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UAS-NOISECHECK - A SYSTEM IMPLEMENTING THE EASA GUIDELINES ON DRONE NOISE MEASUREMENT

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ABSTRACT

Unmanned aerial systems (UAS) are on the rise and are about to transform civil aviation. As their proliferation grows, the social and legal acceptance of drones is becoming increasingly important, particularly with regard to noise pollution. So far, the lack of standardized methods and systems to measure in-flight noise emissions of UAS has hindered the creation of legal frameworks. To close this gap, the EASA introduced guidelines for UAS noise measurement in October 2022, for which feedback is currently being collected on their practical implementation and measurement results. In this work, we present *UAS-NoiseCheck*, a prototype system designed to implement these guidelines. It integrates acoustic, visual, GNSS and meteorological components to enable comprehensive, multisensory data acquisition and thus represents a novelty in the multimodal metrological description of UAS. Since our system not only contains a single microphone as a sound level meter but also features a hemispherical 32-microphone array, it can also facilitate the certification and regulation of noise emissions when used in the context of drone detection and localization. In initial field experiments, we analyze noise emissions of different multicopter UAS recorded with a ground-based and an inverted microphone setup as well as the microphone array.

Keywords: *noise measurement, sound pressure level, sound emission, microphone array, uav, drone*

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1. INTRODUCTION

Unlike conventional aircraft, UAS produce distinctive high-frequency and tonal noise signatures, which can lead to noise annoyance populated areas. Previous research studies have shown that UAS are likely to be perceived as more annoying than road vehicles, airplanes or helicopters at similar sound levels, in particular when combined with low-altitude flight maneuvers and hovering [1, 2].

In response to growing concerns [3], the European Union Aviation Safety Agency (EASA) introduced guidelines in 2022 [4] aimed at standardizing noise measurement for UAS operating in the *specific* category, which has not been addressed so far. These guidelines mark a significant step in bridging the gap between traditional noise assessment methods [5, 6] and the evolving acoustic profiles of modern UAS [7]. Previous studies have largely focused on controlled environments such as anechoic chambers, wind tunnels or complex and costly outdoor configurations [5, 8]. Nevertheless, field measurements are still essential to capture the complex interplay between UAS noise emissions and environmental factors such as ground effects and meteorological conditions.

In [9], sound pressure level (SPL) and noise variability under different flight conditions was analyzed in an extensive flight test campaign for small UAS, focusing on the comparison between ground-plane and elevated microphones. [10] presents a robust framework for field measurements to accurately characterize UAS noise emissions during flyovers, using multiple measurement positions and backpropagation techniques to calculate directivity noise hemispheres. In this comprehensive work the inverted microphone setup over a ground plate proposed in [4, 6] is used. Similar measurements were performed in [11] with results providing insights into sound pressure, sound power, spectral content and directional patterns.

At the same time, numerous papers have been published on the human perception of drone sounds, with the aim of finding a link between objective noise metrics and psychoacoustic sound quality metrics. [1] used the sound exposure levels (SEL), effective perceived noise level (EPNL), and loudness exceeded 5% of the time (L5) together with subjective listening tests, to compare human annoyance responses to noise from UAS flyovers and road vehicle drive-bys. [2] recommends a combination of qualitative and quantitative methods, including laboratory studies and real-world testing to understand human responses to UAS and to develop the most meaningful noise metrics. In particular, loudness, sharpness, tonality and roughness should be considered, as A-weighted SPL, SEL or EPNL are considered insufficient.

There exist only few works on the noise measurement including SPL estimation with microphone arrays. In [12] the use of microphone arrays is recommended due to their localization capabilities and improved signal-to-noise ratio (SNR) given by possibility of focusing in a desired direction via beamforming (BF). In a previous paper [13], we presented a hemispherical 32-microphone array specifically designed to capture typical UAS noise and investigated its performance in fixed and mobile setups.

In this paper, we present *UAS-NoiseCheck*, a research project and equally named system, designed to implement the EASA noise measurement guidelines [4]. By integrating ground-plate microphones, a sound level meter (SLM) and a microphone array from [13], with visual, GNSS and meteorological components, our system enables a comprehensive, multimodal characterization of drone noise. Based on the results of initial field tests, we show that the system has the potential to combine noise measurement with acoustic drone tracking to enable directional SPL estimation in future regulatory tasks.

2. METHODOLOGY

The guidelines of [4] describe two different approaches for the objective measurement of UAS noise: a level-flight to estimate the A-weighted sound exposure level (L_{AE}) and a hover procedure to compute the A-weighted equivalent continuous SPL (L_{Aeq}) recorded using the inverted setup (INV) with a 1/2" microphone spaced 7 mm above a ground plate [6] and an SLM, both complying with IEC 61672-1 (Class 1). This setup is recommended for its simplicity instead of a ground-based microphone (GND) mounted flush with the plate. In *UAS-NoiseCheck*, we implement both setups to analyze potential SPL differences.

