



Digital maintenance for sustainable and flexible
operation of HYDROpower plant

Innovative sensor technologies for biodiversity and environmental monitoring



INOSENS



This project has received funding by the European Union's Horizon Europe research and innovation programme under Grant Agreement N° 101122311

Table of contents

01 Environmental & Biodiversity Monitoring in HPP Međuvršje

02 Tasks regarding Biodiversity Monitoring and Modelling

03 Environmental & Biodiversity Sensors

04 Environmental and biodiversity monitoring

05 Environmental and biodiversity model

Tasks

- Research and development of sensor technologies and automation
- Novel sensing device for biodiversity and environmental monitoring
 - Algae sensor
 - Ammonia Sensor
 - E. Coli sensor
- Develop a **multiparametric platform for real-time evaluation of the micro-organism's** population present in the water composed of
 - fluorescence sensor for estimating pathogenic bacteria concentration
 - multispectral system
- **Testing and assessing efficiency of Di-Hydro sensor technologies**
- **Environmental, biodiversity monitoring and models**



This project has received funding by the European Union's Horizon Europe research and innovation programme under Grant Agreement N° 101122311

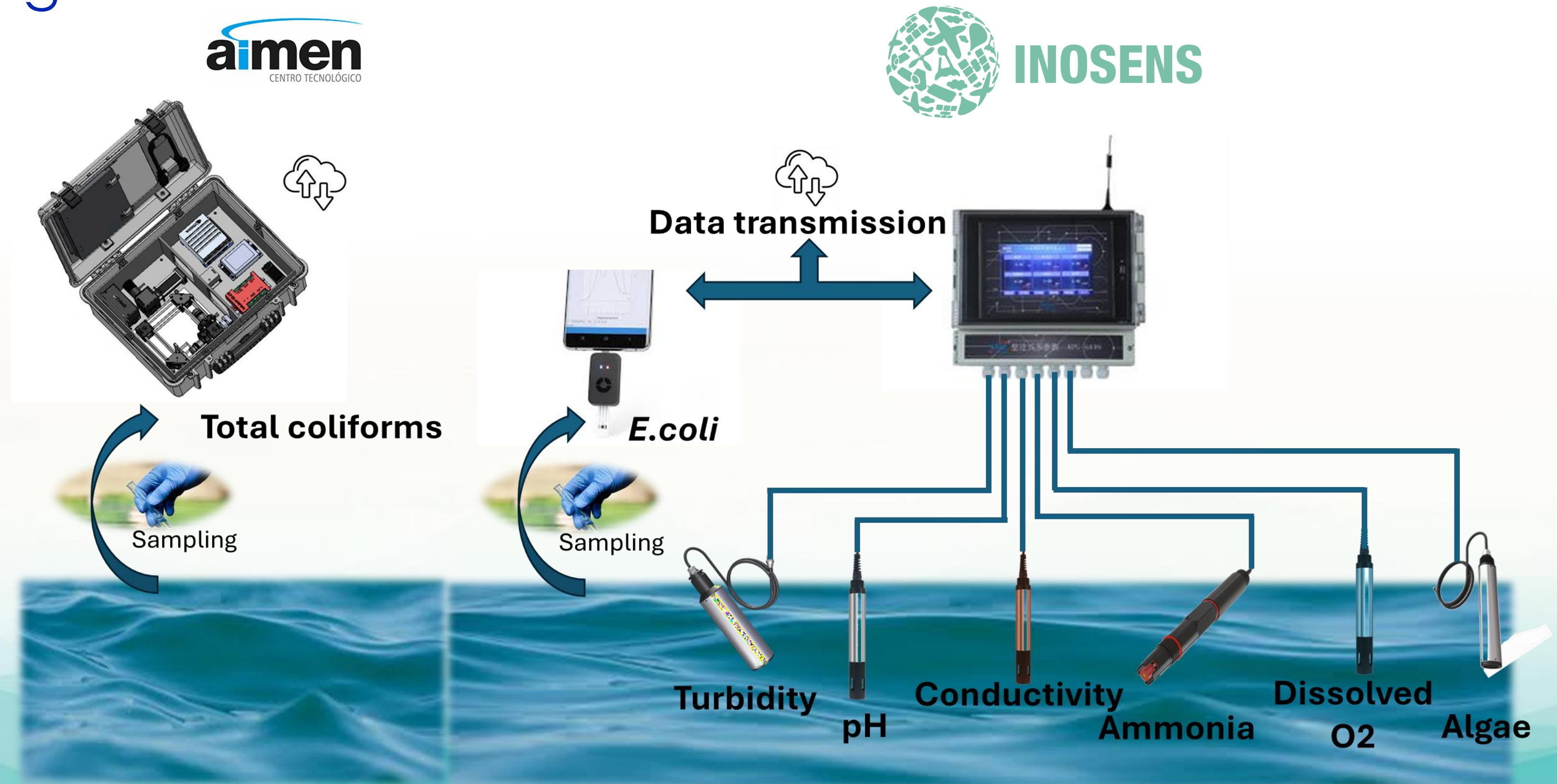


Developed sensors for **real-time monitoring of the water quality parameters**

1. **Fluorescence-based sensor** that measures a critical concentration of blue-green **algae**,
2. **Electrochemical sensor** with the ion-selective membrane to measure the **concentration of ammonia**,
3. **Electrochemical aptamer-based biosensor** for quantitative determination of **Escherichia coli** bacteria
4. **Biodiversity sensors - Digital Holographic Microscope (DHM) and Tryptophan-like fluorescence (TLF) sensor.**
5. Set of commercially sensors: **Dissolved Oxygen, water EC, pH value, oxidation reduction and water temperature.**
6. **Installation of sensors and communication platform** to collect and send real-time data



Monitoring system for biodiversity and environmental monitoring



Sensor development and testing



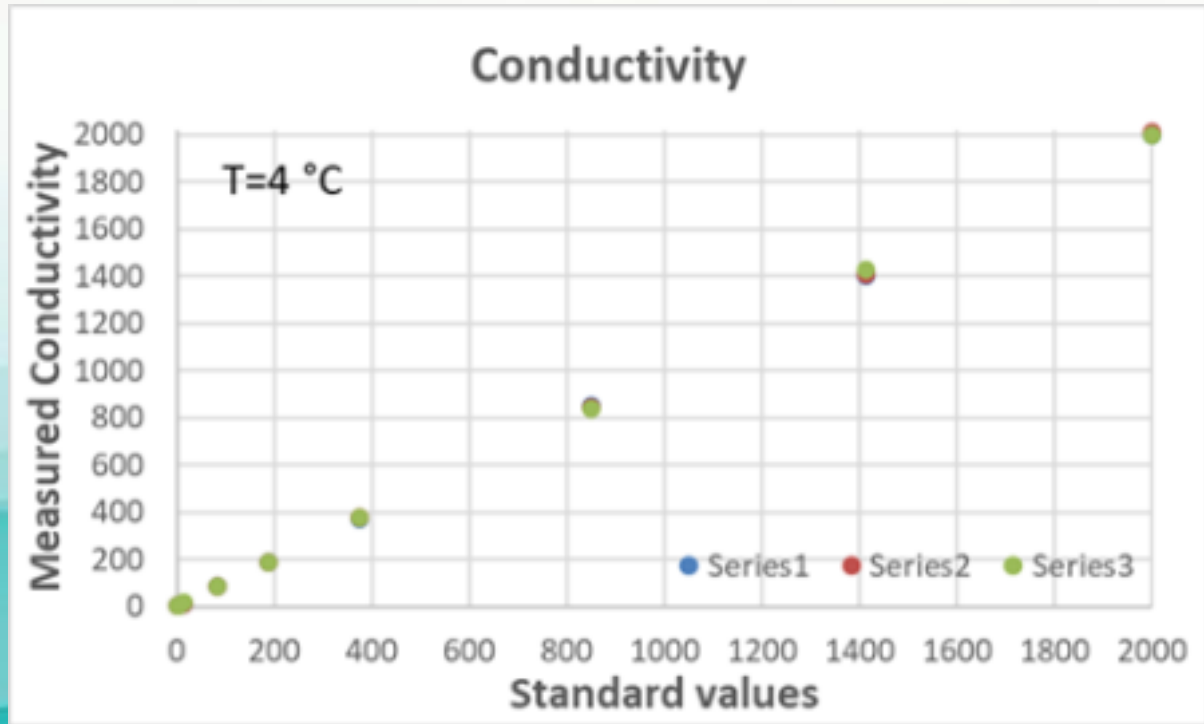
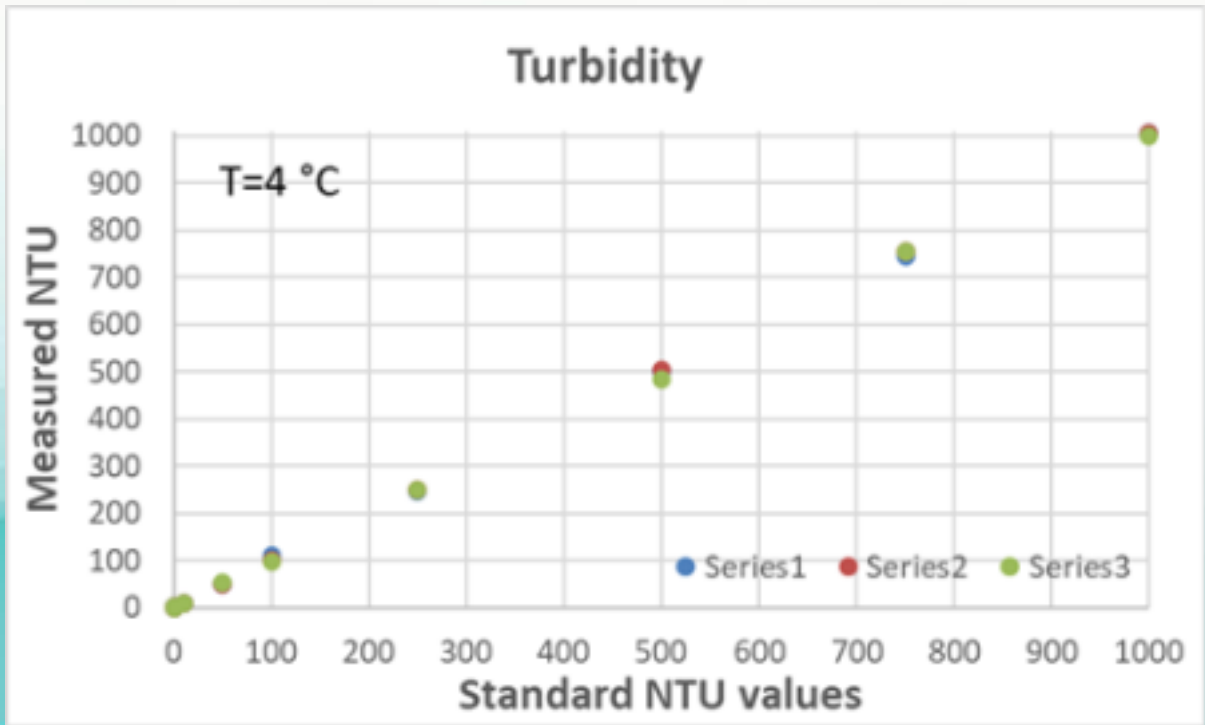
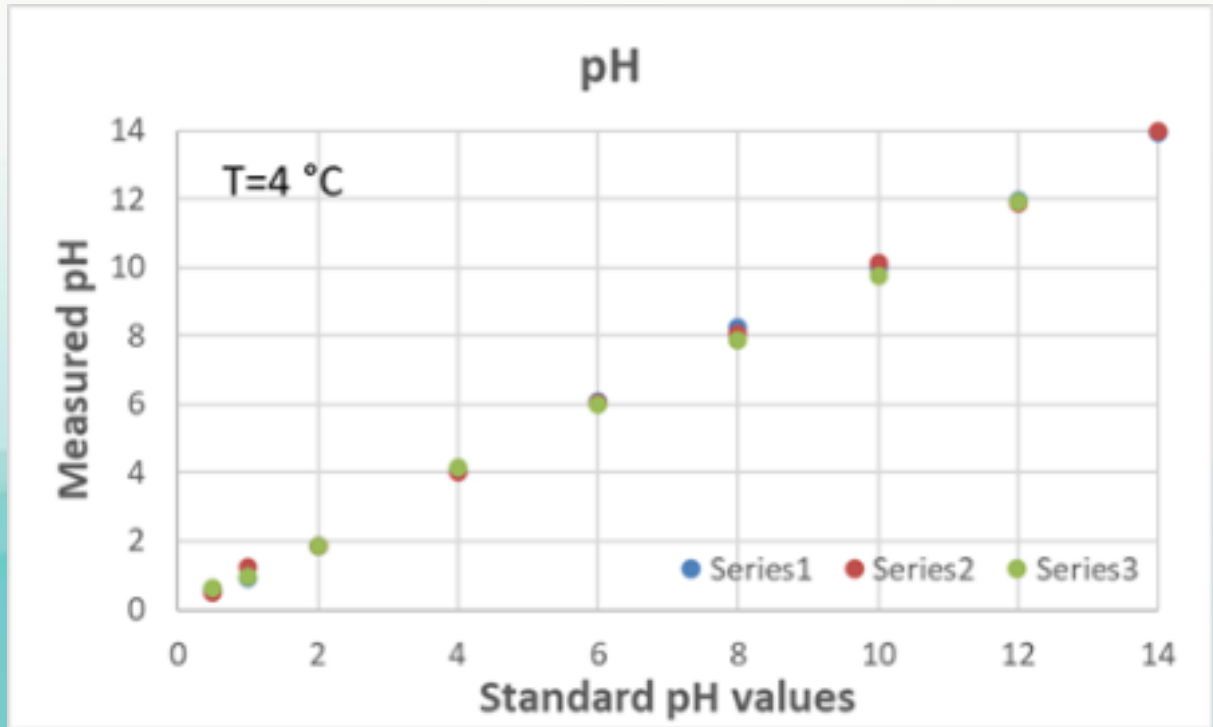
pH sensor IOT-485-PH BH-485



