SNIFFDRONE

Drone-based Environmental Odour Monitoring

9th IWA ODOURS & VOC/AIR EMISSIONS CONFERENCE

INTRODUCTION

SNIFF DRONE

Project period

May 2019 – October 2020

Project Partners

IBEC | DAM Depuración de Aguas del Mediterráneo

ATTRACT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777222

INTRODUCTION

To provide spatially dense odour measurements and localize emission hotspots, in complex industrial environments with several emission foci

A custom e-nose for odour concentration measurements at WWTPs was designed, constructed and tested in pilot field campaigns

The prototype integrates the developed e-nose and a sample collection system into a drone

The prototype has been tested and calibrated in a real WWTP with satisfactory preliminary results for instantaneous odour mapping of the facilities

E-NOSE DESIGN AND CONSTRUCTION

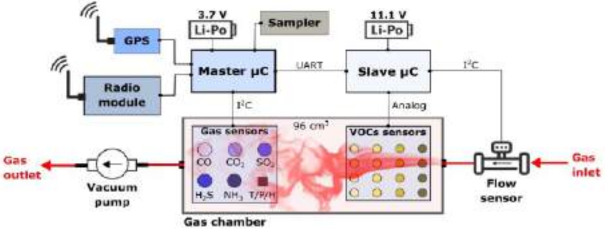
SNIFFDRONE custom made e-nose specifications

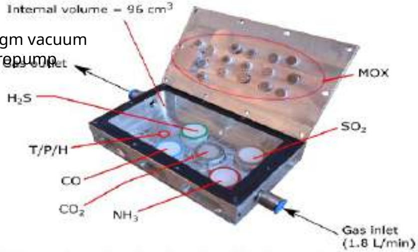
Specifications of electrochemical, NDIR and environmental sensors.

	Technology	Range	Accuracy	Response time (T_{90})
Temperature	Integrated	-40 to +85 ºC	± 1 ºC	< 2 s
Humidity	Integrated	0 to 100% RH	± 3% RH	< 2 s
Pressure	Integrated	30 to 110 kPa	± 0.1 kPa	< 2 s
Flow rate	Ultrasonic	-33 to +33 L/min	± 3% m.v.	< 1 s
CO_2	NDIR	0 to 5000 ppm	± 100 ppm	< 60 s
CO	Electrochemical	0 to 100 ppm	± 0.5 ppm	< 20 s
H_2S	Electrochemical	0 to 20 ppm	± 0.1 ppm	< 20 s
NH_3	Electrochemical	0 to 100 ppm	± 0.5 ppm	< 90 s
SO_2	Electrochemical	0 to 20 ppm	± 0.1 ppm	< 45 s

Parameter	Value
Gas sensors	4 x Electrochemical cells (EC) for NH_3, H_2S, SO_2, CO 1 x Nondispersive infrared (NDIR) for CO_2 16 x Metal oxide semiconductor (MOX)
Other sensors	Temperature, humidity, pressure, flow rate
Output signals	Raw data + calibrated output ($ou_E \cdot m^{-3}$)
Odour range	$50 - 10^5$ $ou_E \cdot m^{-3}$
Prediction accuracy[1]	50% - 200% of reference value
Sampling frequency	1 Hz (GPS disabled); 0.2 Hz (GPS enabled)
Flow rate	1.8 L/min
GPS accuracy	±3 m
Radio link	ZigBee 868 MHz (point-to-point)
Radio range	2 km
Power consumption	1 W
Main (external) battery	LiPo 3S 11.1V 5100 mAh
Internal battery	LiPo 2S 3.7V 500 mAh
Autonomy	5 h of continuous measurements
Dimensions	15 x 25 x 10 cm^3
Weight	1325 g (incl. battery)