Similar to our previous work [13], we use an acoustic localization algorithm providing DOA estimation (DOAE) of multiple sound sources in order to track potential UAS targets. The algorithm relies on the BF steered response power and adopts a Gaussian Mixture Model (GMM) based approach for the use in 3D with custom frequency and sampling grid settings to enable probabilistic modeling and tracking of an unknown number of sources and signal extraction using masked delay-and-sum beamforming (DSB) [14]. It provides good localization accuracy even with coarse spatial scanning grids with a computational load that enables real-time application.

3. SENSOR SYSTEM

The sensor system consists of the following components that provide data streams a central unit (CORE):

- SPL: *GRAS 67AX* (INV, GND) + *NTi Audio XL2* SLM → 2x audio via USB, 1x JSON message via LAN,
- ARR: *JR-IcoDome32* microphone array + *MOTU AVB* → 32x audio via USB,
- CAM: 2x *FLIR Blackfly GigE* + *NVIDIA Jetson Orin* → 1x JSON message via LAN,
- GNSS: *Holybro H-RTK F9P GNSS* + *Pixhawk 6X* → 1x GNSS message via USB from *RFD868x-EU*,
- METEO: *DAVIS Vantage Pro 2* + *Weatherlink LIVE* → 1x JSON message via LAN.

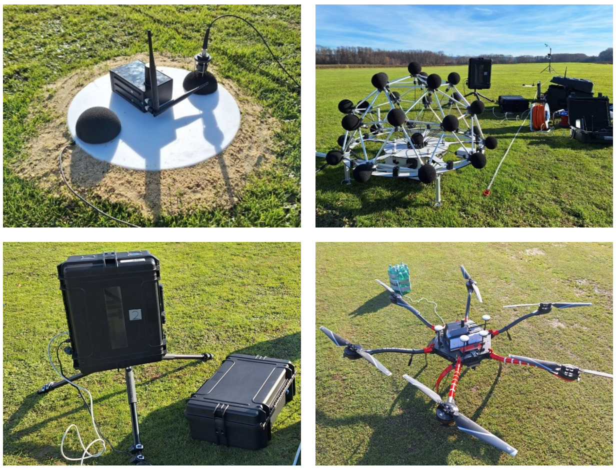

Figure 1: Measurement setup: SPL with GNSS for positioning (top left), ARR with windscreens (top right), CAM in case (bottom left), and a *ViewCopter V6H* with payload for MTOM (bottom right).

Figure 1 shows the measurement setup during the initial field test in 2024. All components are synchronized in time by an NTP server on an LTE router. For SPL, we use a *GRAS 47AX* (GND) and a *Z-TECH 333-507* (INV) microphone. The audio signal of INV is split with an XLR Y-adapter and used as SLM input. ARR has 32 ICP electret array microphones, 26 of which are arranged on a geodesic dome and 5 as a pentagon, with one in the center of a solid plate. Signal conditioning, A/D conversion and time synchronization is done with *MOTU AVB* USB audio interfaces. CAM only sends position estimates to CORE and stores video data locally. GNSS is used to record sensor positions and is mounted on the UAS during flights.

For our initial field test, we used four UAS [1] [2]:

UAS	**DIM** (cm)	$\mathbf{V_{Gref}}$ (m/s)	**MTOM** (kg)
ViewCopter V6H	150x150x45	10	32
twinFOLD KAT	173x187x30	10	12
twinFOLD GEO	125x115x26	10	5
twinFOLD SCI	52x52x17	15	2

Table 1: UAS with dimensions, reference ground speed V_{Gref} and maximum take-off mass (MTOM).

According to [4], UAS must be operated at V_{Gref}, i.e. at the fastest speed at which the level-flight can be maintained under the atmospheric reference conditions, with their maximum take-off mass (MTOM) at an altitude between 17 m and 150 m and ensuring a lateral deviation of $\pm 10°$ from the vertical above the noise measurement point (SPL). For the hover procedure, the UAS must maintain a stabilized position for 30 s at an altitude between 12 m and 50 m within a cone of 8° from the vertical above the noise measurement point. For both level and hover scenarios at least 6 valid runs must be performed.

4. RESULTS

The first field tests were carried out at *UMFC Stocking* airfield in November 2024. All microphones and the SLM were calibrated with a 1 kHz sine signal at 94 dB. Audio data was recorded at a sampling rate of 48 kHz at 24 bits together with the SLM metrics L_{AF} and L_{AS} logged at 5 Hz for fast and slow time weightings, respectively. For FFT processing in DOAE, we set the size of the time window (square-root Hann) and the FFT to 4096, with a frame overlap of 50% to ensure perfect reconstruction of the DSB signals extracted from the estimated source tracks. Considering the predominant characteristics of drone sound, i.e. rotor noise, the frequency range for DOAE was set to [300 2300] Hz and for DSB signal extraction to the whole range [0 24] kHz. As scanning grid we choose a hemisphere of 200 quasi-uniformly distributed points. The number of initial and maximum sound sources was set to 3 and 16, respectively [13].