ZDYG-2088-01QX digital turbidity sensor



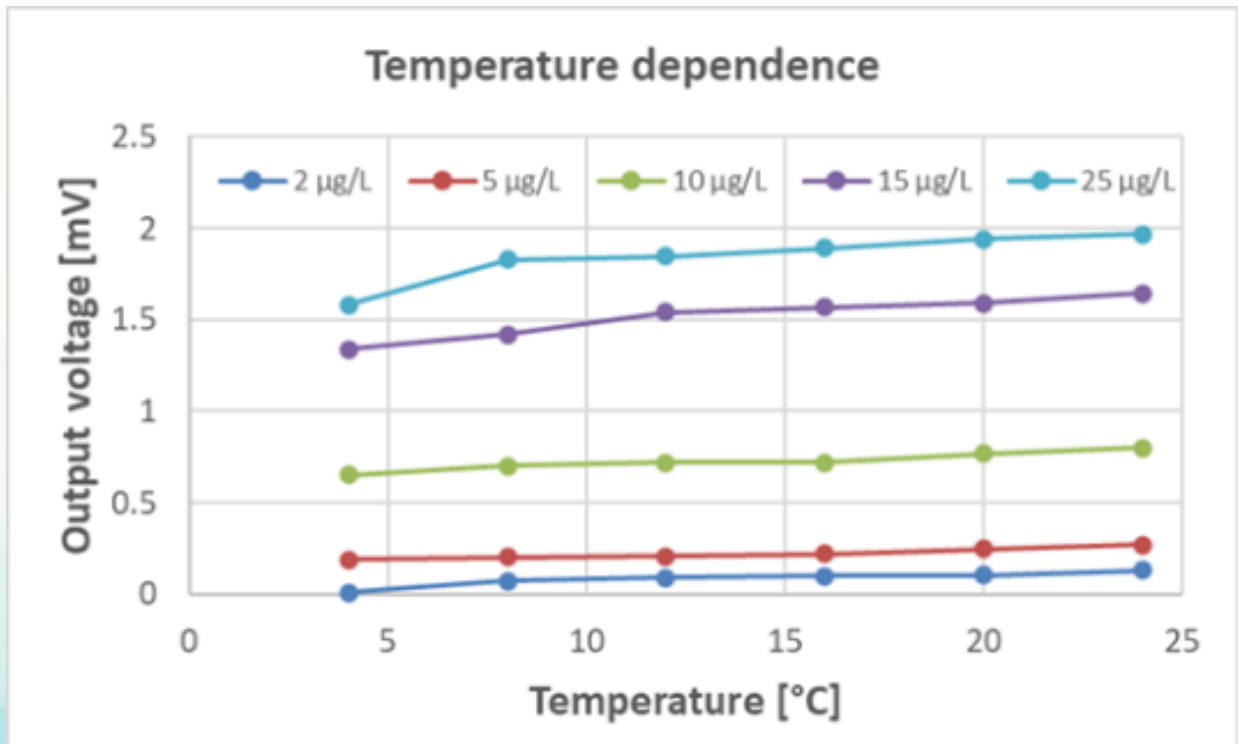
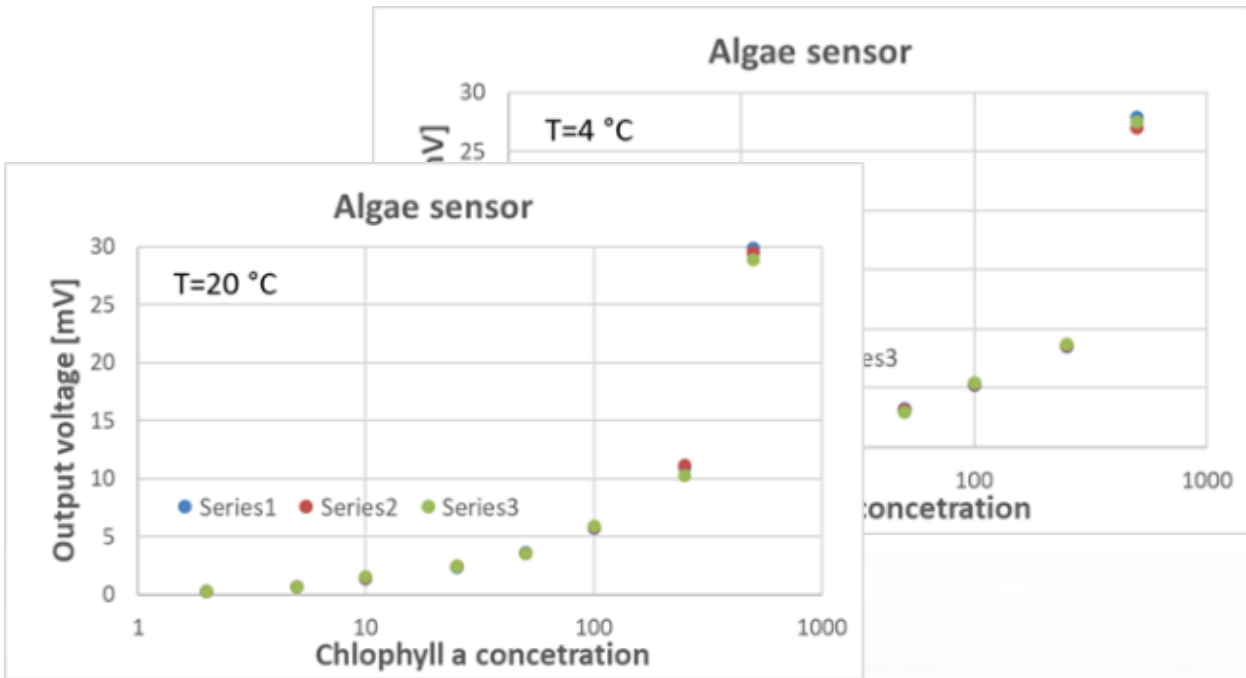
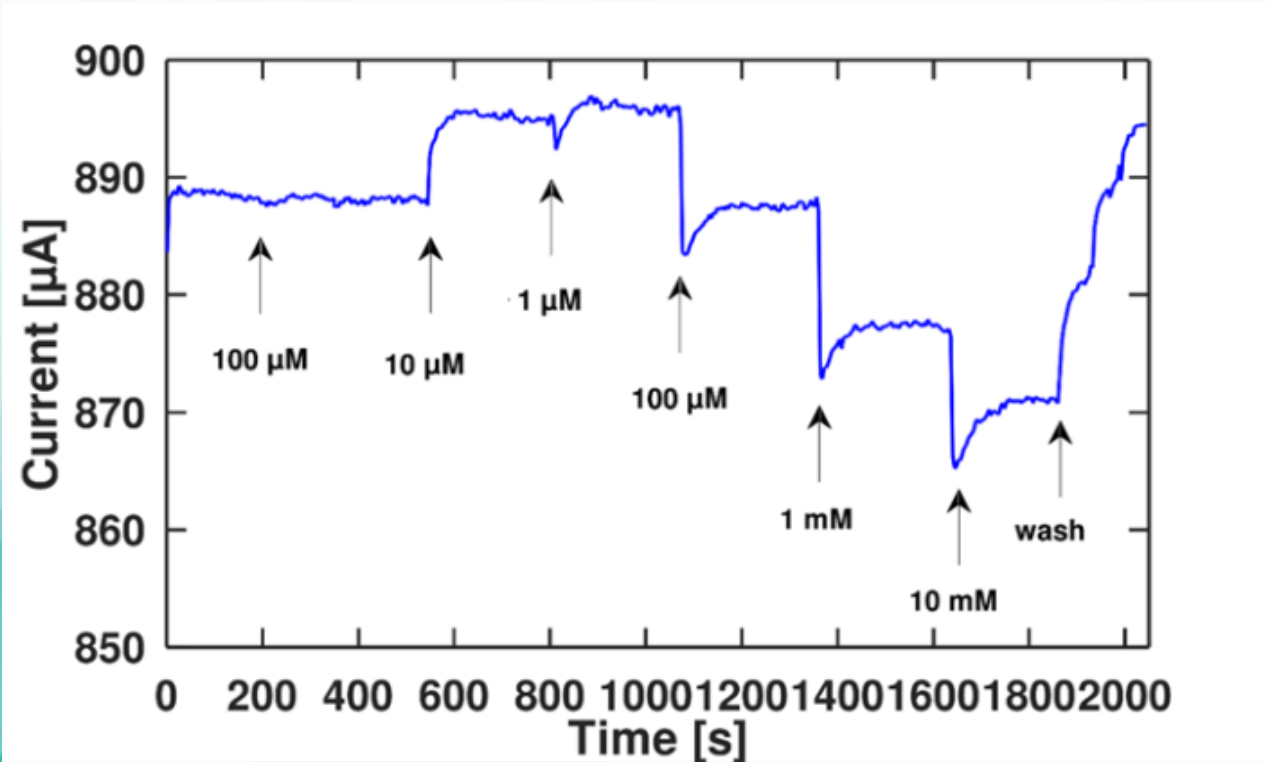
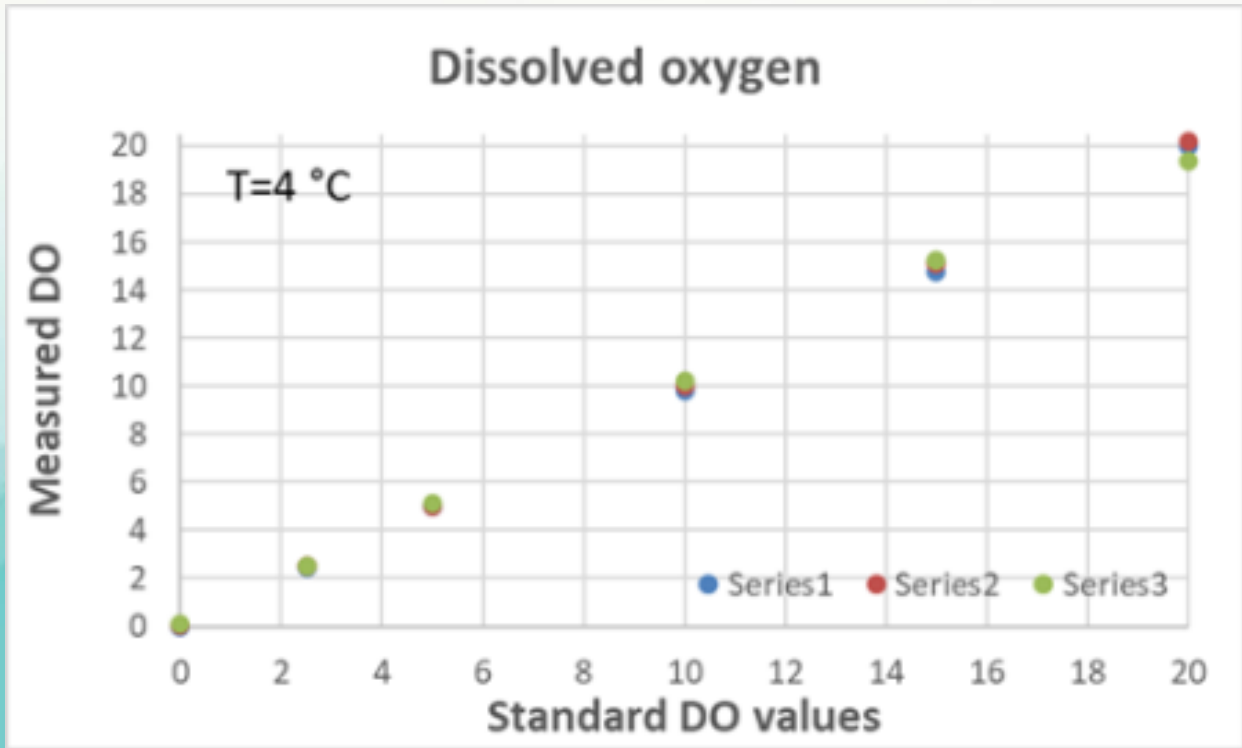
BH-485-DD digital conductivity sensor



Sensor development and testing

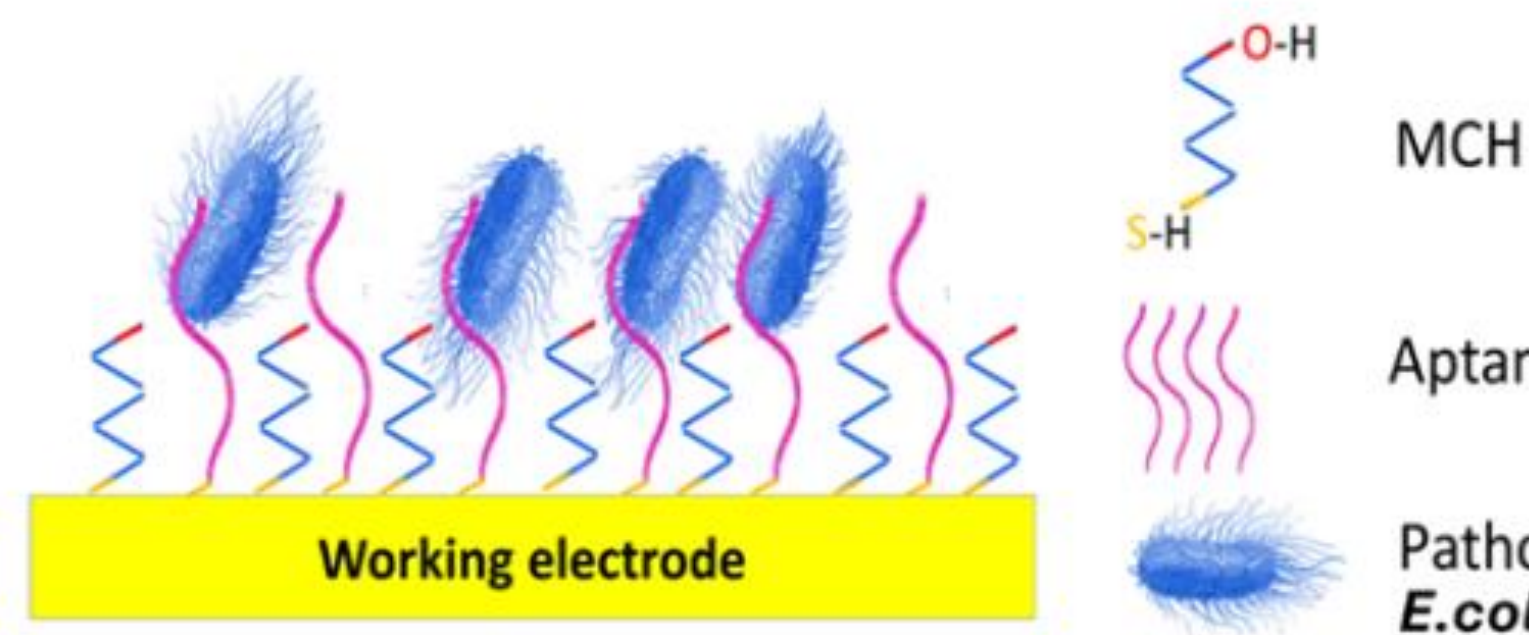


Ammonia sensor - Ion selective membrane
BH-485-DO digital dissolved oxygen sensor

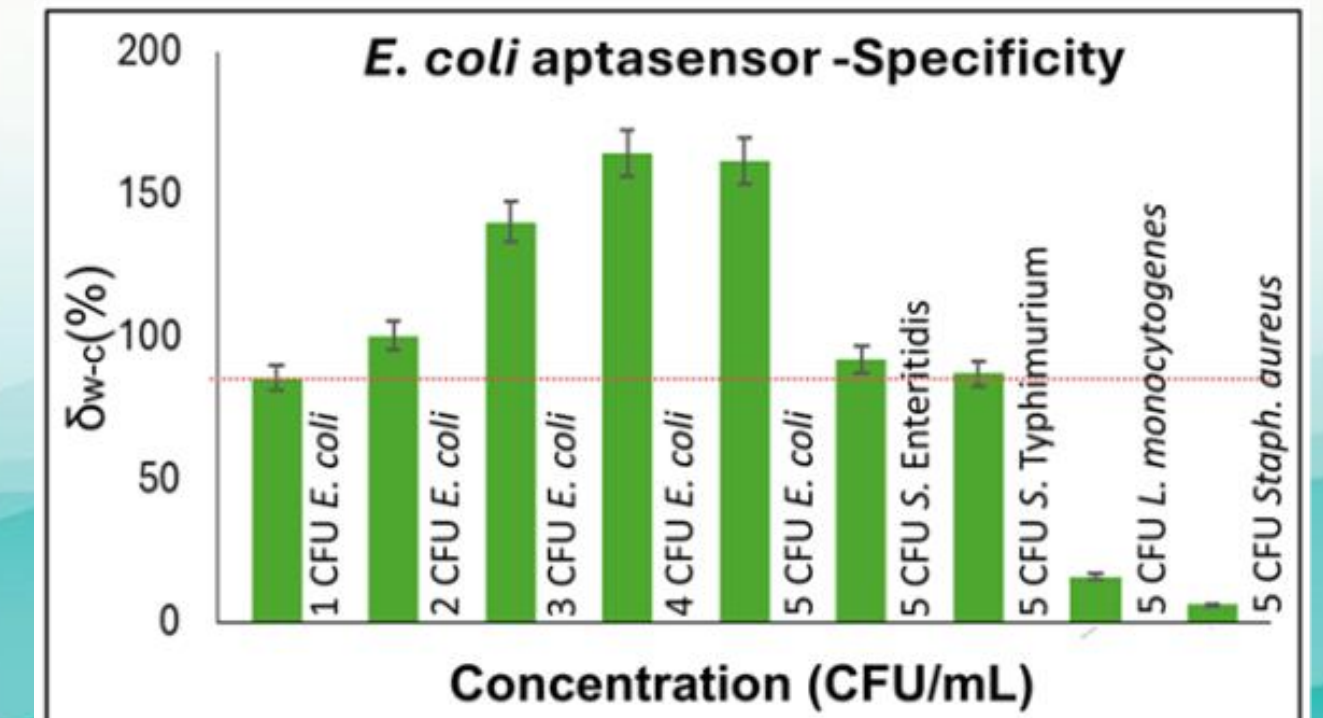
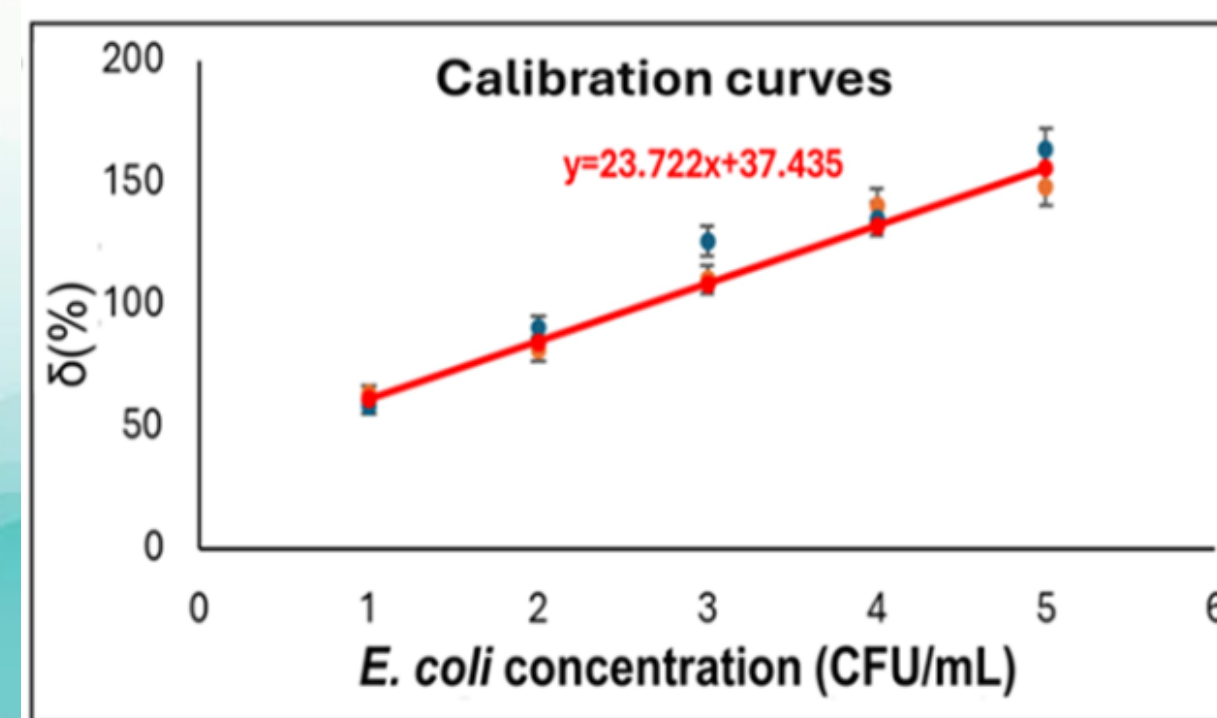
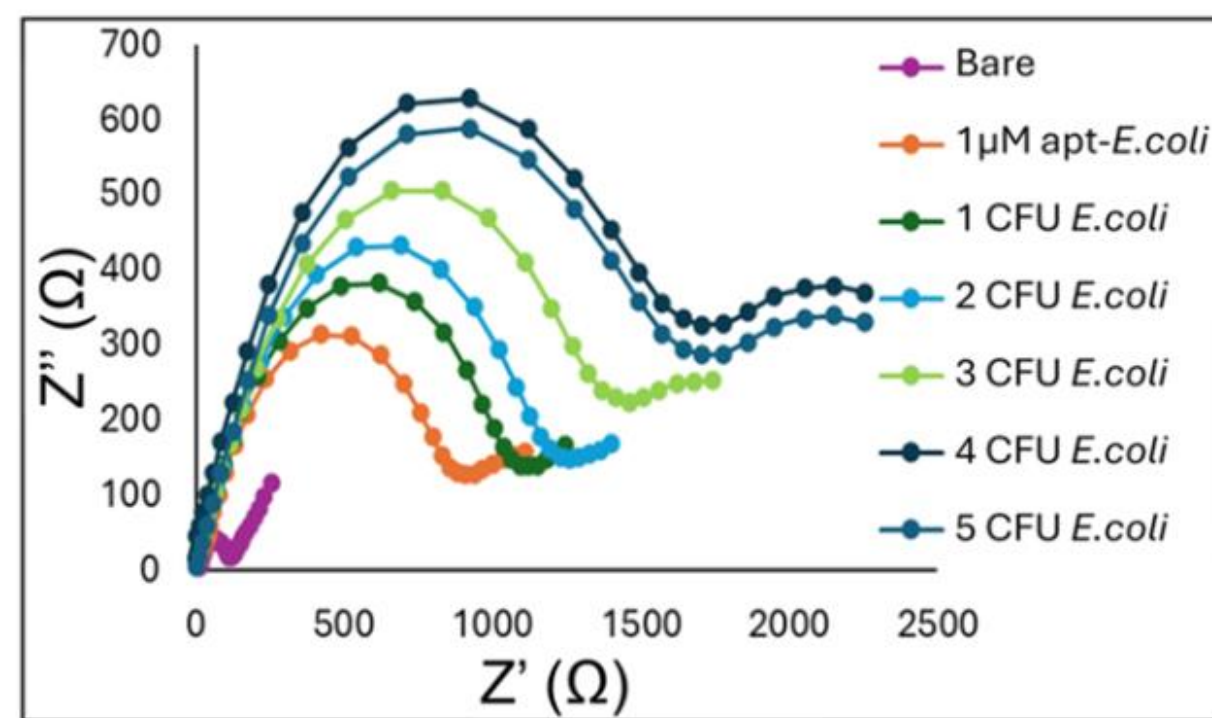