E-NOSE DESIGN AND CONSTRUCTION





Diaphragm vacuum micropump

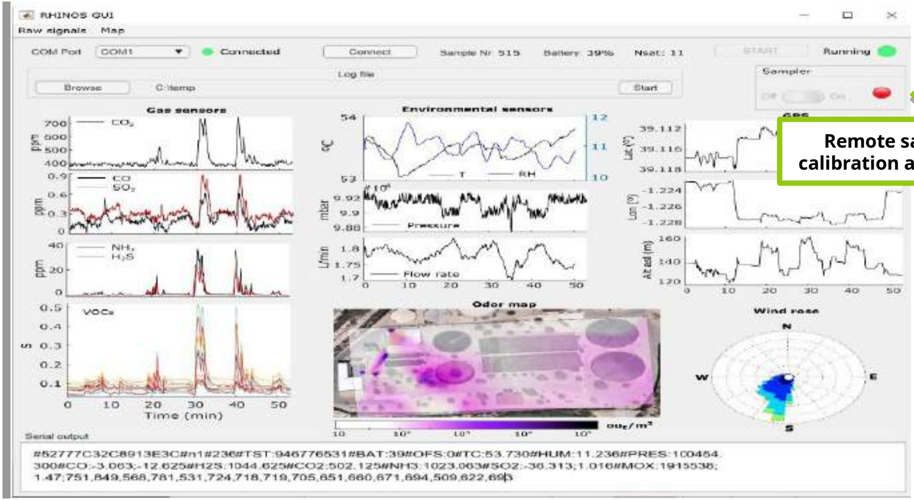
Less than 200 g sensing chamber

SNIFFDRONE custom made e-nose specifications

Detail of the 16 MOX sensors included

Sensor	Model	Target gases	Heater voltage
M1	TGS 2600	H_2, CO, Ethanol	1.6 V
M2	TGS 2600	H_2, CO, Ethanol	3.2 V
M3	TGS 2600	H_2, CO, Ethanol	4.0 V
M4	TGS 2600	H_2, CO, Ethanol	4.9 V
M5	TGS 2602	H_2S, NH_3, Toluene	1.6 V
M6	TGS 2602	H_2S, NH_3, Toluene	3.2 V
M7	TGS 2602	H_2S, NH_3, Toluene	4.0 V
M8	TGS 2602	H_2S, NH_3, Toluene	4.9 V
M9	TGS 2611	CH_4, Hydrocarbons	1.6 V
M10	TGS 2611	CH_4, Hydrocarbons	3.2 V
M11	TGS 2611	CH_4, Hydrocarbons	4.0 V
M12	TGS 2611	CH_4, Hydrocarbons	4.9 V
M13	TGS 2620	Alcohols, ketones	1.6 V
M14	TGS 2620	Alcohols, ketones	3.2 V
M15	TGS 2620	Alcohols, ketones	4.0 V
M16	TGS 2620	Alcohols, ketones	4.9 V

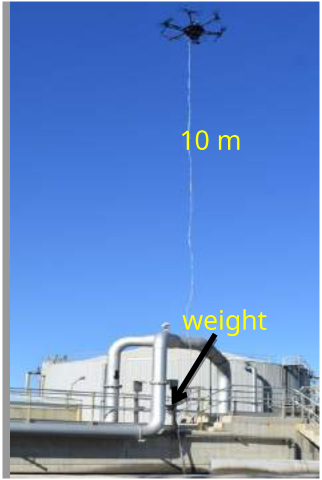
GRAPHICAL USER INTERFACE



Remote sampler for calibration and validation

DRONE COUPLING

Integration in a DJI Matrice 600 drone



TEST SITE AND SAMPLING

Date	Sources						
	BLK	MHL	PRE	BIO	SET	SLT	CHI
28/01/20	2	1	0	1	1	1	0
25/06/20	2	0	3	3	3	0	3
15/07/20	2	0	3	3	3	0	3
TOTAL	6	1	6	7	7	1	6

Sampling campaigns for enose calibration and validation in Molina del Segura WWTP, Murcia (Spain)

Olfasense sampler mounted in the drone + pararlel field **e-nose measurements**

E-NOSE CALIBRATION

Olfatometric Analysis of samples according **EN13725:2003**

Dilution of remaining samples to 1/10; 1/100 and 1/1000

Measurement of original samples and the diluted ones **with the e-nose** in duplicate

Calibration model construction

Set of bags used for calibration.

