

# Supplementary Materials: An Overview of Small Unmanned Aerial Vehicles for Air Quality Measurements: Present Applications and Future Prospective

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**Table S1.** Search terms.

Aerosol	Airborne	Aircraft	Ambient	Environment
Air	Composition	Compounds	Satellite	Ground
Atmosphere	Approach	Methodology	Manned	Impact
Combustion	Source	Plume	Sensing	Sensor
Emission	Reference	Concentration	Climate	Sensing
Health	Outdoor	Method	Platform	Factor
Station	Data	Collection	Measure	Measurements
Trap	Onboard	In-situ	On-line	Atmospheric
UAV	UAS	Unmanned	System	Sampling
VOCs	Gases	Gaseous	Pollution	Pollutant
Drone	Remote	Control	Model	Hexacopter
Quadcopter	Multicopter	Tethersonde	Plane	Helicopter
UAR				

**Table S2.** Summary of the lightweight UAV onboard technology for air quality research.

UAV Name	Onboard Technology	UAV Weight (Kg)	UAV Payload Weight (kg)	Targeted Analytees (Gases, VOCs)	UAV Endurance (Minutes)	UAV Dimensions
[109] Kite Plane, Sky Remote	Non-Dispersive Infra-red (NDIR) gas analyser (LI-800, LI-COR)	16	3.5	atmospheric CO <sub>2</sub>	Typically 60 but it can be extended until 90	224 cm × 308 cm × 119 cm (length × width × height)
[134] Thunder Tiger Raptor 90 Helicopter	Ultraviolet spectrometer Infrared spectrometer Electrochemical sensor	3.5	3	SO <sub>2</sub> flux CO <sub>2</sub> /SO <sub>2</sub> ratio CO <sub>2</sub> /SO <sub>2</sub> ratio	12	141 cm × 46.5 cm × 19 cm
[125] DP Volcan	Infrared spectrometer Electrochemical sensor	13	5	CO <sub>2</sub> SO <sub>2</sub>	30	Wing span: 239 cm Height: N/A Length: N/A

Table S2. Cont.

UAV Name	Onboard Technology	UAV Weight (Kg)	UAV Payload Weight (kg)	Targeted Analytees (Gases, VOCs)	UAV Endurance (Minutes)	UAV Dimensions
[117,118] SIERRA	Laser gas analyser Off-Axis ICOS	180 (gross take-off weight)	19.5	H <sub>2</sub> O, CO <sub>2</sub> , CH <sub>4</sub>	480–600	Wing span: 609.6 cm (20 feet) Length: 309.66 cm (11.8 feet) Height: 140.21 cm (4.6 feet)
[169,170] T-Rex Align 700E Helicopter	Vertical cavity surface emitting laser (VCSEL)-based sensors	4.7	5	CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O	20	Length: 133 cm long, Height: 41 cm Main rotor diameter: 156 cm
[115] MANTA	Mixing condensation particle counter (MCPC) Three-wavelength absorption photometer (BMI ABS) Multi-Channel Chemical Filter Sampler	16.3	11.4 maximum	Atmospheric aerosol not used	270	Wingspan: 270 cm Height: 62 cm Length: 192 cm
[119] Skywalker	Electrochemical Concentration Cell (ECC)	3 (max take-off weight)	N/A	Ozone	60 minimum	Wingspan: 188 cm Height: N/A Length: 110 cm
[33] Manta	Optical particle counter (OPC) Aerosol absorption photometer	27 (max take-off weight)	5	Total particle concentration (number/cm <sup>3</sup> )	270	Wingspan: 270 cm Height: 62 cm Length: 192 cm
[159] Patria MASS mini-UAV	Gamma-ray spectrometer (Georadis RT-10)	3	0.5	gamma-ray emissions	60	Wing span: 150 cm Height: N/A Length 105 cm

Table S2. Cont.

UAV Name	Onboard Technology	UAV Weight (Kg)	UAV Payload Weight (kg)	Targeted Analytees (Gases, VOCs)	UAV Endurance (Minutes)	UAV Dimensions
[120,122] Mini-UAV (M2AV)	5-hole probe for wind speed and direction measurement Vaisala hmp 50 for temperature and humidity measurements Thermocouple for measuring fast Temperature fluctuation	6 (max take-off weight)	1.5	Meteorological information	50–60	Wing span: 200 cm Height: N/A Length N/A
[36] Aerosonde	Sulphur and Carbon compounds detector	13–15	2	Cloud physics SO <sub>2</sub> , CO <sub>2</sub>	>than 30 h	Wing span: 290 cm Height: N/A Length N/A
[131] RAVEN UAV	Fourier micro-interferometer based on MOEMS technology	56 (max take-off weight)	N/A	Atmospheric trace gases	N/A	Wing span: 460 cm Height: N/A Length: 365 cm
[141] Aerosonde	Vaisala RSS901 PTU sensor (fast-response pressure-temperature-humidity sensor)	13–15	2	Pressure, Temperature and Humidity measurements	>than 30 h	Wing span: 290 cm Height: N/A Length N/A
[104,146] Airrobot AR100-B microdrone	Drager X-am 5600 gas detector, which include: catalytic, electrochemical and infrared sensors	1.3	0.2	Combustion gases and other toxic gases	20–30	Diameter: 100 cm
[136] THE DRAGON EYE $\mu$ UAV	Small electrochemical SO <sub>2</sub> sensor Small optical particle counter (0.5–5 $\mu$ m range) Small evacuated vacuum sampling bottle (0.1deci-liter) with an automatic actuator Temperature-pressure-humidity sensors		<0.5 kg	SO <sub>2</sub> , t, p, %H <sub>2</sub> O, Gps, opc, nanopc, Color vis, lo light Vis, thermal ir, Evacuated Sampling bottle	N/A	Wing span: 114 cm Height: N/A Length N/A
[136] Vector Wing 100	Small electrochemical SO <sub>2</sub> sensor Temperature-pressure-humidity sensors	3.6	<1 kg	SO <sub>2</sub> , t, p, %H <sub>2</sub> O, Gps, color vis	N/A	Wing span: 210 cm Height: N/A Length N/A

Table S2. Cont.