Temperature compensation for all sensors

Sensor development and testing

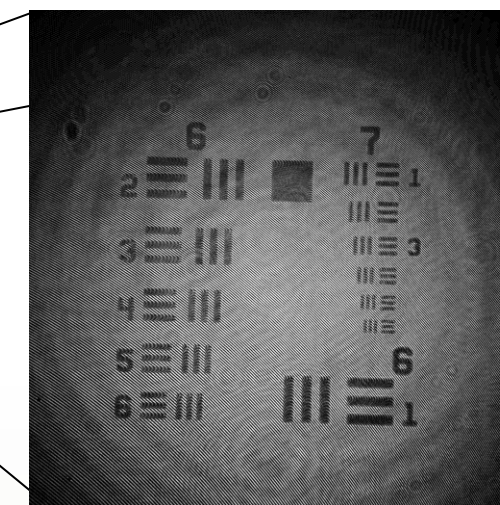
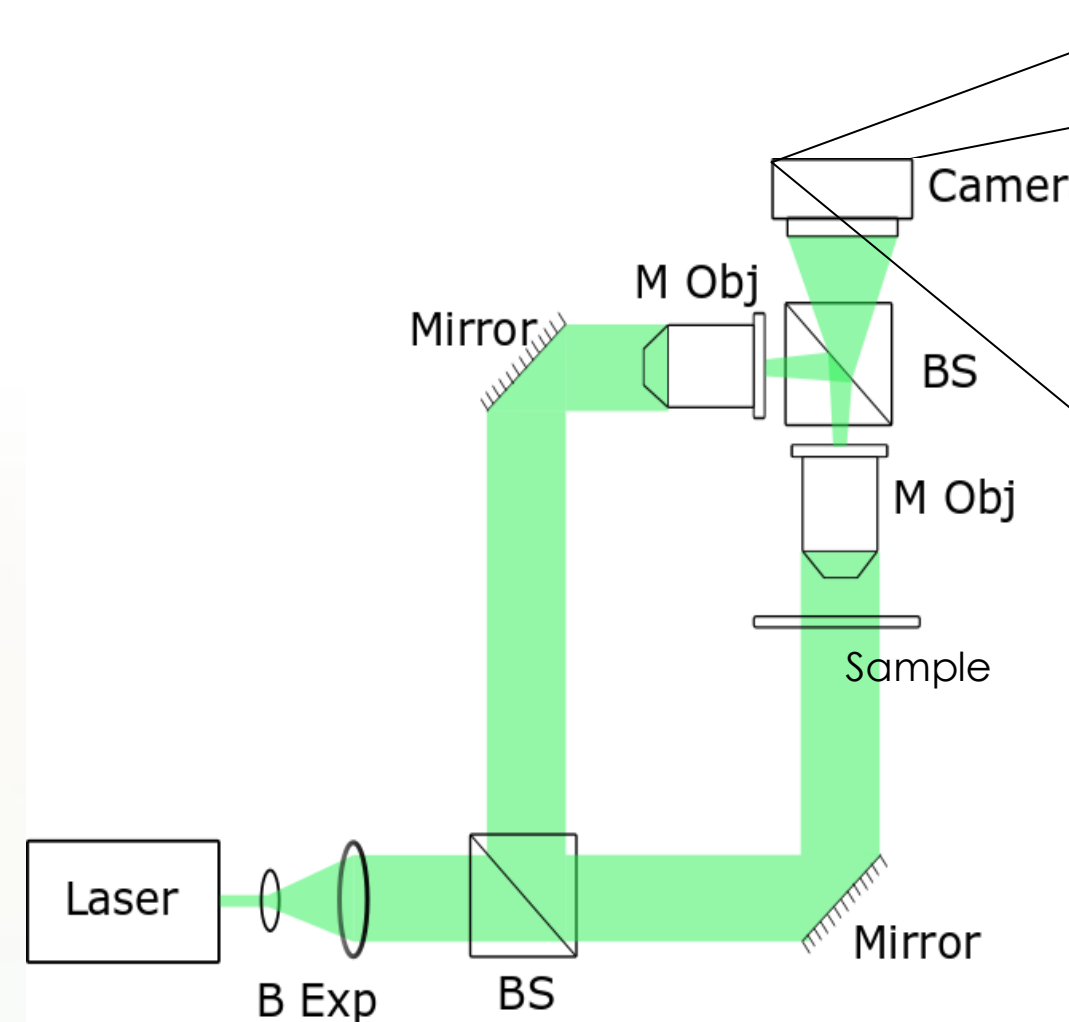
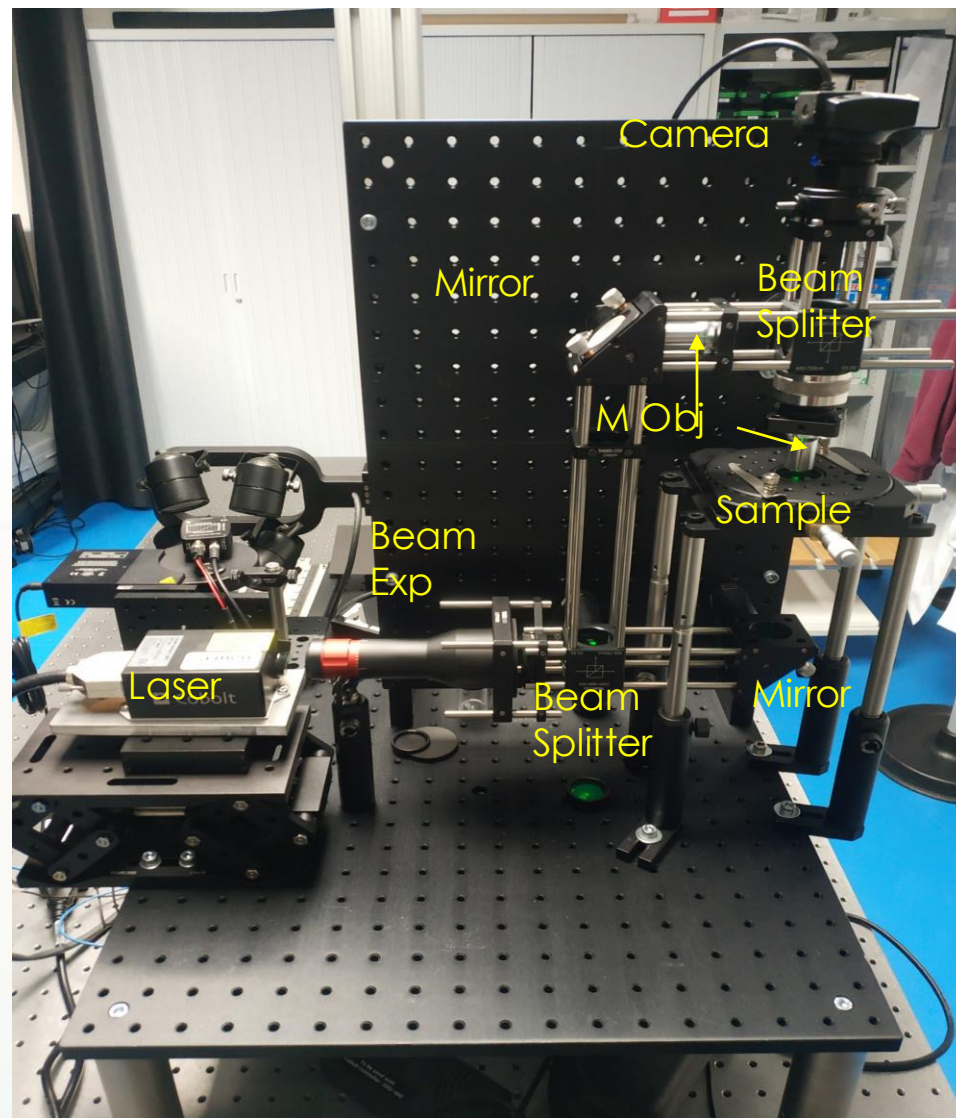


E.Coli biosensor

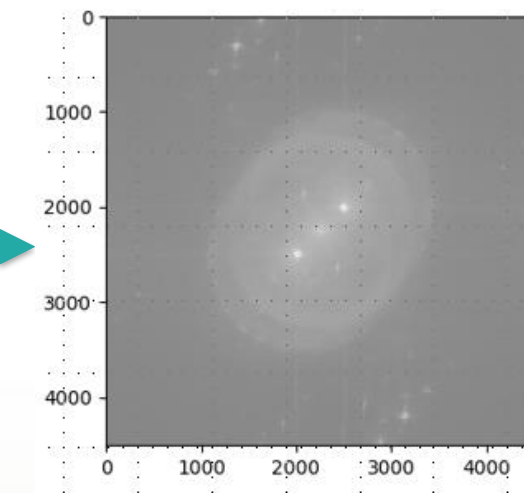


Sensor development and testing

Digital Holographic Microscopy (DHM)



FFT



Mask

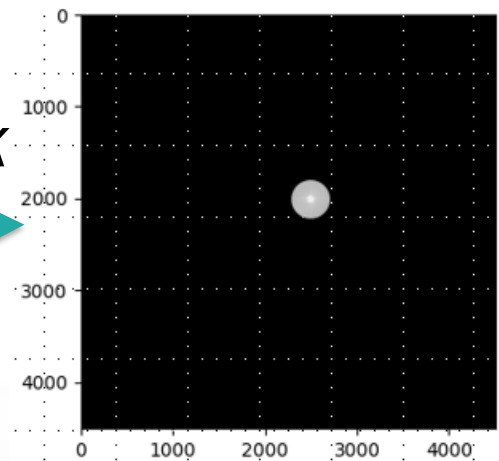
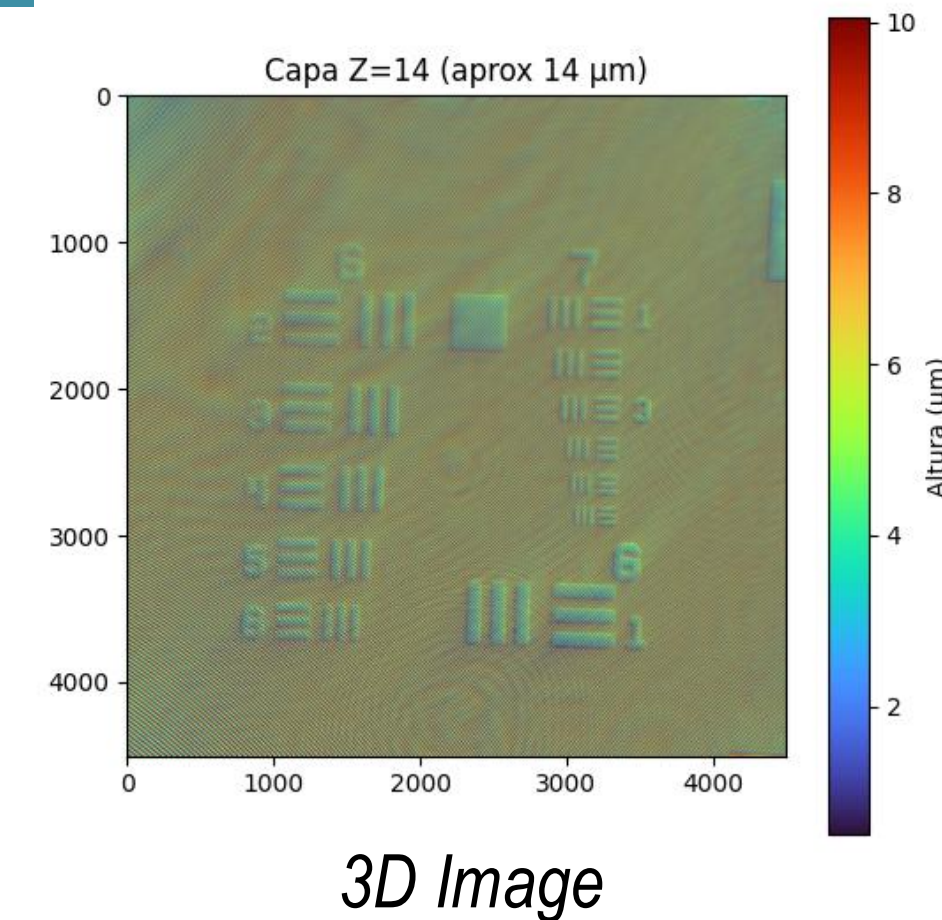
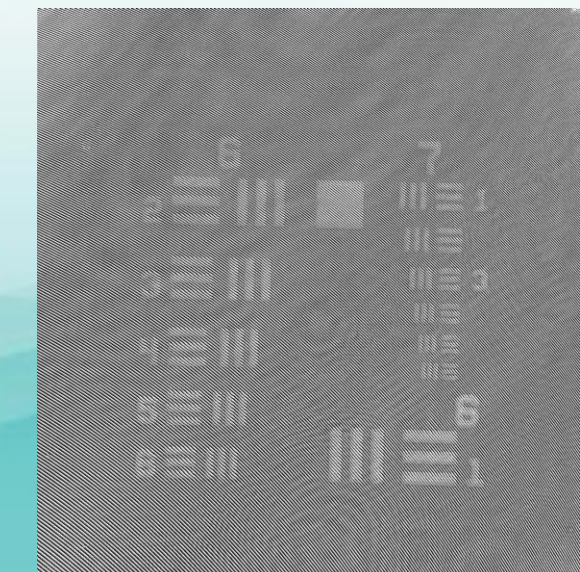