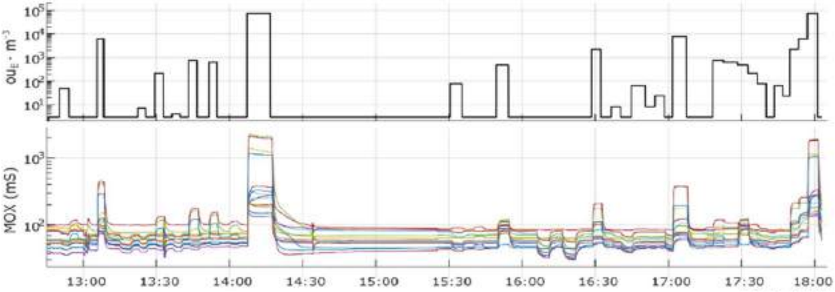
Bag ID	Date	Source	Distance	Odour concentration ($ou_E \cdot m^{-3}$)			
				Original	1/10	1/100	1/1000
1-1	28/01/20	Bioreactor	0.5m	76,111	7,611	761	76
1-2	28/01/20	Sludge thickener	0.5m	6,222	622	62	6
1-3	28/01/20	Settler	0.5m	2,165	216	21	2
1-4	28/01/20	Influent manhole	0.5m	477	47	4.7	0.47
2-1	25/06/20	Settler	0.5m	9,742	974	97	-
2-2	25/06/20	Settler	2m	3,069	-	-	-
2-3	25/06/20	Settler	5m	304	-	-	-
2-4	25/06/20	Bioreactor	0.5m	96,653	9,665	966	-
2-5	25/06/20	Bioreactor	2m	[illegible]	289	-	-
2-6	25/06/20	Bioreactor	5m	483	-	-	-
2-7	25/06/20	Pretreat	0.5m	3,444	344	-	-
2-8	25/06/20	Pretreat	2m	323	-	-	-
2-9	25/06/20	Pretreat	5m	256	-	-	-
2-10	25/06/20	Chimney	0.5m	91,952	9,195	919	91
2-11	25/06/20	Chimney	2m	3,649	365	-	-
2-12	25/06/20	Chimney	5m	40	-	-	-
3-1	15/07/20	Settler	0.5m	609	61	-	-
3-2	15/07/20	Settler	2m	76	-	-	-
3-3	15/07/20	Settler	5m	91*	-	-	-
3-4	15/07/20	Bioreactor	0.5m	1,722	172	-	-
3-5	15/07/20	Bioreactor	2m	72*	-	-	-
3-6	15/07/20	Bioreactor	5m	912	-	-	-
3-7	15/07/20	Chimney	0.5m	1,290	-	-	-
3-8	15/07/20	Chimney	2m	32,254	3,225	322	-
3-9	15/07/20	Chimney	5m	3,069†	-	-	-
3-10	15/07/20	Pretreat	0.5m	362	-	-	-
3-11	15/07/20	Pretreat	2m	2,048	205	-	-
3-12	15/07/20	Pretreat	5m	1,085	108	-	-

E-NOSE CALIBRATION

Calibration Model: **Partial Least Squares regression**

Two campaigns for model construction and third for model validation

The performance of the models during optimization was evaluated through the Root Mean Squared Error in cross-validation