UAV Name	Onboard Technology	UAV Weight (Kg)	UAV Payload Weight (kg)	Targeted Analytees (Gases, VOCs)	UAV Endurance (Minutes)	UAV Dimensions
[136] SIERRA	Two laser altimeters	180 (gross take-off weight)	<45 kg	SO <sub>2</sub> , t, p, %H <sub>2</sub> O, Gps, opc, nanopc, Color vis, lo light Vis, thermal ir, Evacuated sampling bottle	480–600	Wing span: 609.6 cm (20 feet)
	Synthetic aperture radar (sar)					
	Zenith- and nadir-pointing micro-spectrometers					
	Digital still and video tracking cameras					
	Pyrometer					
	Zenith pointing					
	Pyronometer					
	Also tested on SIERRA UAV:					
	TSI Inc., Shoreview, Minnesota, USA Model 3007 particle counter					
	TSI Inc. Model 3330 Optical Particle Spectrometer					
	Droplet Measurement Technologies					
	Mini-nephelometer – to obtain particulate scattering coefficients					Length: 309.66 cm (11.8 feet)
	Aerosol Drum Impactor					
Bolometer						
Temperature, pressure & relative humidity	Height: 140.21 cm (4.6 feet)					
Hal Technology (haltech), LLC HPC-600 six-channel hybrid handheld particle counter						
Electrochemical SO <sub>2</sub> sensor						
ULISSES mass Spectrometer						
[133]Silver Fox	Visible electro-optical and IR cameras	9.1 (20lb)	3.6 (8lb)	Thermal and visible images 7 different gases (no further information are provided by the authors)	10 to 20 h	Wing span: 244 cm (8 feet)
	Gas sensors					Height: N/A
						Length N/A
[166] Aerosonde	Vaisala RSS901 radiosonde	15	5 (2 of fuel)	Pressure, Temperature & humidity H <sub>2</sub> O, CO <sub>2</sub> O <sub>3</sub> CO, CO <sub>2</sub> , SO <sub>2</sub>	>than 30 h	Wing span: 290 cm
	Infrared gas analyzer					Height: N/A
	UV ozonesonde					Length N/A
	Conductometric detector					
	Electrochemical detector					

Table S2. Cont.

UAV Name	Onboard Technology	UAV Weight (Kg)	UAV Payload Weight (kg)	Targeted Analytees (Gases, VOCs)	UAV Endurance (Minutes)	UAV Dimensions
[171] Green Falcon	Metal oxide (MOX) nanowires gas sensor	5	<500 gr	NH <sub>3</sub> ,NO <sub>2</sub>	30	Wing span: 3.6 m Length 1.3 m
[151] Senior Telemaster (ST) model airplane	Petri dish lid 2 × 100-mm	N/A	N/A	Air samples	N/A	Wingspan: 240 cm Height: N/A Length N/A
[153] Flamingo	Spore trap	12–15	10	Air samples	420	Wingspan: 400 cm Height: N/A Length: 290 cm
[116] CAROLO P360	Optical particle counter OPC (model GT-526, Met One Instruments Inc., Washington, DC, USA) O.M. two condensation particle counters, CPC (model 3007, TSI Inc., Shoreview, Minnesota, USA)	25 (max take-off weight)	<2.8 kg	UFPs number concentration of particles with different diameters OPC: diameters between 0.3 to 10 µm CPC: diameters between 11 nm and 2 µm (N11) PC: between 18 nm and 2 µm (N18 25)	40	Wingspan: 3.6 m Height: N/A Length: N/A
[156] Parrot AR. Drone 2.0	Temperature/Humidity sensor (RHT03) CO <sub>2</sub> sensor (MG811) Luminosity sensor (TSL2561)	0.420 (take-off)	N/A	CO <sub>2</sub> concentration Air temperature and humidity Solar radiation	N/A	Wheelbase: 51.7 cm
[100] AMR Payload Master 100	Custom laser based open path methane sensor	N/A	N/A	CH <sub>4</sub> , temperature, pressure, wind speed and direction	N/A	Wingspan: 335 cm Length: 244 cm
[99] AMR Payload Master 100	Grimm 1109 aerosol spectrometer	N/A	N/A	PM <sub>1</sub> , PM <sub>2.5</sub> , PM <sub>10</sub> , temperature, pressure, humidity, airspeed	N/A	Wingspan: 335 cm Length: 244 cm
[101] 3D Robotics Iris+	Optical particulate counter MetOne 80080 two-channel particle counter. CO <sub>2</sub> Meter K-30	1.282	400 g	PM 0.5 µm < d <sub>p</sub> < 1 µm (channel 1), PM d <sub>p</sub> > 1 µm (channel 2), CO <sub>2</sub>	16–22	Wheelbase 55.5 cm