Image processing

$$H(f_x, f_y) = e^{ikz\sqrt{1-(\lambda f_x)^2-(\lambda f_y)^2}}$$

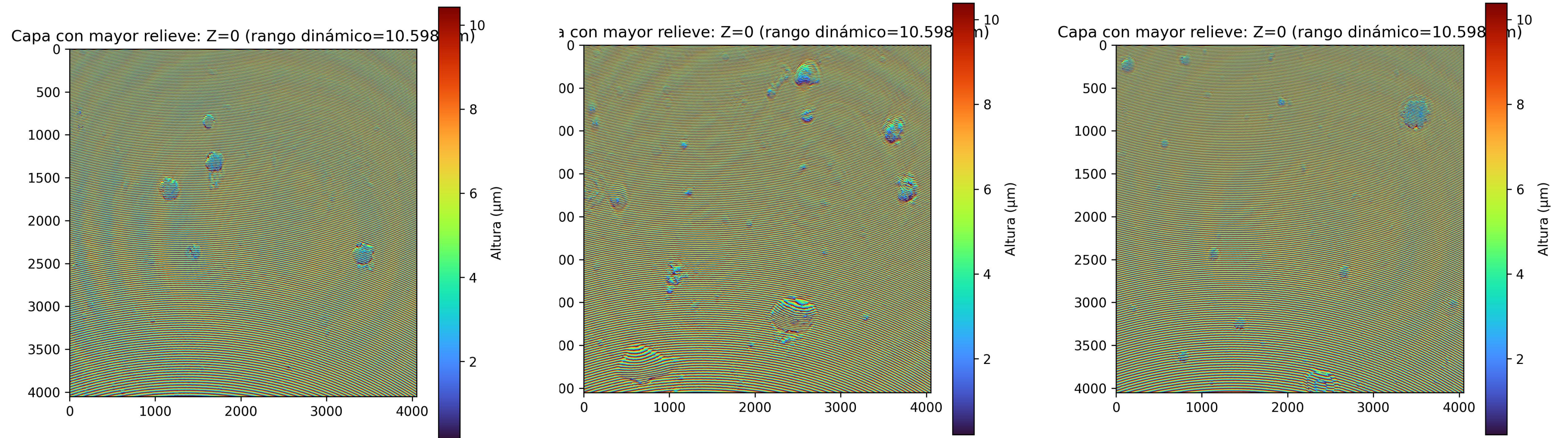
Phase image extracted



- DHM: coherent **imaging system**, convenient in **phase contrast** imaging for biological and biomedical samples..
- Instantaneous acquisition of **phase information** used to determine **3D characteristics of cells and tissues** with no pre-treatment or manipulation of the sample..
- It records an hologram containing 3D structures of an object without mechanical focus adjustment.

Sensor development and testing

Digital Holographic Microscopy (DHM)



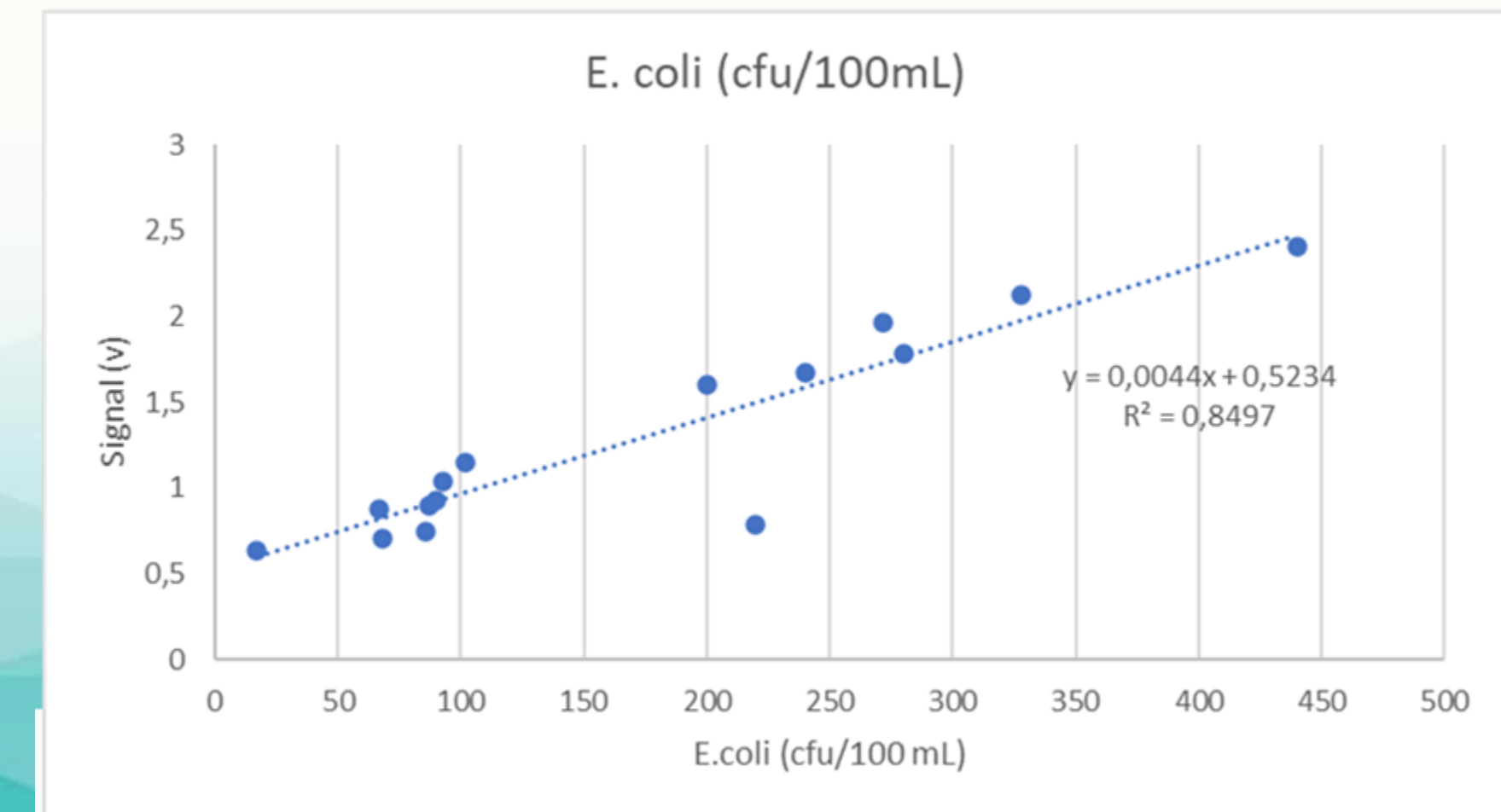
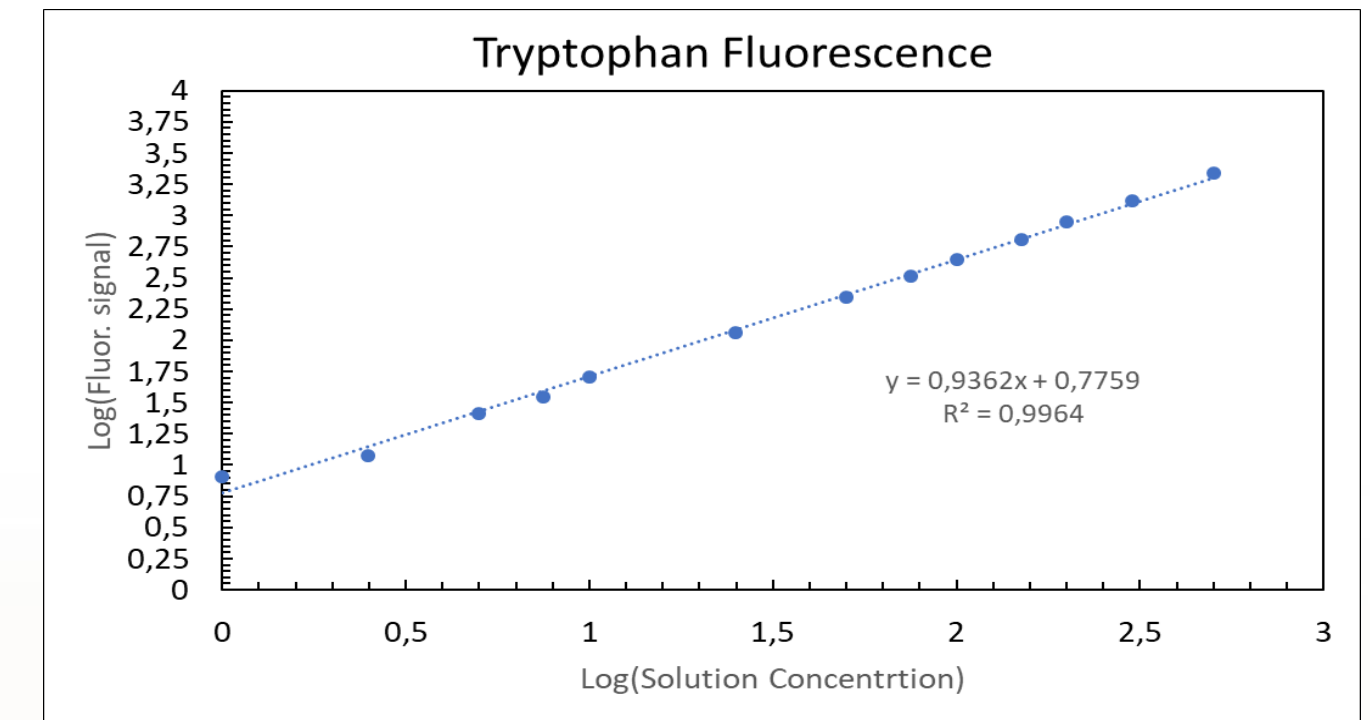
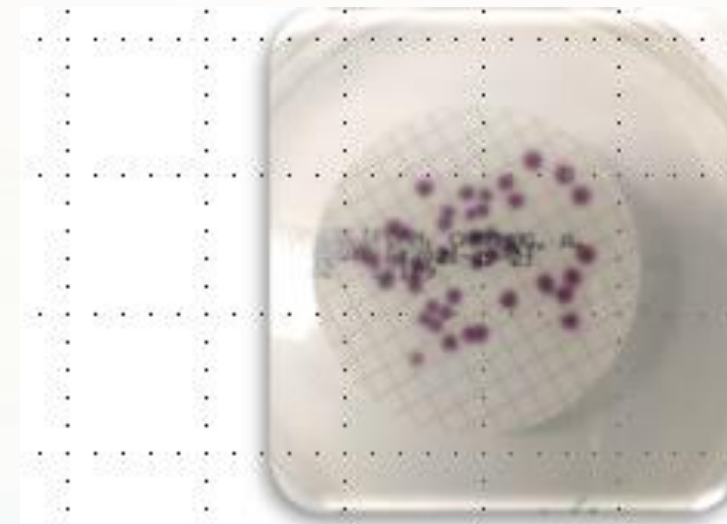
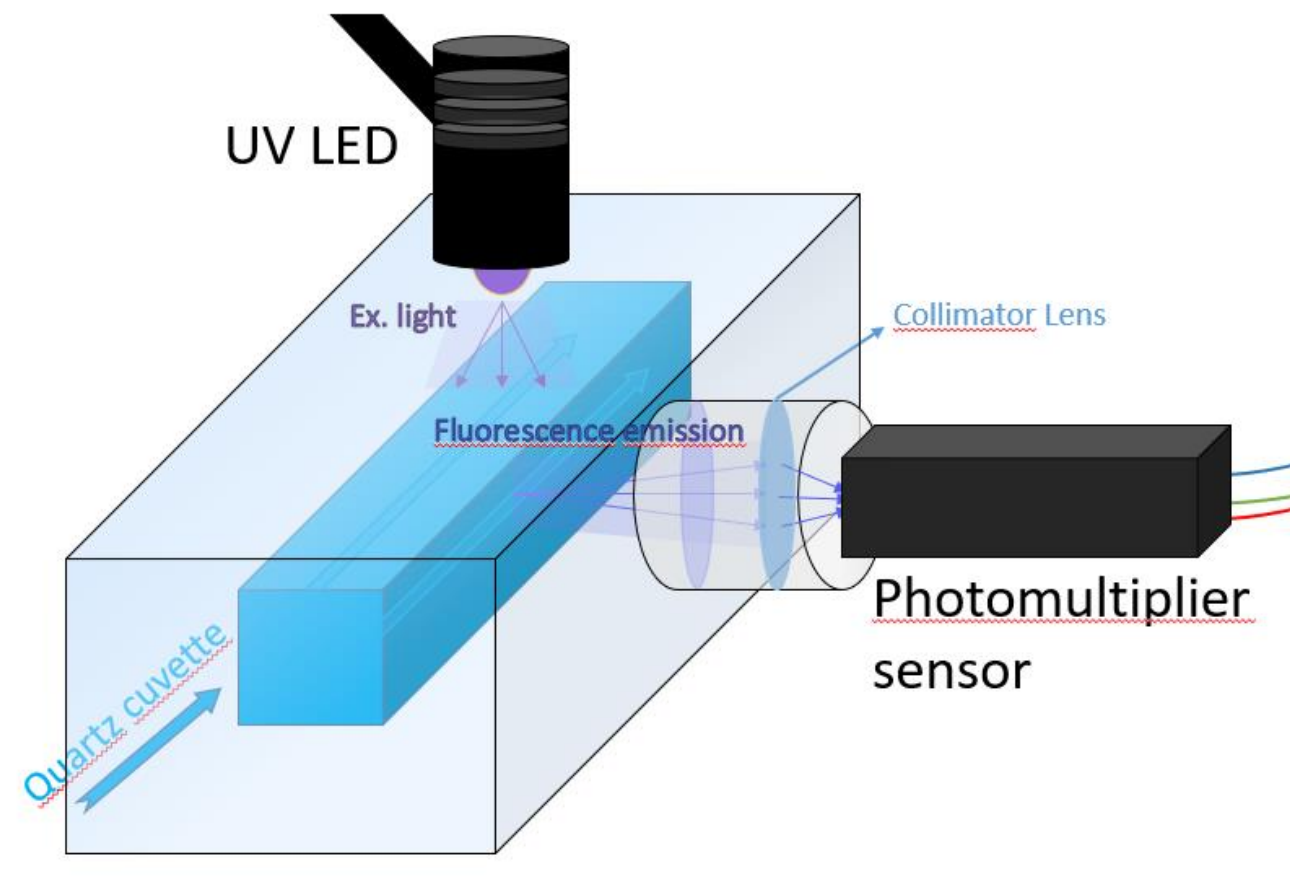
3D reconstruction microscopic green algae: resolves surface volume features $\sim 100 \text{ nm}$

Sensor development and testing

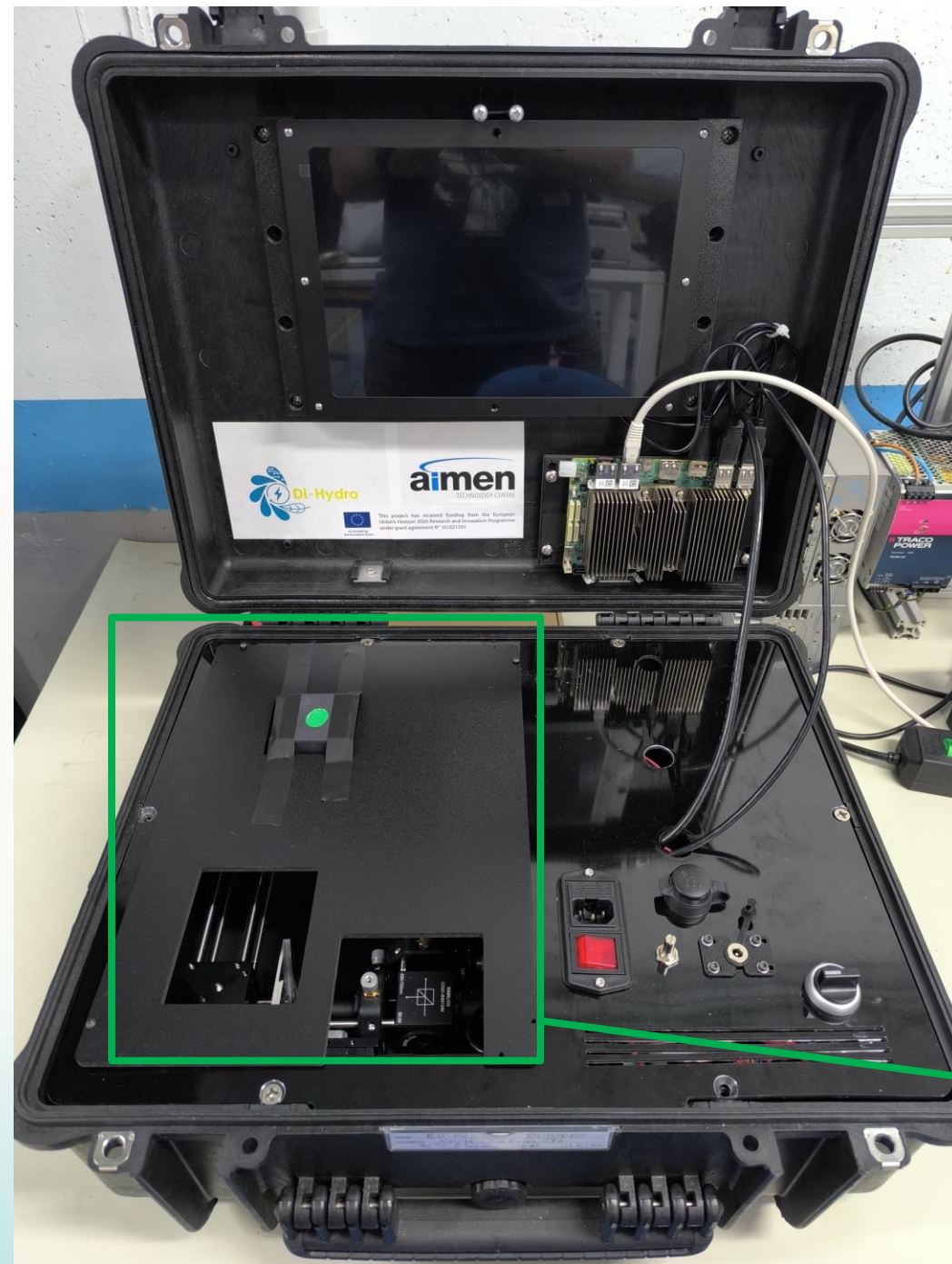
Tryptophan-like fluorescence (TLF) sensor

Fluorescence sensors for detecting Tryptophan-like emission peak (350 nm) indicators of **pathogenic concentration** (particularly associated with **E. coli and coliforms**).