In Figures 2 and 3 we show exemplary runs for a level and a hover flight of the *ViewCopter V6H*, respectively. The top two subplots represent the DOAE tracking results of three sound source hypotheses (SRC1-3) compared to the GNSS based position ground truth (TRUE) in terms of azimuth and elevation angles. The respective absolute angle error for each source is shown in the third diagram. The fourth subplot shows the distance and velocity profile of the UAS flight with respect to SPL as origin. The bottom two plots display the SPL recordings of INV as reference (which is also used as input to SLM), GND, ARR as the central microphone on the array base, and DSB as the extracted beamformer output of the SRC closest to TRUE.

The measurement results for the entire dataset are presented as follows: Table 2 provides the calculated noise metrics defined in [4] for each UAS: the arithmetic average sound level L_{AEref_av} and L_{Aeqref_av} for level and hover flight, with the corresponding standard deviation (SD).

UAS	$\mathbf{L_{AEref\_av}}$ (dBA)	$\mathbf{L_{Aeqref\_av}}$ (dBA)
ViewCopter V6H	77.6 ± 0.81	77.6 ± 0.76
twinFOLD KAT	74.4 ± 0.67	66.4 ± 1.09
twinFOLD GEO	77.3 ± 0.48	57.6 ± 1.73
twinFOLD SCI	66.3 ± 0.39	50.8 ± 1.32

Table 2: UAS noise metrics L_{AEref_av} and L_{Aeqref_av} averaged over runs for level-flight and hover, resp.

Scenario	**GND** (dB)	**ARR** (dB)	**DSB** (dB)
level	0.23 ± 0.06	-0.03 ± 1.84	-2.69 ± 2.63
hover	0.06 ± 0.83	0.50 ± 4.82	-3.86 ± 4.88
level & hover	0.17 ± 0.71	0.16 ± 3.24	-3.11 ± 3.64

Table 3: SPL differences of GND, ARR and DSB w.r.t. INV: mean $\pm$ SD for level-flight and hover.

[1] https://www.vcopter.net/drohnenbau.html
[2] https://www.twins.co.at/multirotorsysteme

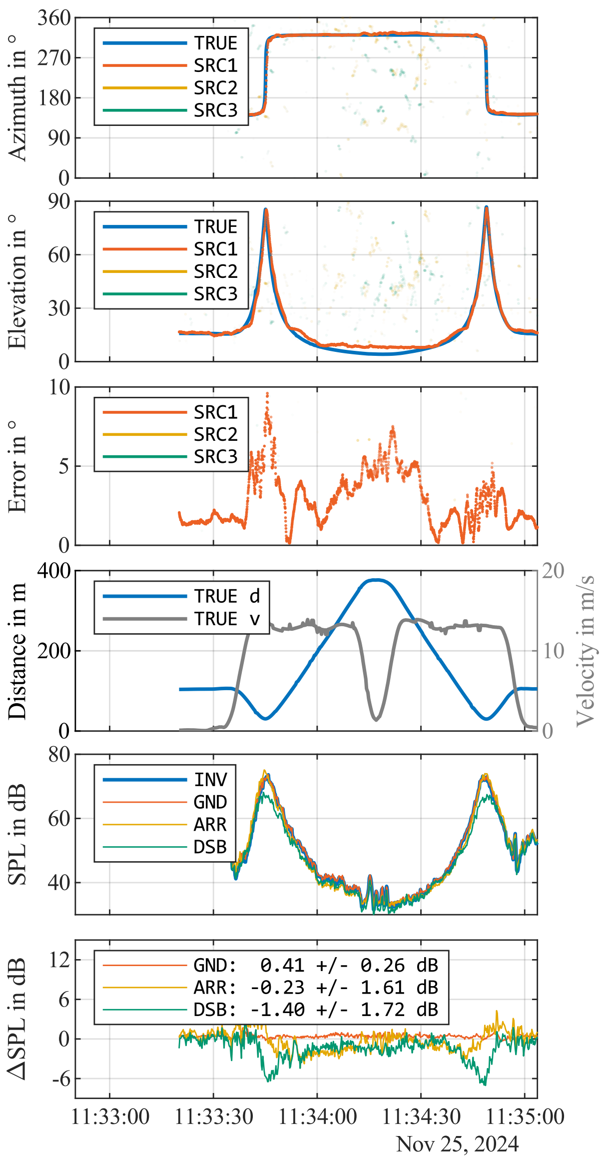

Figure 2: Level-flight example of *ViewCopter V6H*: The UAS is tracked during the entire run up to a distance of 400 m with a DOAE error below 10°. The average SPL differences w.r.t. INV are within 1.5 dB for all signal types. The deviations in ARR and DSB are mainly due to time differences during overflights. The relatively large SPL differences in DSB of -6 dB indicate that the tracker is not able to follow the UAS fast enough, leading to steering errors and unwanted attenuation of the target signal in the BF process.

