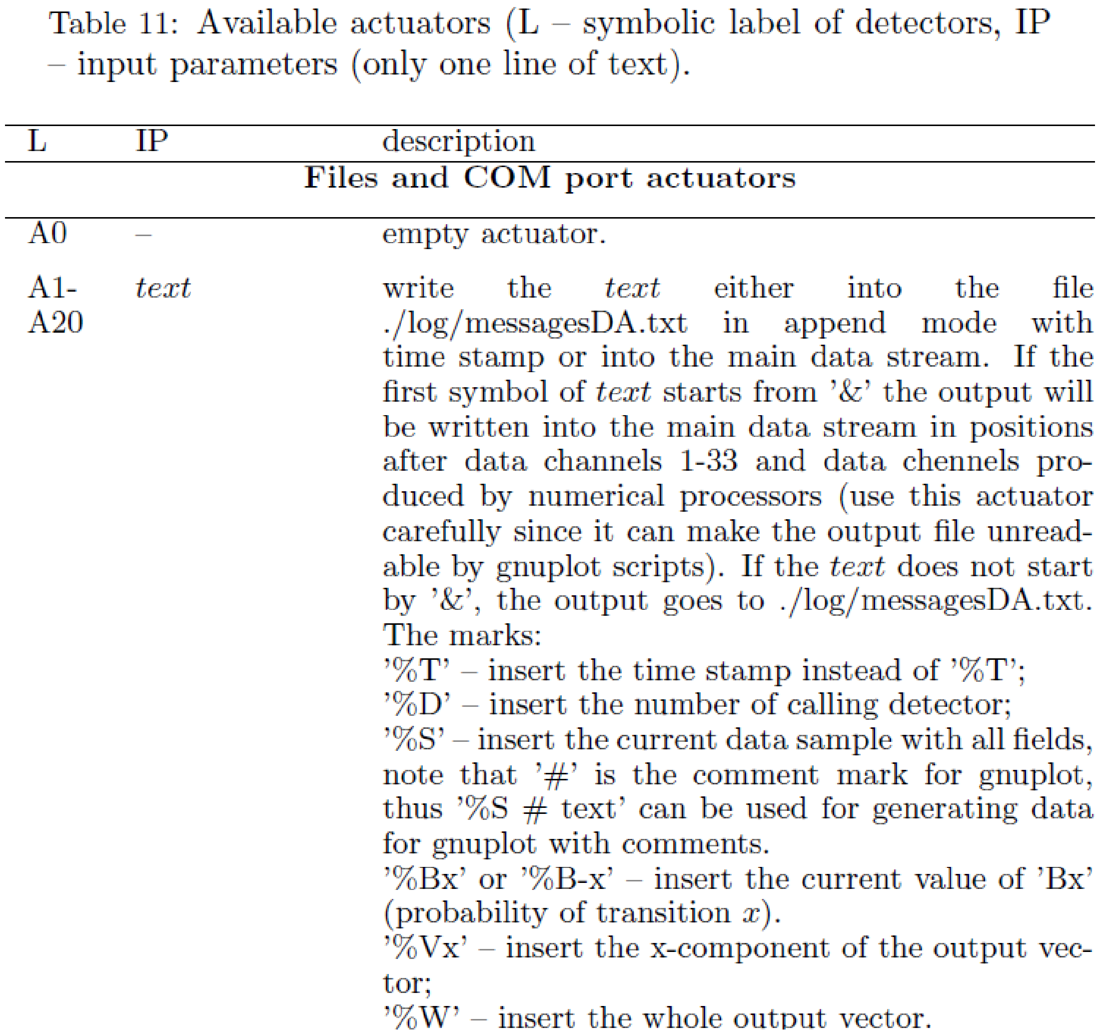


Table 11: Available actuators (L – symbolic label of detectors, IP – input parameters (only one line of text).

L	IP	description
		Files and COM port actuators
A0	–	empty actuator.
A1-A20	*text*	write the *text* either into the file ./log/messagesDA.txt in append mode with time stamp or into the main data stream. If the first symbol of *text* starts from '&' the output will be written into the main data stream in positions after data channels 1-33 and data chennels produced by numerical processors (use this actuator carefully since it can make the output file unreadable by gnuplot scripts). If the *text* does not start by '&', the output goes to ./log/messagesDA.txt. The marks: '%T' – insert the time stamp instead of '%T'; '%D' – insert the number of calling detector; '%S' – insert the current data sample with all fields, note that '#' is the comment mark for gnuplot, thus '%S # text' can be used for generating data for gnuplot with comments. '%Bx' or '%B-x' – insert the current value of 'Bx' (probability of transition x). '%Vx' – insert the x-component of the output vector; '%W' – insert the whole output vector.