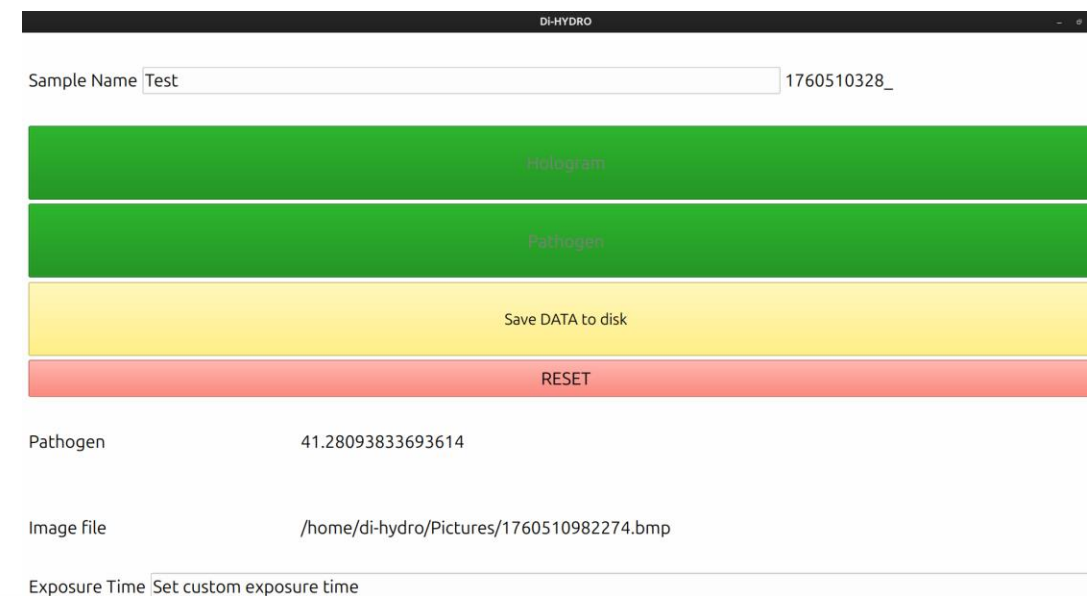
Measurements is almost instantaneous (compared to 24-hour laboratory incubation tests). No need for sample pre-treatment or any chemical reagents.



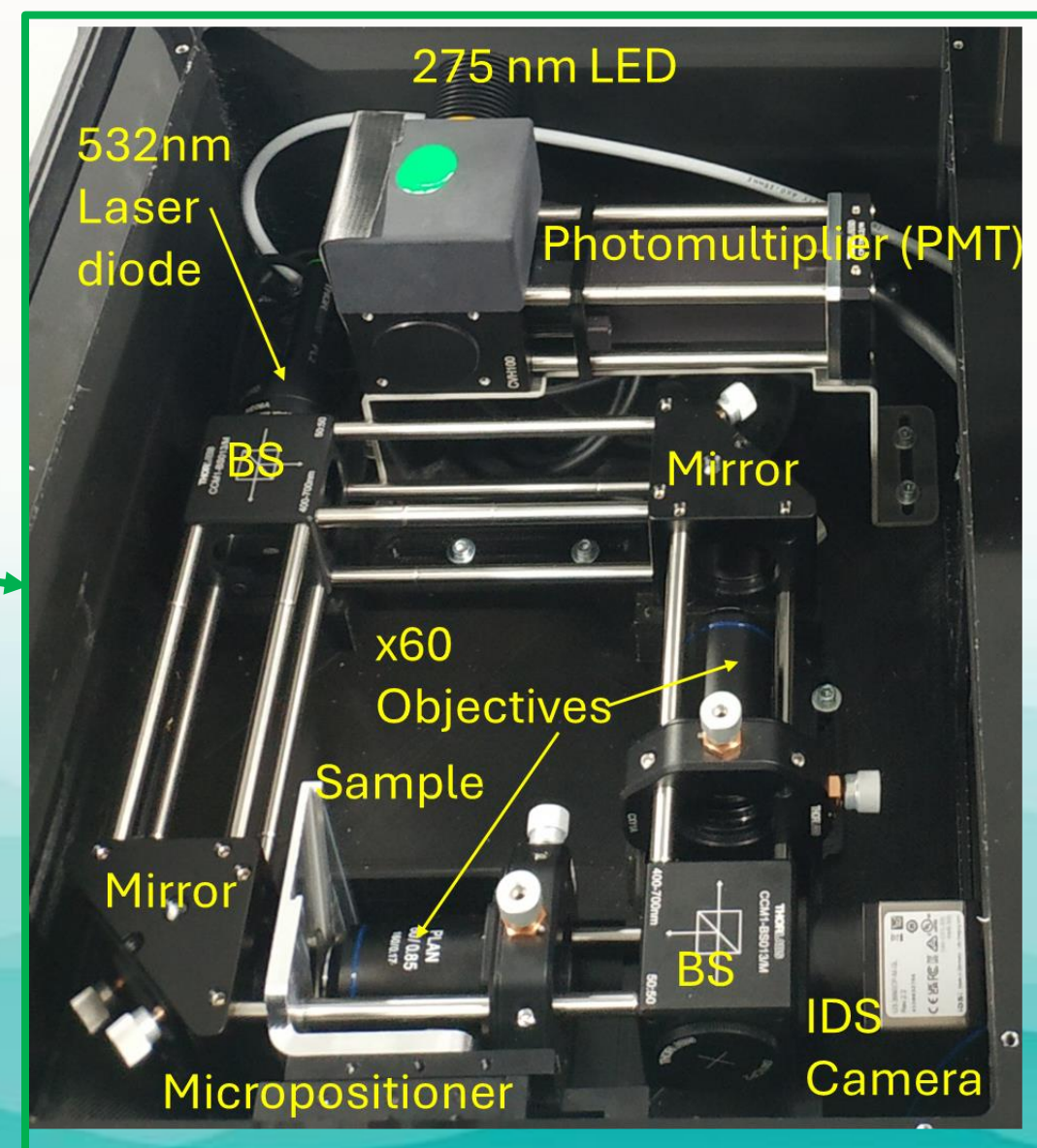
Installation and testing



DHM & TLF integrated sensors.



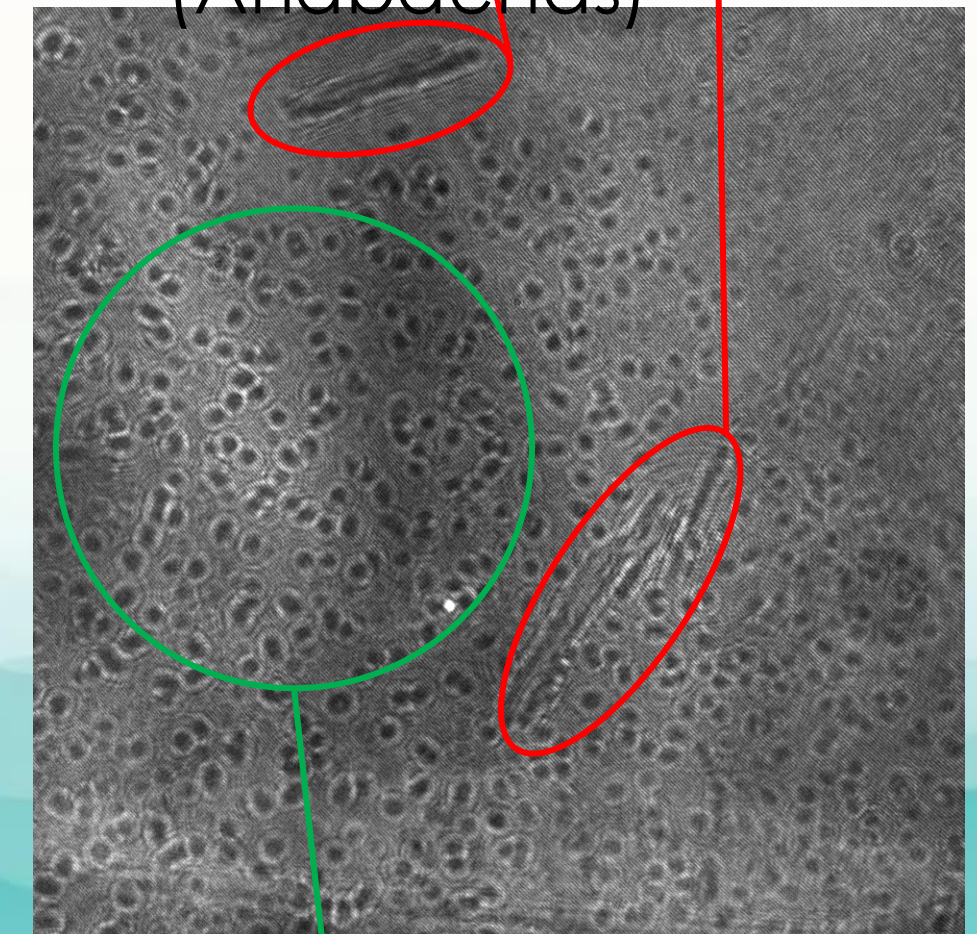
Control software



- **Portable suitcase** configuration with **DHM & TLF** sensors integrated (custom design of mechanics and electronics).
- Custom GUI displayed on **touchscreen** for **sensor control** and **data display**.
- Handled to EPS personnel (training included) to periodically perform measurements in their water reservoir.



Filamentous Blue-Green algae (Anabaenas)

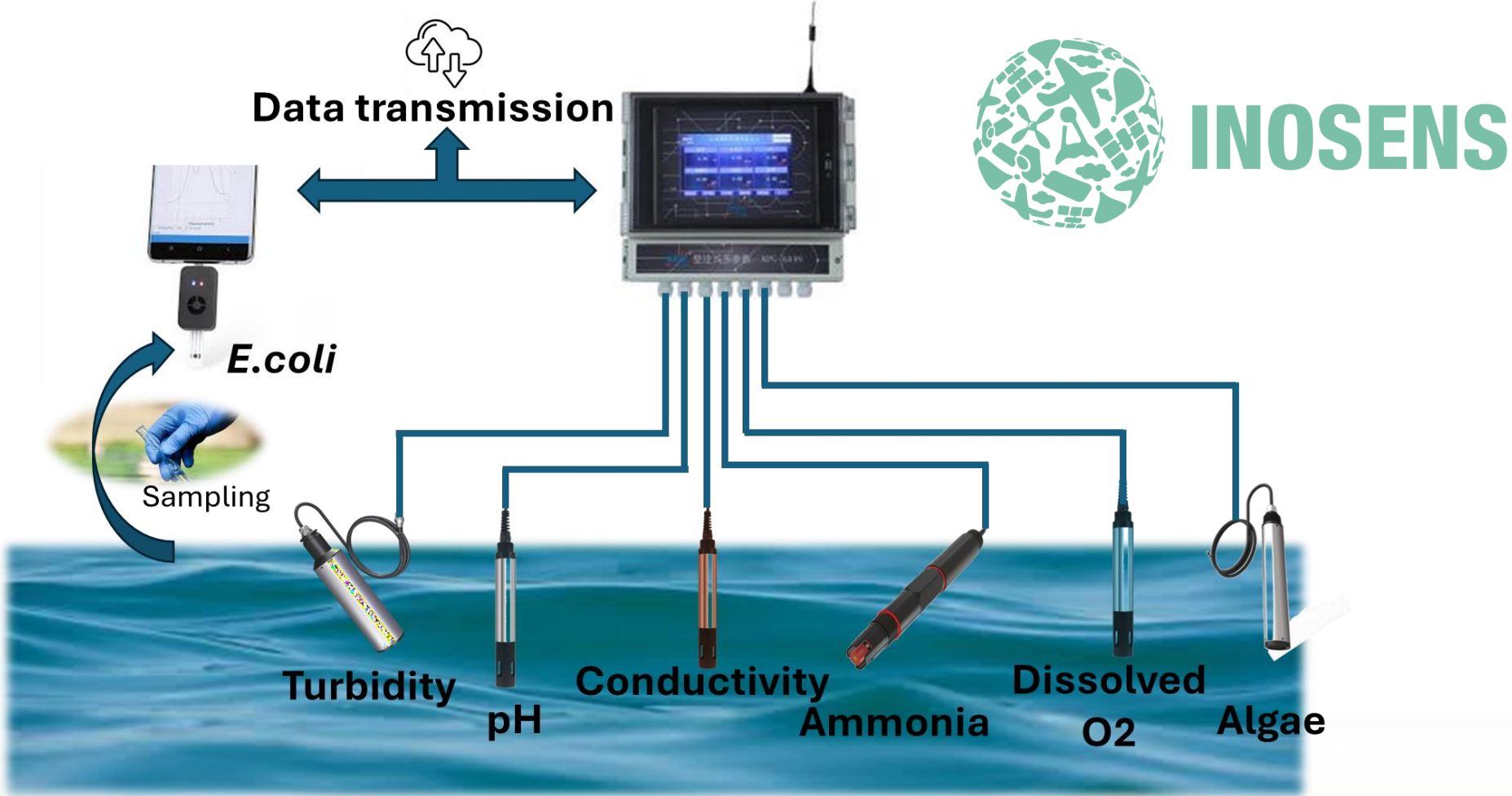


Unicellular Cyanobacteria

Installation and testing



MPG-6099 Multi-parameter analyser node

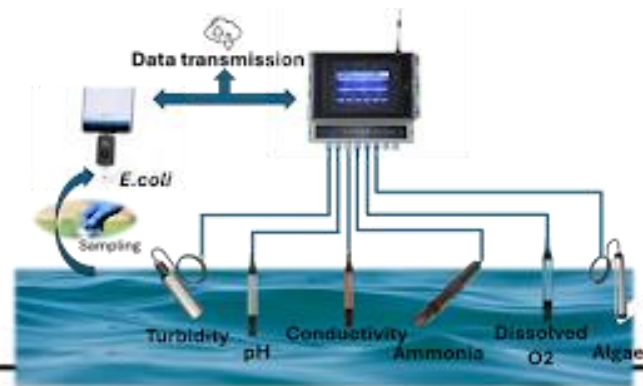


MCGS_TIME	MCGS_TIMEMS	Turbidity	叶绿素	DO	Cond	PH	Temp1	NH4
2025/08/01 0:01:55	35	3.919608	1.297296	8.71	441	7.59	24.3	0.05
2025/08/01 0:06:55	35	3.982404	1.314639	8.83	441	7.6	24.3	0.05
2025/08/01 0:11:55	35	4.207532	1.282877	8.72	441	7.6	24.3	0.05
2025/08/01 0:16:55	36	3.98345	1.290476	8.74	442	7.59	24.2	0.05
2025/08/01 0:21:55	35	3.90217	1.272162	8.73	441	7.59	24.3	0.05
2025/08/01 0:26:55	35	4.096453	1.242161	8.85	442	7.55	24.2	0.06
2025/08/01 0:31:55	35	3.934812	1.303922	8.75	438	7.58	24.2	0.05
2025/08/01 0:36:55	35	4.316707	1.255407	8.73	439	7.59	24.2	0.06
2025/08/01 0:41:55	35	4.246978	1.29184	8.87	438	7.58	24.2	0.06
2025/08/01 0:46:55	35	3.73769	1.319706	8.77	437	7.58	24.2	0.05
2025/08/01 0:51:55	35	3.698941	1.278786	8.74	438	7.58	24.2	0.06
2025/08/01 0:56:55	35	3.838009	1.31425	8.85	437	7.57	24.1	0.06
2025/08/01 1:01:55	35	3.797193	1.284047	8.74	438	7.59	24.2	0.06
2025/08/01 1:06:55	35	4.149489	1.239434	8.73	437	7.55	24	0.06
2025/08/01 1:11:55	35	4.520885	1.259304	8.72	437	7.55	24.1	0.06
2025/08/01 1:16:55	35	4.010615	1.275474	8.73	438	7.55	24.1	0.06
2025/08/01 1:21:55	35	3.954516	1.209634	8.74	442	7.53	24	0.06
2025/08/01 1:26:55	35	3.61657	1.262615	8.72	442	7.55	24.1	0.06
2025/08/01 1:31:55	35	3.698531	1.252096	8.74	442	7.55	24	0.06
2025/08/01 1:36:55	35	3.706272	1.219372	8.73	443	7.53	24	0.06
2025/08/01 1:41:55	35	4.100794	1.206712	8.72	446	7.51	23.9	0.06
2025/08/01 1:46:55	36	3.930887	1.183343	8.72	447	7.5	23.9	0.06
2025/08/01 1:51:55	35	4.065245	1.184122	8.73	443	7.47	23.8	0.06
2025/08/01 1:56:55	35	3.713174	1.18938	8.72	445	7.46	23.8	0.06
2025/08/01 2:01:55	35	4.155477	1.194638	8.71	449	7.45	23.8	0.06

Sensor emersed in water

Control unit





Real-time monitoring data from the novel sensing devices developed WP2

- water temperature, EC
- pH
- dissolved oxygen
- total coliforms
- turbidity
- concentrations of Cyanobacteria (blue-green algal), ammonia, and *Escherichia coli*



In-situ sampling data obtained through periodic studies of the environmental impact of HPP

- total coliforms
- heavy metals
- microelements
- biodiversity parameters,
- sediments, etc.