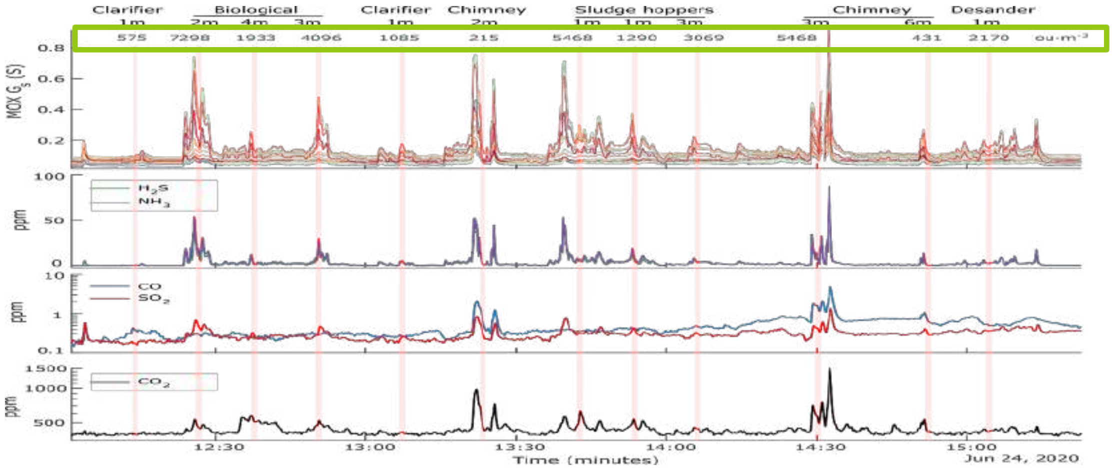
Example of MOX sensors signals during 1st campaign calibration session
(laboratory conditions, real WWTP samples)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

A detailed description and discussion of the models used can be found at:

Burgués, J.; Esclapez, M.D; Doñate, S.; Marco. S. RHINOS: A lightweight portable electronic nose for real-time odour quantification in wastewater treatment plants, iSCIENCE, 2021, in press

E NOSE CALIBRATION



Example of sensor's signals during 1st measuring campaign in flight conditions over the WWTP

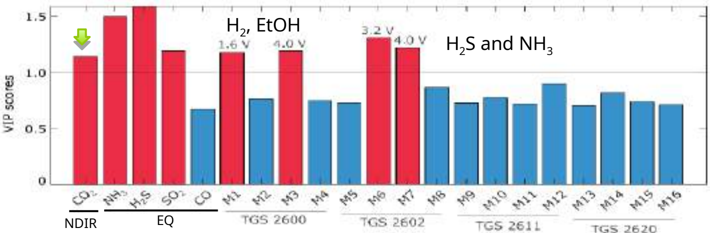
VARIABLE IMPORTANCE PROJECTION

A **VIP score** is a measure of variable's importance in the PLS model; athreshold of **VIP=1.0** can help us to identify de most relevant sensors

It is feasible to give more weight to the **MOX sensors at low concentrations** and rely more on the **electrochemical cells at higher concentrations**

Relevant contribution of **CO_2** sensor to the predictive model

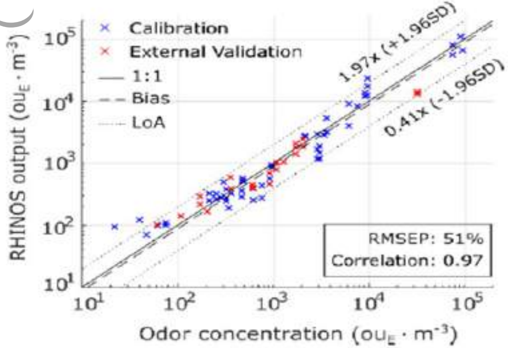
Allows **reduce the size, weight, and power consumption** (e.g. by removing 12 MOX sensors can save 75% of the power consumption, leading to an overall consumption of ~250 mW)

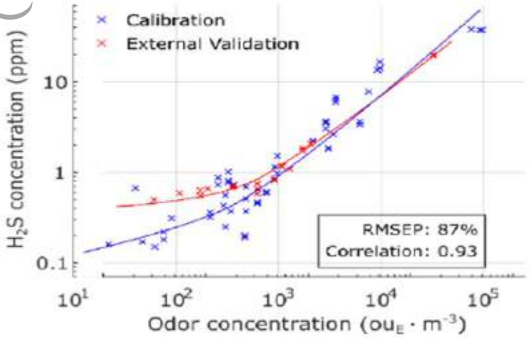


E-NOSE MODEL VALIDATION (DO vs E-NOSE LABORATORY SIGNALS)