see User Manual, sec. 8.13 "Detailed description of implemented detectors and actuators", p.126

More Information

- User Manual
- Application notes
- Publications
- Project Reports
- Videos

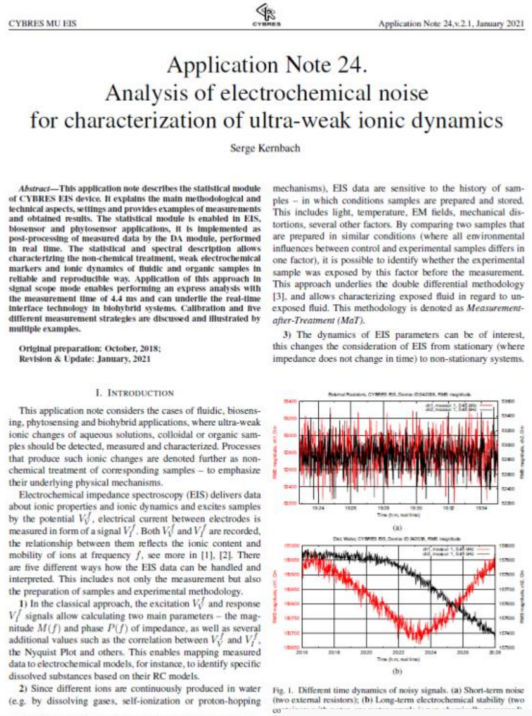
- Contact: info(at)cybertronica.de.com

CYBRES® Measurement Unit (MU3)

for electrochemical and electrophysiological analysis of fluids and organic tissues

- Differential Electrochemical Impedance Spectrometer (EIS)
- Phytosensing and phytoactuating system
- Biosensor based on fermentation activity of yeast

USER MANUAL



CYBRES MU EIS Application Note 24,v.2.1, January 2021

Application Note 24.
Analysis of electrochemical noise
for characterization of ultra-weak ionic dynamics

Serge Kernbach

Abstract—This application note describes the statistical module of CYBRES EIS device. It explains the main methodological and technical aspects, settings and provides examples of measurements and obtained results. The statistical module is enabled in EIS, biosensor and phytosensor applications. It is implemented as post-processing of measured data by the DA module, performed in real time. The statistical and spectral description allows characterizing the non-chemical treatment, weak electrochemical markers and ionic dynamics of fluidic and organic samples in reliable and reproducible way. Application of this approach in signal scope mode enables performing an express analysis with the measurement time of 4.4 ms and can underlie the real-time interface technology in biohybrid systems. Calibration and five different measurement strategies are discussed and illustrated by multiple examples.

Original preparation: October, 2018;
Revision & Update: January, 2021

I. INTRODUCTION

This application note considers the cases of fluidic, biosensing, phytosensing and biohybrid applications, where ultra-weak ionic changes of aqueous solutions, colloidal or organic samples should be detected, measured and characterized. Processes that produce such ionic changes are denoted further as non-chemical treatment of corresponding samples – to emphasize their underlying physical mechanisms.

Electrochemical impedance spectroscopy (EIS) delivers data about ionic properties and ionic dynamics and excites samples by the potential V_V^f, electrical current between electrodes is measured in form of a signal V_I^f. Both V_V^f and V_I^f are recorded, the relationship between them reflects the ionic content and mobility of ions at frequency f, see more in [1], [2]. There are five different ways how the EIS data can be handled and interpreted. This includes not only the measurement but also the preparation of samples and experimental methodology.

1) In the classical approach, the excitation V_V^f and response V_I^f signals allow calculating two main parameters – the magnitude $M(f)$ and phase $P(f)$ of impedance, as well as several additional values such as the correlation between V_V^f and V_I^f, the Nyquist Plot and others. This enables mapping measured data to electrochemical models, for instance, to identify specific dissolved substances based on their RC models.

2) Since different ions are continuously produced in water (e.g. by dissolving gases, self-ionization or proton-hopping mechanisms), EIS data are sensitive to the history of samples – in which conditions samples are prepared and stored. This includes light, temperature, EM fields, mechanical distortions, several other factors. By comparing two samples that are prepared in similar conditions (where all environmental influences between control and experimental samples differs in one factor), it is possible to identify whether the experimental sample was exposed by this factor before the measurement. This approach underlies the double differential methodology [3], and allows characterizing exposed fluid in regard to unexposed fluid. This methodology is denoted as *Measurement-after-Treatment (MaT)*.

3) The dynamics of EIS parameters can be of interest, this changes the consideration of EIS from stationary (where impedance does not change in time) to non-stationary systems.

(a)

(b)

Fig. 1. Different time dynamics of noisy signals. (a) Short-term noise (two external resistors); (b) Long-term electrochemical stability (two

Measurement Unit (MU3)

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