Remote sensing techniques

- water flow
- dam opening
- turbines operation time series
- impoundment and discharge



INOSSENS

aimen
CENTRO TECNOLÓGICO



Hydropower plant parameters

- water flow
- dam opening
- turbine operation time series
- impoundment and discharge



MODELS

- Impact of HPP on ecosystem
- Correlation between HPP operation and water quality change
- Predictive models (e.g., ML/AI)
- Evaluation of seasonal and spatiotemporal patterns

Visualization & reporting

Recommendation for maintenance and operation of HPP

Modeling

Contribution to predictive maintenance

Predictive Model Inputs

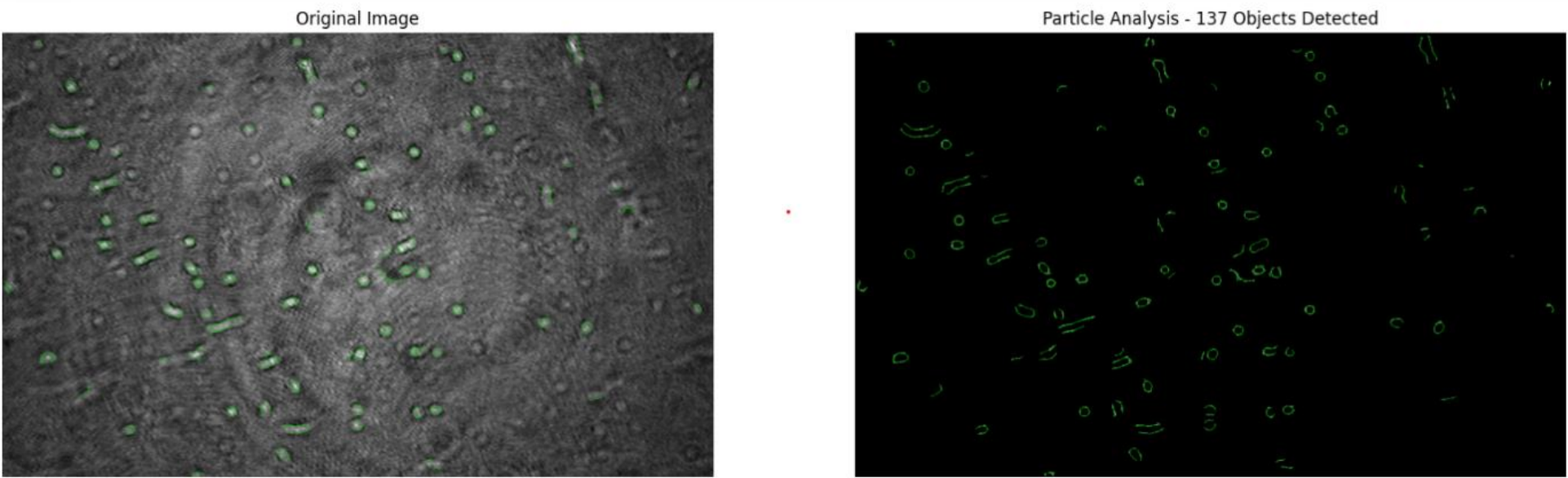
Historical data from water analysis

- Water temperature
- Parameters
- Total coliforms....

Whether condition

HPP operational data and Maintenance Logs:

- Automated counting from reconstructed DHM images using



pH	Suspended matter [mg/L]	Turbidity [NTU]	Electroconductivity [µs/cm]	Dissolved oxygen [mg/L]	Dry residue [mg/L]	Sediment matter after 10min. [mg/L]	HPK [mg/L]	BPK5 [mg/L]	Total N [mg/L]	Total P [mg/L]	Ammonia (as NH4-N) [mg/L]	Nitrate (as NO3-N) [mg/L]	Nitrite (as NO2-N) [mg/L]	Sulfate [mg/L]	Chloride [mg/L]	Fe [mg/L]	Mn [mg/L]	As [mg/L]	Ba [mg/L]	Zn [mg/L]	Cd [mg/L]	Co [mg/L]	Cr [mg/L]
8.03	8	5.7	375	8.3	184	<0.1	22.6	2	2.18	0.01	0.21	1.94	0.006	17.84	9.14	0.05	<0.01	<0.003	<0.1	0.013	<0.0001	<0.003	0.0009
8.02	10	8	352	8.35	185	<0.1	16.3	1.5	2.25	0.021	0.19	1.89	0.011	17.93	9.22	0.066	<0.01	<0.003	<0.1	<0.002	<0.0001	<0.003	0.0008
8.11	11	5.1	411	8.34	203	<0.1	14.7	1.7	3.46	0.017	0.27	2.66	0.013	22.38	8.69	0.032	<0.01	<0.003	<0.1	<0.002	<0.0001	<0.003	0.0007
8.06	9	5.9	413	8.4	213	<0.1	14.2	1.7	3.42	0.024	0.28	2.64	0.015	22.37	8.26	0.039	<0.01	<0.003	<0.1	<0.002	<0.0001	<0.003	0.0007
7.87	<1	6.3	343	7.66	263	<0.1	19.3	2.14	1.7	0.051	0.6	2.25	0.04	21.49	6.91	0.304	0.044	<0.003	<0.1	<0.004	<0.0001	<0.002	0.022
7.89	<1	10.9	353	7.86	266	<0.1	18.4	1.62	1.71	0.05	0.42	2.15	0.041	21.28	6.59	0.506	0.065	<0.003	<0.1	0.011	<0.0001	<0.002	0.0017
7.89	<1	4.5	451	8.33	265	<0.1	18.3	1.81	1.55	0.05	<0.03	1.39	0.023	16.31	6.97	0.25	0.066	<0.003	<0.1	0.015	<0.0001	<0.002	0.0012
7.64	<1	4	343	8.15	264	<0.1	16.1	1.99	1.65	0.05	0.2	1.4	0.014	19.36	7.36	0.108	0.043	<0.003	<0.1	0.014	<0.0001	<0.002	0.0022
7.98	6	3.9	397	9.44	201	<0.1	19.3	1.3	2.8	0.046	0.18	2.37	0.037	19.44	5.82	0.02	<0.01	<0.003	<0.1	0.042	<0.0001	<0.002	0.001
7.92	2.6	3.6	405	9.45	202	<0.1	19	1.9	2.75	0.047	0.19	2.38	0.033	19.92	5.95	0.016	<0.01	<0.003	<0.1	0.047	<0.0001	<0.002	0.002
7.91	1.6	4.8	386	9.43	193	<0.1	16.3	1.7	3.57	0.03	0.16	1.74	0.033	16.05	5.55	0.452	<0.01	<0.003	<0.1	0.042	<0.0001	<0.002	0.011
7.91	2	2.8	391	9.36	195	<0.1	20	1.3	2.27	0.035	0.14	1.76	0.025	16	5.6	0.404	<0.01	<0.003	<0.1	0.013	<0.0001	<0.002	0.003
7.95	<1	35	338	9.5	168	<0.1	17.6	2	1.93	0.042	0.17	1.51	0.011	14.26	6.77	0.372	<0.01	<0.003	<0.1	0.018	<0.0001	<0.002	0.003
7.91	<1	64	343	9.89	171	<0.1	18.3	2.44	18.4	0.045	0.16	1.55	<0.01	14.03	6.53	0.36	<0.01	<0.003	<0.1	0.016	<0.0001	<0.002	0.007
8.01	<1	23	336	9.59	168	<0.1	20.9	2.1	2.05	0.04	0.12	1.69	0.012	15.19	6.25	0.45	0.016	<0.003	<0.1	0.016	<0.0001	<0.002	0.002
7.94	<1	35	340	9.61	171	<0.01	17.8	2.5	2.01	0.043	0.12	1.65	0.01	15.45	6.21	0.734	0.021	<0.003	<0.1	0.021	<0.0001	<0.002	0.002
7.91	17.7	1.7	324	7.33	180	<0.1	7.8	2.8	1.75	0.05	<0.1	1.27	0.177	15.48	5.43	0.054	<0.05	<0.003	<0.1	<0.05	<0.0001	<0.002	0.0015

Contribution to predictive maintenance



Predictive Model Inputs

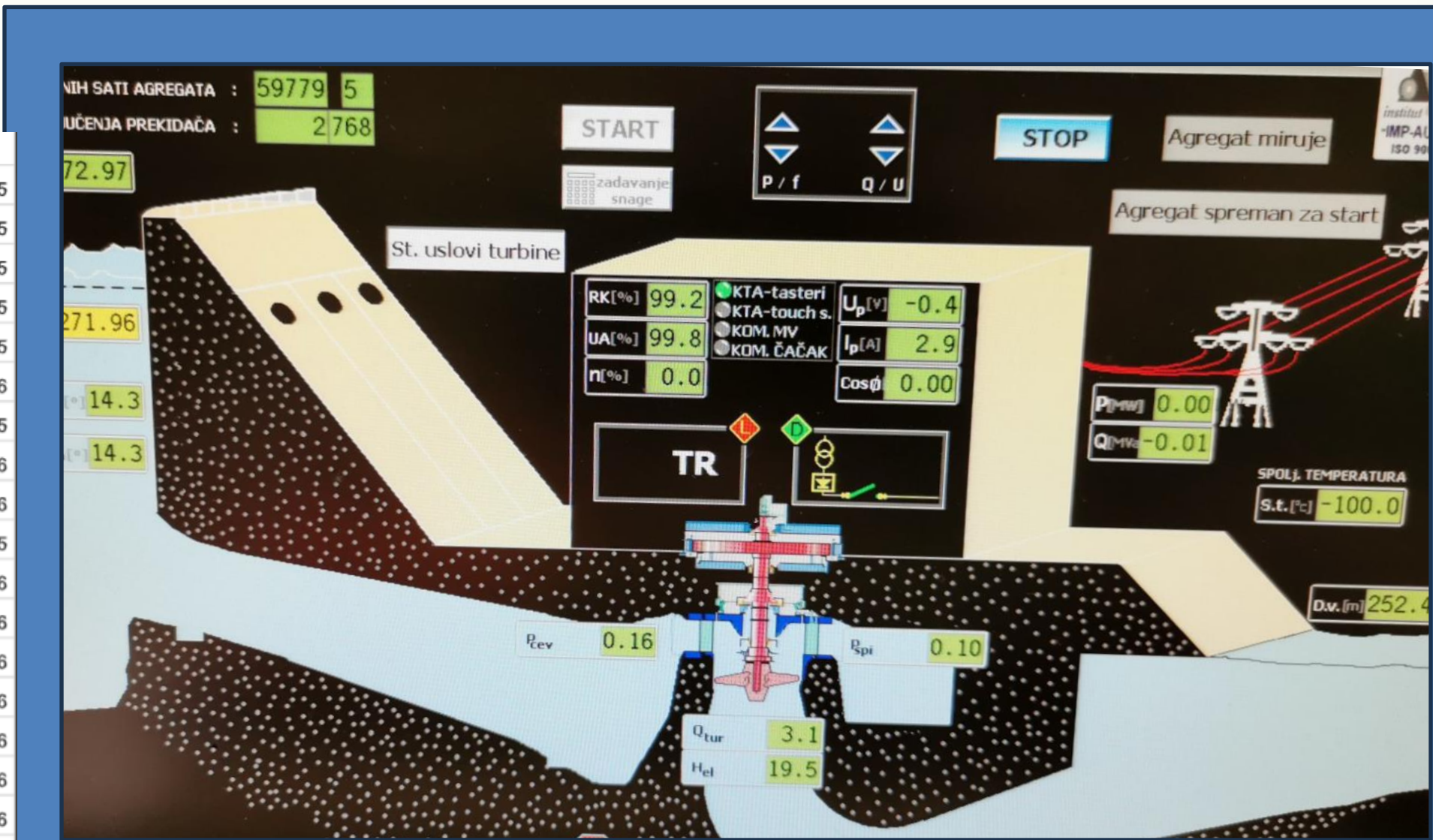
Sensor Data:

- Water temperature
- Total coliform concentrations
- Algae and E. coli levels
- Biodiversity sensors detecting species like SRB
- Turbidity measurements...

MCGS_TIME	MCGS_TIMEMS	Turbidity	叶绿素	DO	Cond	PH	Temp1	NH4
2025/08/01 0:01:55	35	3.919608	1.297296	8.71	441	7.59	24.3	0.05
2025/08/01 0:06:55	35	3.982404	1.314639	8.83	441	7.6	24.3	0.05
2025/08/01 0:11:55	35	4.207532	1.282877	8.72	441	7.6	24.3	0.05
2025/08/01 0:16:55	36	3.98345	1.290476	8.74	442	7.59	24.2	0.05
2025/08/01 0:21:55	35	3.90217	1.272162	8.73	441	7.59	24.3	0.05
2025/08/01 0:26:55	35	4.096453	1.242161	8.85	442	7.55	24.2	0.06
2025/08/01 0:31:55	35	3.934812	1.303922	8.75	438	7.58	24.2	0.05
2025/08/01 0:36:55	35	4.316707	1.255407	8.73	439	7.59	24.2	0.06
2025/08/01 0:41:55	35	4.246978	1.29184	8.87	438	7.58	24.2	0.06
2025/08/01 0:46:55	35	3.73769	1.319706	8.77	437	7.58	24.2	0.05
2025/08/01 0:51:55	35	3.698941	1.278786	8.74	438	7.58	24.2	0.06
2025/08/01 0:56:55	35	3.838009	1.31425	8.85	437	7.57	24.1	0.06
2025/08/01 1:01:55	35	3.797193	1.284047	8.74	438	7.59	24.2	0.06
2025/08/01 1:06:55	35	4.149489	1.239434	8.73	437	7.55	24	0.06
2025/08/01 1:11:55	35	4.520885	1.259304	8.72	437	7.55	24.1	0.06
2025/08/01 1:16:55	35	4.010615	1.275474	8.73	438	7.55	24.1	0.06
2025/08/01 1:21:55	35	3.954516	1.209634	8.74	442	7.53	24	0.06
2025/08/01 1:26:55	35	3.61657	1.262615	8.72	442	7.55	24.1	0.06

HPP operational data and Maintenance Logs:

- HPP operational data from Scada system
- Historical data on cleaning times and durations to help predict future maintenance requirements.