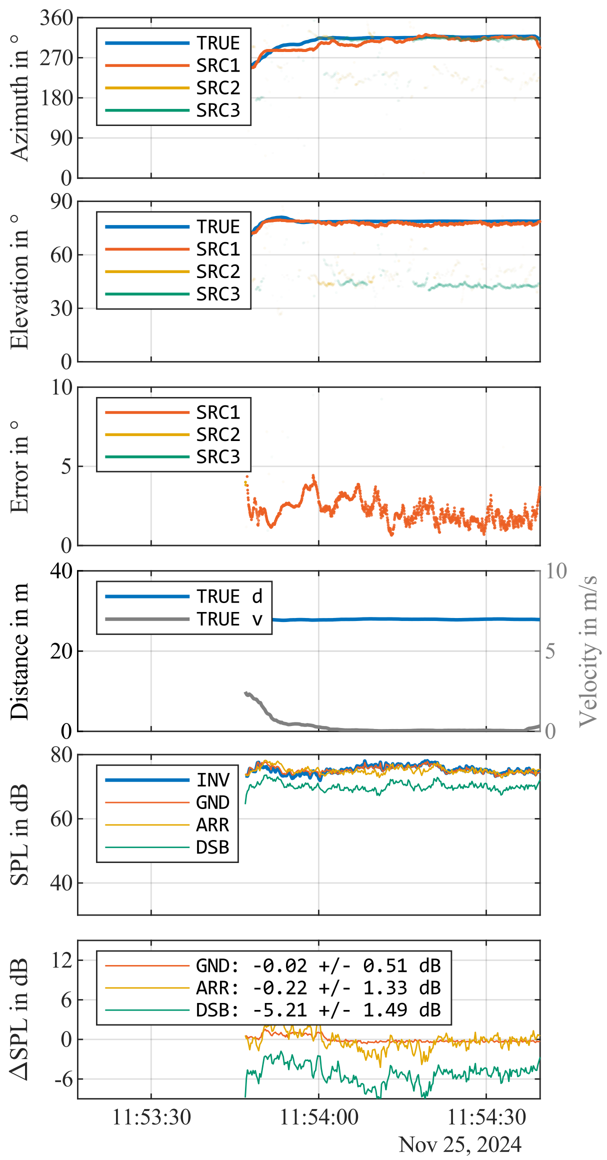

Figure 3: Hover-flight example of *ViewCopter V6H*: The UAS is stabilized at a height of 31 m above the ground plate (SPL) and tracked with a DOAE error below 5°. The average SPL differences w.r.t. INV are within 1 dB for GND and ARR. The deviations at DSB of -6 dB are due to spatial filtering effects, such as suppressed ground reflections, turbulent incoherent noise etc., and possibly also due to the fact that the array mainlobe is too narrow to focus on the UAS as a whole and therefore does not capture its entire frequency content.

Table 3 examines the SPL differences in terms of L_{AF} of GND, ARR and DSB compared to the inverted setup microphone signal (INV) averaged over all runs. To get a more detailed insight, we divide the analysis into the contributions of level, hover, and both scenarios.

Table 4 shows a statistical evaluation of the DOAE in terms of mean absolute error (MAE) including SD and median absolute deviation with the respective interquartile ranges, which represents a more outlier prone error metric. Again, we split the evaluation into level, hover, and both.

Scenario	**MAE $\pm$ SD** (°)	**MAD** (°)	**IQR** (°)
level	5.94 ± 8.27	3.63	[2.08, 7.25]
hover	6.08 ± 5.36	3.69	[2.34, 8.83]
level & hover	5.99 ± 7.37	3.65	[2.16, 7.88]

Table 4: DOAE performance: mean $\pm$ SD, median and IQR of absolute error for level-flight and hover.

5. CONCLUSION

We have presented *UAS-NoiseCheck*, a multimodal system for UAS noise measurement. We draw the following conclusions from our results obtained in a first field test:

- Both the inverted and the ground microphone setup are suitable for accurately measuring UAS noise metrics.
- The DOAE performance highlights the effectiveness of microphone arrays to automatically localize UAS.
- To accurately measure SPL based on BF, special care must be taken to ensure robust sound source tracks and to compensate for the spatial array response.

Future work lies in extensive field testing to verify the results on larger datasets and improve DOAE tracking.

6. ACKNOWLEDGMENTS

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