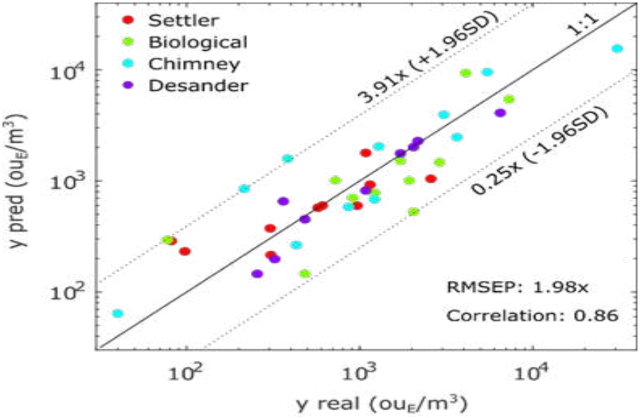
Third measurement campaign for model validation **by Bland-Altman methodology**

Linear sensitivity in the range 50-10^5 $ou_E \cdot m^{-3}$, correlation of 97%, and RMSEP of 51%





E-NOSE MODEL VALIDATION (DO vs SNIFFDRONE SIGNALS WHILE FLYING)

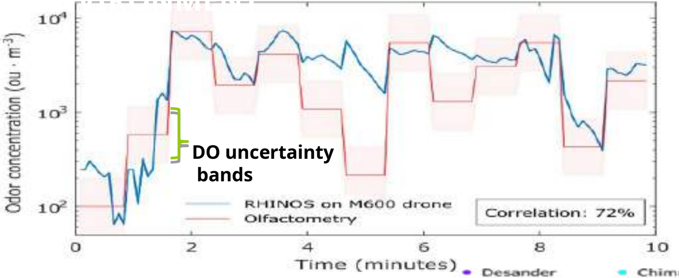


Drone based odour estimation compared with DO in external validation samples based on sensors signals (4) **performed at the WWTP during the drone flight (dynamic signals)**

LoA factor of two wider than those of dynamic olfactometry ([0.5x, 2x])

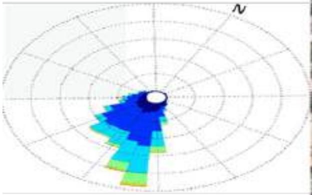
Cost reduction, temporal and spacial resolution improved

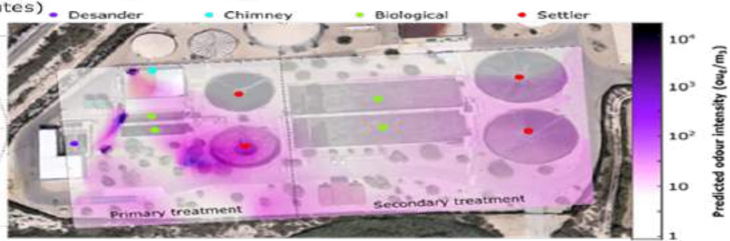
PROTOTYPE VALIDATION IN REAL WWTP ENVIRONMENT



Real-time odour prediction from Sniffdrone prototype **in flying conditions** compared to parallel dynamic olfactometry measurements

Interpolated odour concentration map at 1m/s and an odour concentration result every 5s (Natural neighbour interpolator)





CONCLUDING REMARKS

Drone based mapping of real time odor concentration in WWTPs with slightly worse accuracy than the reference method is feasible

1. *Burgués, J.; Esclapez, M.D.; Doñate, S.; Pastor, L.; Marco, S. Aerial Mapping of Odorous Gases in a Wastewater Treatment Plant Using a Small Drone. Remote Sens. 2021, 13, 1757*
2. *Burgués, J.; Esclapez, M.D; Doñate, S.; Marco. S. RHINOS: A lightweight portable electronic nose for real-time odour quantification in wastewater treatment plants, iSCIENCE, 2021, in press*
3. *Burgués, J.; Esclapez, M.D; Doñate, S.; Marco. SNIFFDRONE: Drone-based environmental odor monitoring, under review process*
4. *European Patent Presented: EP21382280.1*

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