Model A

- Predicts the **vegetative activity** in water
- Biological activity by analyzing holographic **data acquired from a digital holographic microscope and sensors data**, using advanced computer vision methods based on machine learning to estimate the concentration of pathogenic species, cyanobacteria, and green algae populations.
- Used to develop and validate **predictive models of water quality**

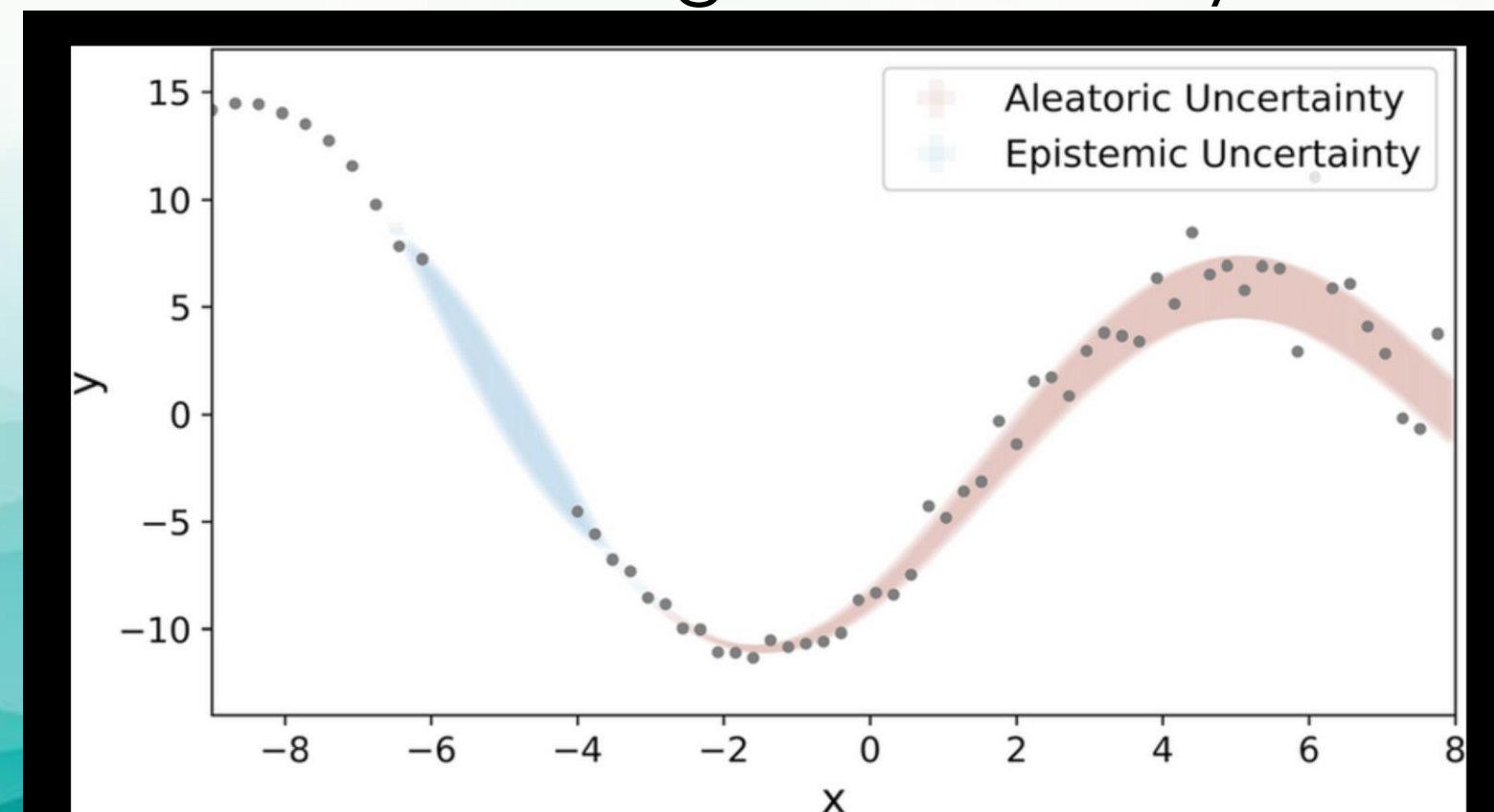
Model B

- Using **data from the SCADA** system for HPP operation across various parameters, together with the **assessment of biological activity** in water the operational state of the HP will be estimated.
- The resulting model will also provide an estimate of uncertainty associated with the predicted HP operational state, enhancing the reliability and interpretability of the system's outputs



INOSENS

aimen
CENTRO TECNOLÓGICO



Model B

- System functions will be **expert-informed model**
- We already know that bacterial/microbe growth occurs within minutes or hours under favorable conditions, or how long it takes for biofilm formation once the bacterial concentration exceeds a certain threshold, etc.
- Using data from the SCADA system for HPP operation across various parameters, together with the assessment of biological activity in water obtained from the model A developed the operational state of the HP will be estimated.
- For this purpose, a cascade machine learning (ML) model will be developed to recognize patterns of abnormal performance in HP components through fault detection, fault identification, and remaining useful lifetime (RUL) estimation.
- The categorized water quality levels will serve as an additional input to the model, alongside SCADA system measurements. The resulting model will also provide an estimate of uncertainty associated with the predicted HP operational state, enhancing the reliability and interpretability of the system's outputs

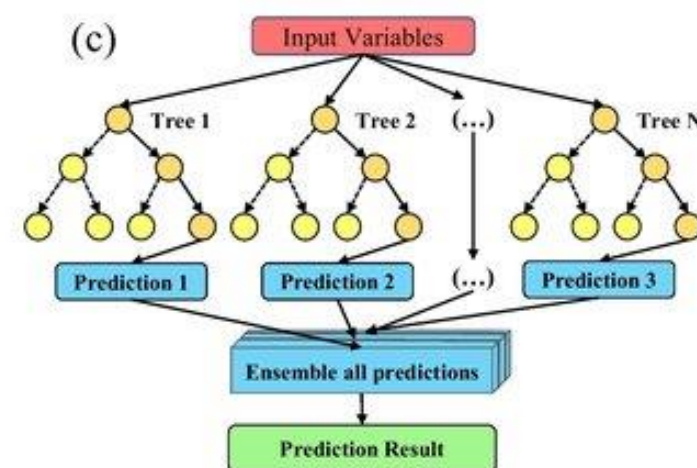
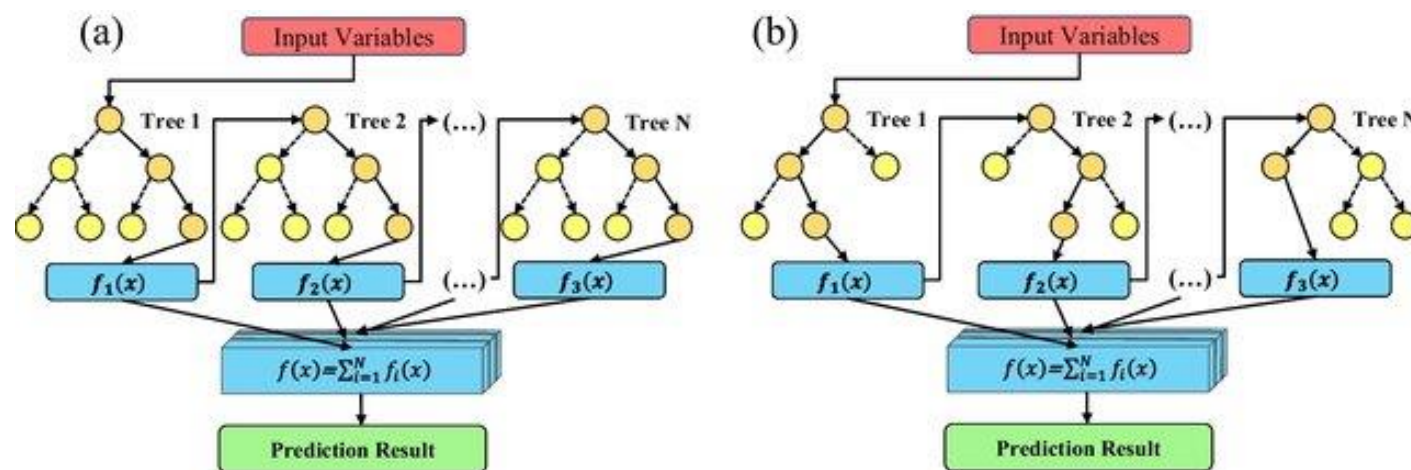
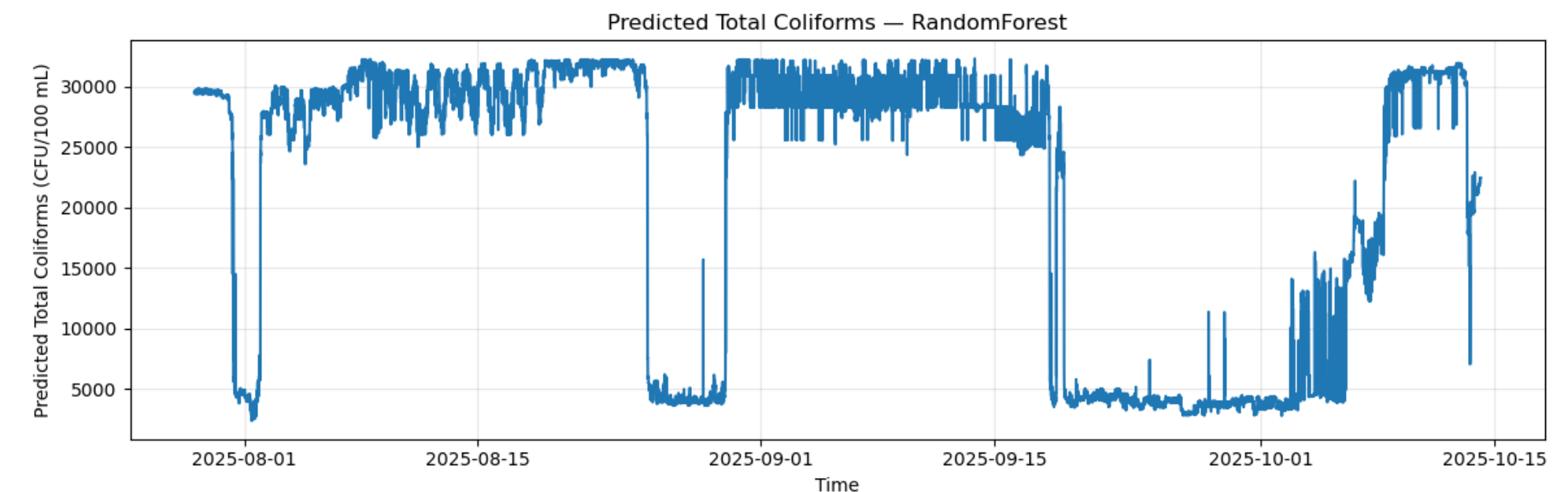
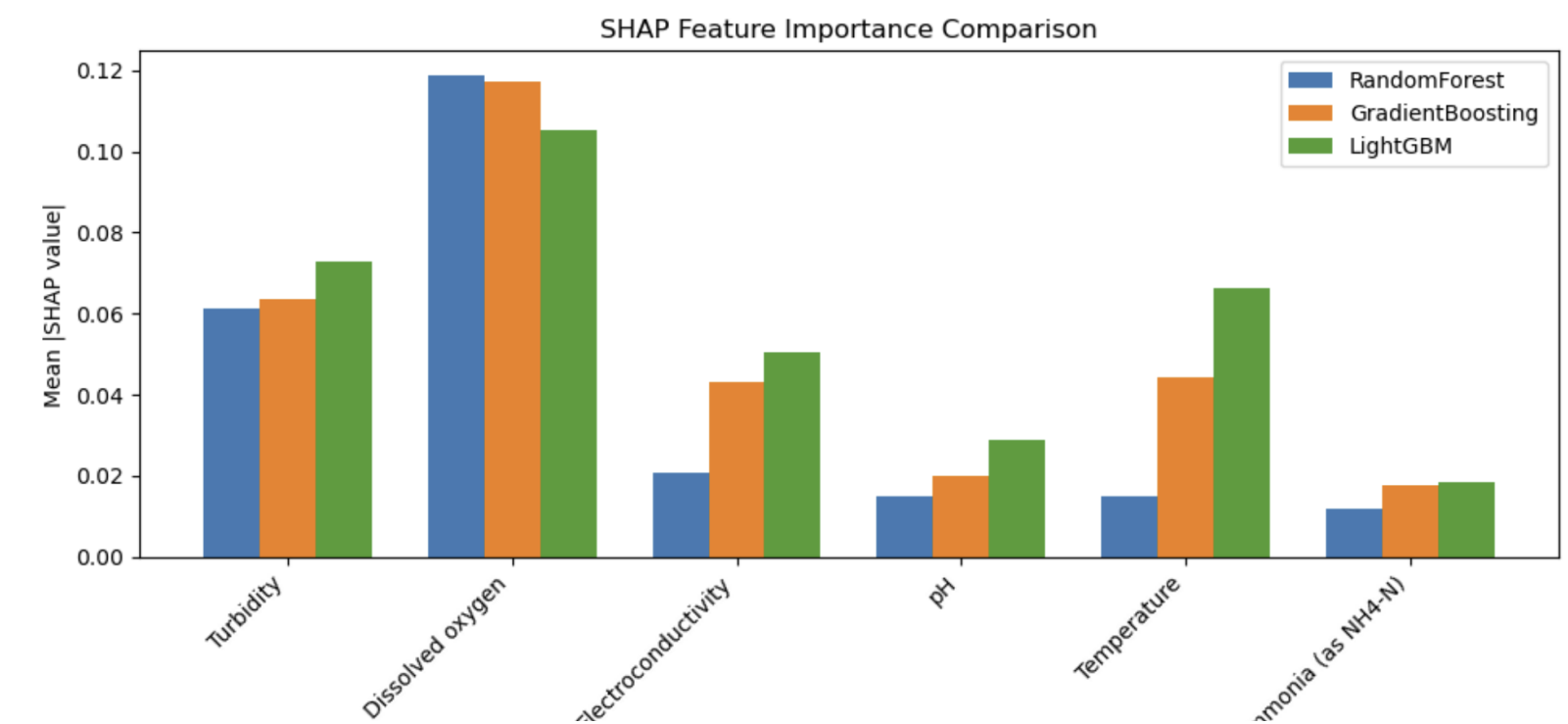
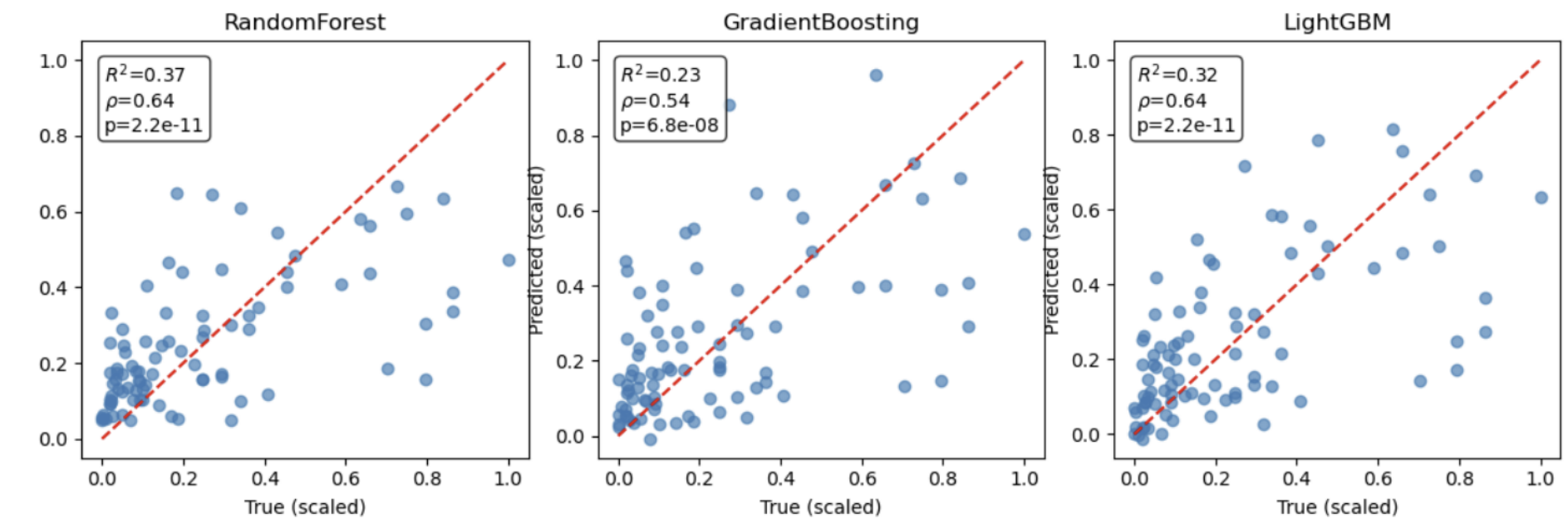
Prediction modelling:

Ensemble models (**Random Forest**, **Gradient Boosting** and **LightGBM Regressor**)

R² and **RMSE** metric for evaluation using **Leave-One-Out Cross-Validation (LOO-CV)**

SHAP library for feature importance

Best performing model on validation tested on sensor data



Models:

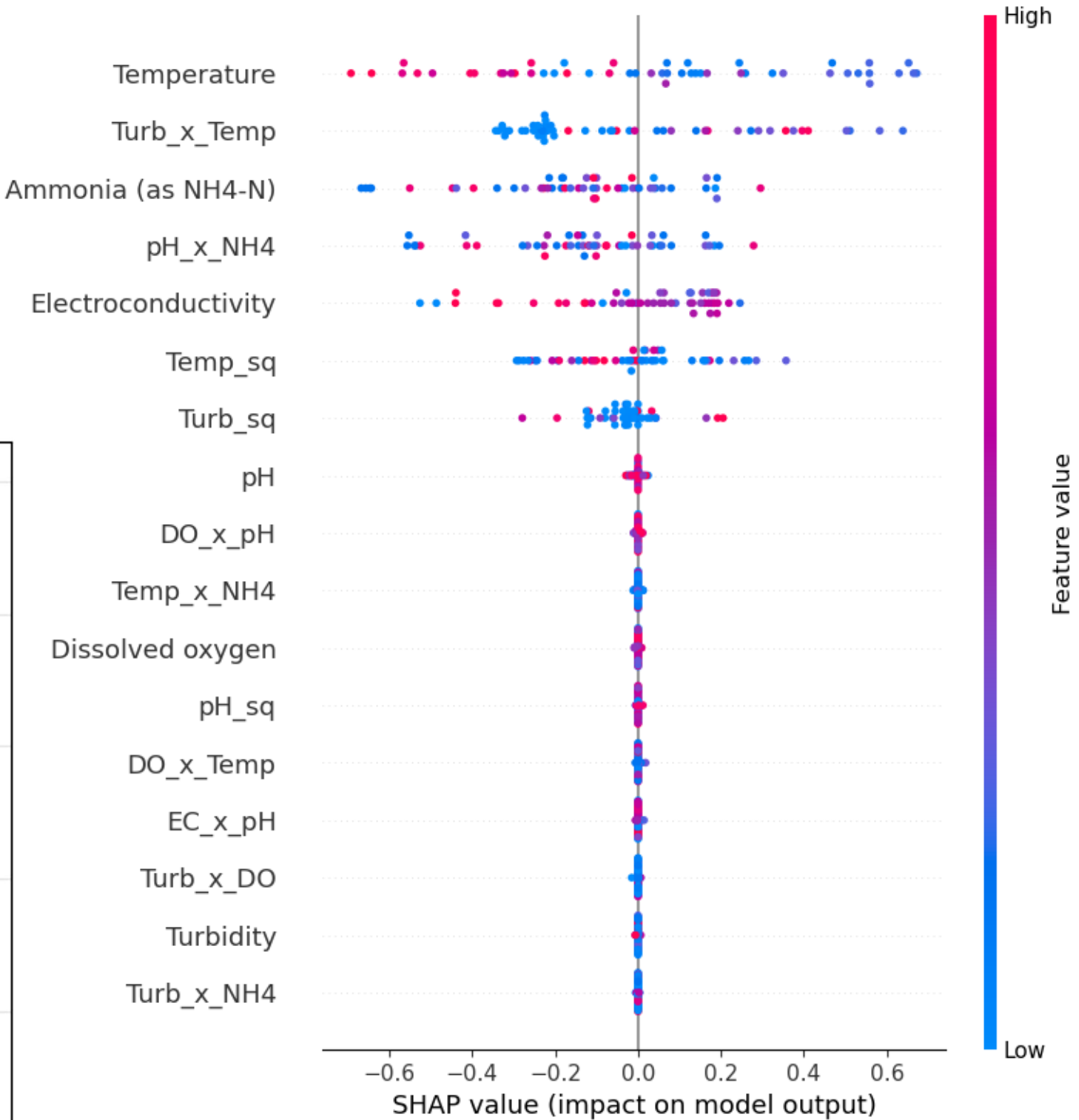
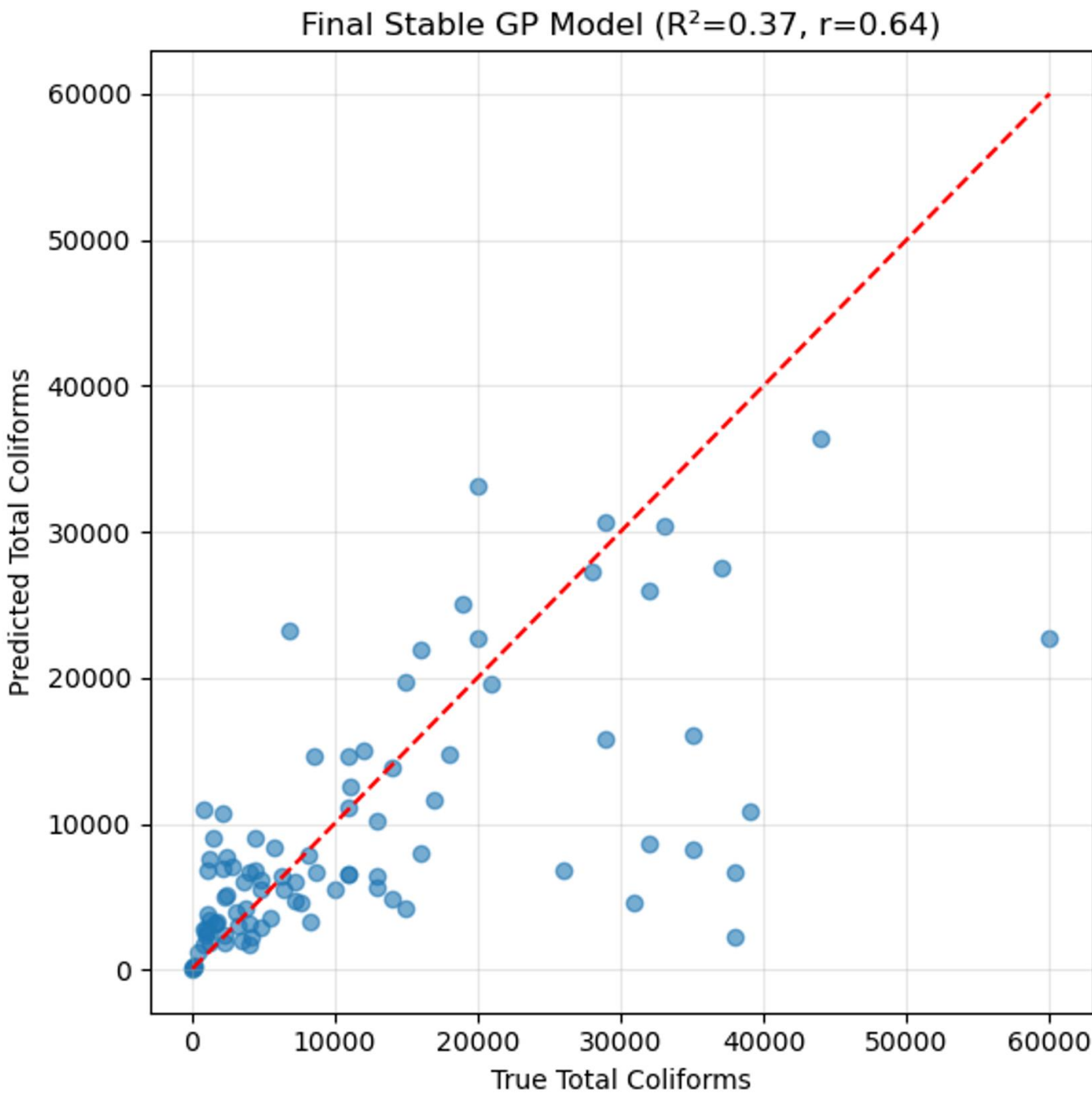
a) XGBoost

b) LightGBM

c) Random Forest

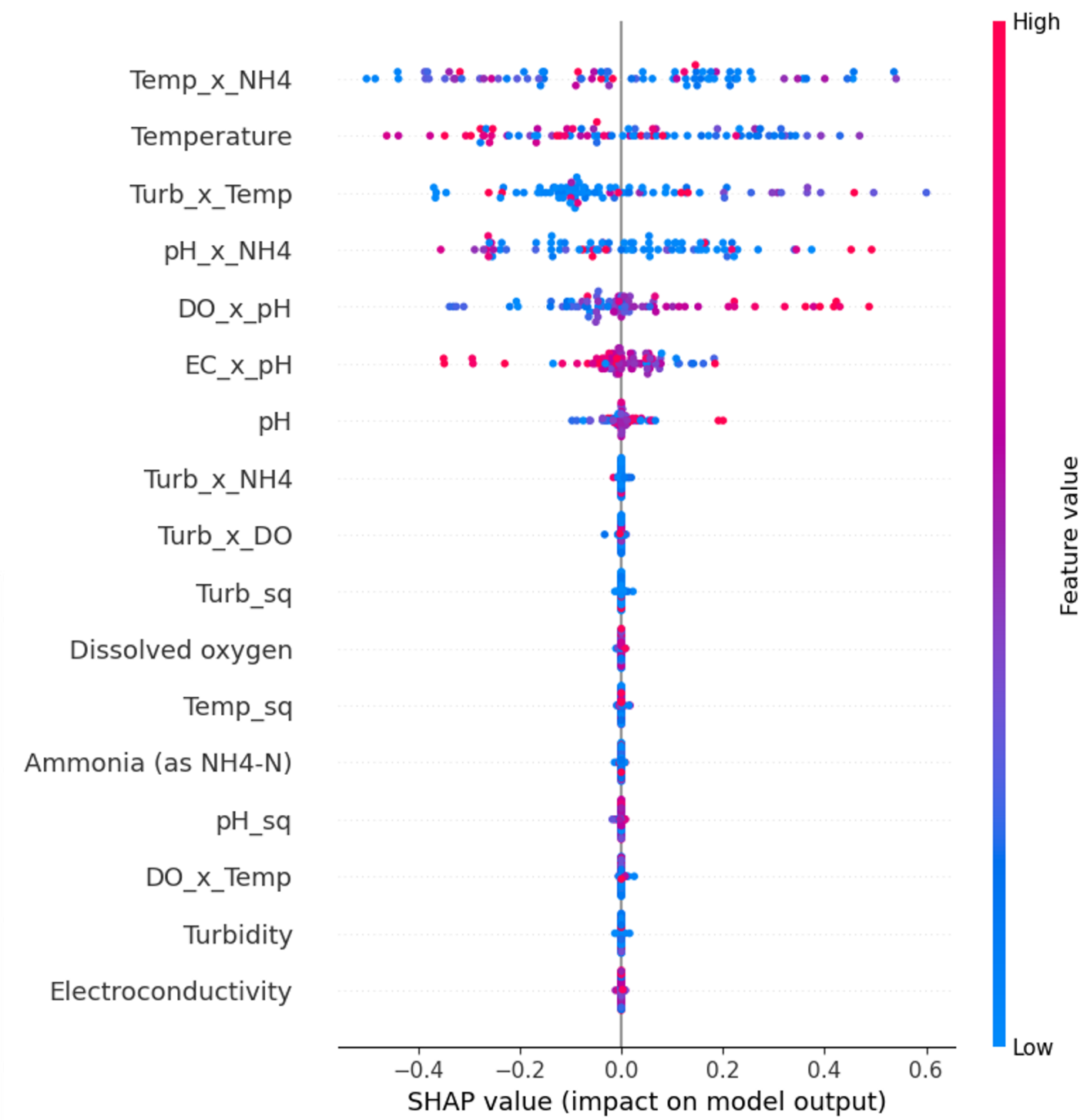
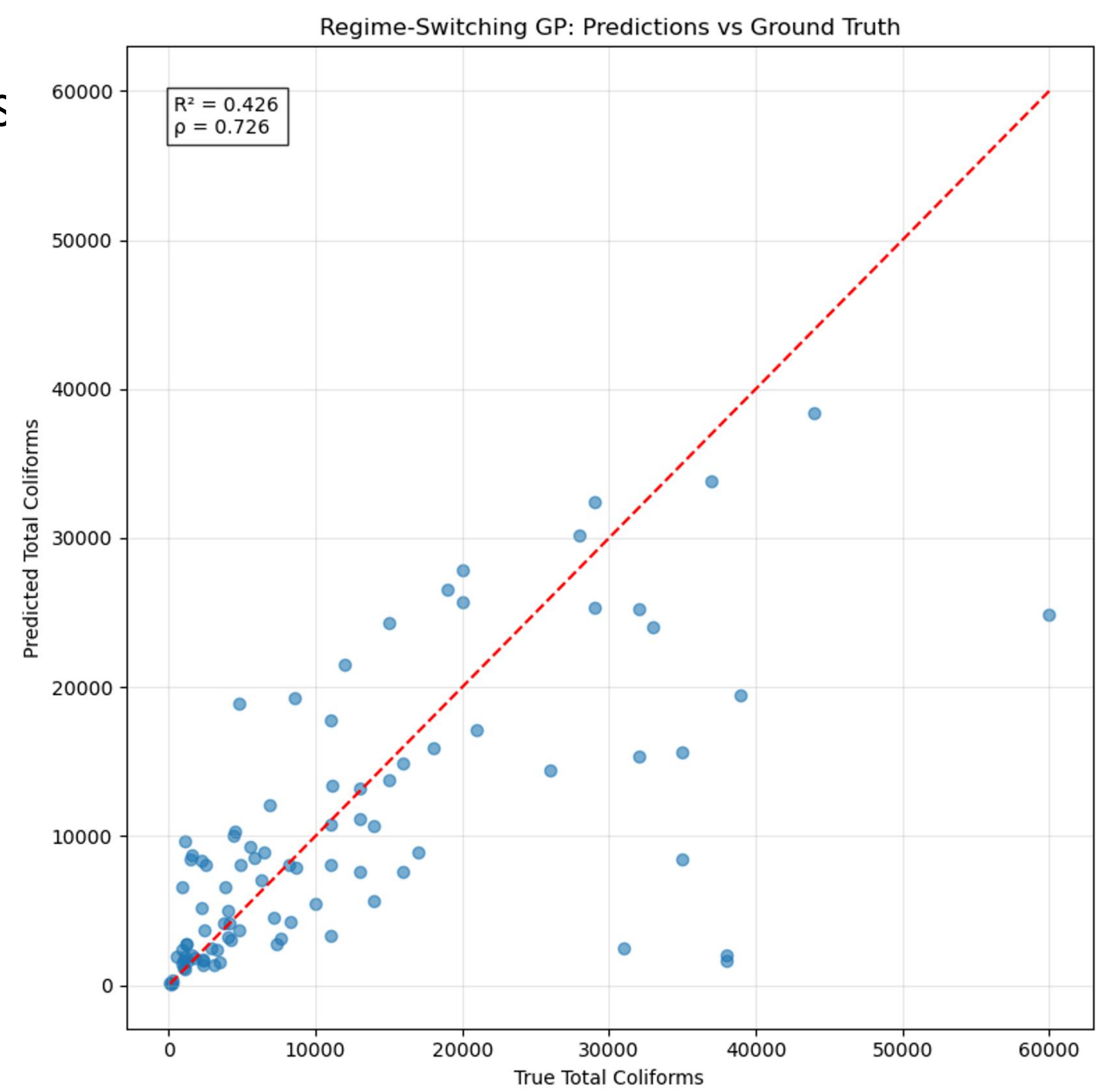
Gaussian Process Regression

Total coliforms values preprocessed
(Power transformation “yeo-johr”)
Physically meaningful
interaction terms
LOO crossvalidation
 $R^2 = 0.369$
(Determination coefficient)
 $\rho = 0.683$
(Spearman)
 $r = 0.638$
(Pearson)



Regime-switching Gaussian Process Regression

Total coliforms values preprocessed
(Power transformation “yeo-johns
Phisically meaningfull
interaction terms
Kmeans clustering for regime
LOO crossvalidation
 $R^2 = 0.426$
(Determination coefficient)
 $\rho = 0.726$
(Spearman)
 $r = 0.672$
(Pearson)



Follow Di-Hydro!

Visit the **Di-Hydro website**, where you'll find all the Di-Hydro Materials, such as flyers, reports, our newsletter issues, as well as what they say about Di-Hydro around!

Di-Hydro Website: <https://dihydro-project.eu/>

Follow us also on **LinkedIn**:

<https://www.linkedin.com/company/di-hydro-project/>

Check out the **Di-Hydro Podcast Series**:

https://youtube.com/playlist?list=PLna5U7-OPgOtFKTmZXYVby8mP_Daibnwh&si=5n1tL1Ikj0KBLZIZ

Subscribe to our LinkedIn Newsletter:

<https://www.linkedin.com/build-relation/newsletter-follow?entityUrn=7406647955916541952>



Check out the
Di-Hydro Innovation Handbook,
featuring the main results from
the project!



Digital maintenance for sustainable and flexible
operation of HYDROpower plant

Thank you.

Miguel Placer Lorenzo
AIMEN



Vasa Radonic
INOSSENS



This project has received funding by the European Union's Horizon Europe research and innovation programme under Grant Agreement N° 101122311