DOI: 10.61782/fa.2025.0338

FORUM ACUSTICUM EURONOISE 2025

EMPIRICAL STUDY ON ACTIVE NOISE CONTROL IN UAVS

Jonas Steiner[1*] **Florian Hilgemann**[1] **Peter Jax**[1]
[1] Institute of Communication Systems, RWTH Aachen University, Aachen, Germany

ABSTRACT

Unmanned aerial vehicles (UAVs) are known for their characteristic noise emissions, which are inevitable during operation, but often perceived as annoying. Current research on UAV noise mitigation focuses on passive technology, but active noise control (ANC), commonly used in headphones and related applications, might prove to be more effective. However, ANC algorithms require comprehensive knowledge of acoustic transfer paths, across all operational modes of the UAV. Commercially available UAVs lack components such as microphones and loudspeakers as required by ANC applications. The purpose of this work is to investigate the estimation accuracy achievable with a simplified linear time-invariant (LTI) model of the generally non-linear aerodynamic system of UAV sound emission. For this, a prototype UAV-ANC system, which extends a UAV with added microphones and loudspeakers, is considered. Extensive measurements are conducted in a controlled indoors environment to assess the applicability of state-of-art system identification methods for estimating the associated acoustic transfer paths. These transfer path estimates can be used to determine the efficacy of ANC algorithms in the considered application through simulation. They are made available online for research purposes.

Keywords: *Active Noise Control, System Identification, Unmanned Aerial Vehicles*

1. INTRODUCTION

The sound produced by UAV quadrocopters is an undesirable byproduct of rotor-based propulsion systems. The subjective impact of this sound depends on the frequency of occurrence of UAV flyby events as well as on the sound pressure level of the noise [1]. Participants of that study perceived scenes that feature UAV noise as highly annoying. The reduction of UAV noise is vital as it has the potential to improve the acceptance of UAV technology, e.g., in urban delivery tasks.

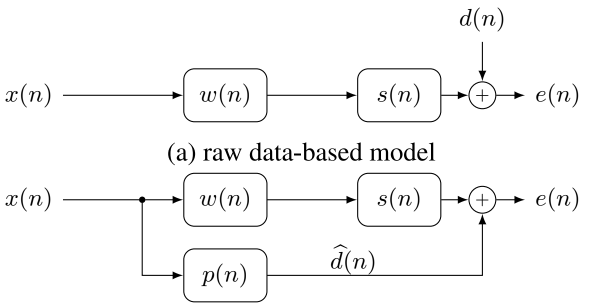
Currently, the mitigation of drone noise receives scientific and practical interest. As an example, In [2], a looped rotor blade that reduces the sound pressure level (SPL) at the blade passing frequency (BPF) by four decibels was proposed. However, the thrust force of the less noisy rotor was also significantly reduced. Another method for reducing the perceived SPL is ANC, which is typically used in headphones [3], and was proposed as a suitable means of mitigating UAV noise [4, 5]. One advantage of active approaches is that they do not interfere with the rotor design.

The working principle of ANC is based on destructive interference, which requires accurate knowledge on the acoustic sound propagation with respect to both, magnitude and phase. In classical ANC applications such as ANC headphones, this sound propagation is modeled using LTI models of the electro-acoustic transfer paths. While these transfer paths were studied thoroughly in headphone applications, fewer results are available for UAVs. For instance, the reproduction of rotor noise was studied using analytic [6] and data driven methods [7], but these approaches lack accurate information about amplitude and phase required by ANC.

This paper presents a database of spatially distributed noise measurements of a commercially available UAV, together with simultaneously recorded reference signals in proximity of the UAV. Impulse responses with corresponding raw data that reflect the primary- and secondary paths are made available online [1]. The main purpose of this data is the analysis of the transfer paths for ANC ap-

*Corresponding author: steiner@iks.rwth-aachen.de.

[1] https://www.doi.org/10.5281/zenodo.15064305



(a) raw data-based model

(b) path-based model

Figure 1: Block diagrams of systems considered.

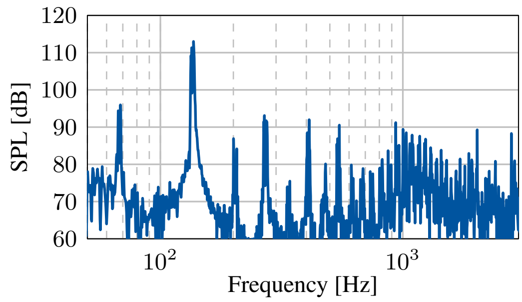


Figure 2: SPL of reference signal for 137 Hz BPF.

plications. For this, the prediction error of a conventional system identification algorithm on the measurement data is analyzed, and a case study of a basic feed-forward ANC system is included. The study brings insight into UAV transfer path modeling and highlights the potential and difficulties of real-world spatial ANC for UAVs.

2. SYSTEM OVERVIEW

The system at hand consists of four main components: a reference microphone and loudspeakers close to the UAV, error microphones further away, and a signal processor. In general, the primary path $p(n)$ models sound propagation from a microphone collocated towards the primary noise source, in this case, the reference microphone signal $x(n)$, to a point in space where noise cancellation is desired. The signal at this point is denoted by $d(n)$ or $e(n)$ when the ANC system is disabled or enabled, and is picked up by one of the error microphones. The secondary path $s(n)$ models the sound propagation to the same point but originating from a loudspeaker that is used to generate the anti-phase signal which achieves the noise reduction [8]. For this analysis, the path-based model from Fig. 1b, which estimates $d(n)$ by the means of the linear model $p(n)$, will be compared with the raw data-based model from Fig. 1a, which uses recordings of $d(n)$ and therefore does not require $p(n)$ explicitly. The latter raw-data approach could turn out as favorable because modeling inaccuracies cannot occur. In practice, the reference signal $x(n)$ is afflicted with acoustic feedback from the loudspeaker, which is not considered here for the sake of a simplified evaluation. In headphone applications, ANC is required to attenuate broadband signals with limited a priori knowledge of the signal source characteristics [8]. Therefore, the objective is to minimize the expected broadband SPL of the remaining noise signal. With UAVs, an estimate of the excitation signal can be measured and exploited in a band limited ANC approach focused on reducing the SPL at the BPF.

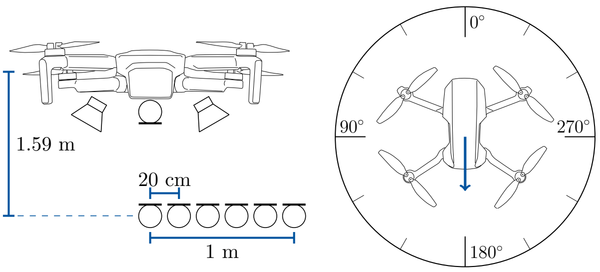
To define electro-acoustic transfer paths, a commercially available drone was extended by loudspeakers and microphones. Generally, the objective is to derive an optimal finite impulse response (FIR) filter $w(n)$ that causes cancellation of the disturbance signal $d(n)$, reducing the signal power of the remaining error signal $e(n)$.

3. MEASUREMENT SETUP

The measurements were done in two parts. In the first part, the propagation of UAV noise was measured, while in the second part, the sound emitted by the loudspeakers was recorded. The objective of each measurement was to gather signal components required for deriving the optimal FIR filters $w(n)$ and subsequent simulation. While the secondary path estimation can be done with optimized excitation signals [9], the primary paths are required to be estimated using the UAV noise, which is inherently tonal (Fig. 2) and therefore not suited for broadband estimation. This excitation complicates the identification of $p(n)$, which could degrade the ANC performance.

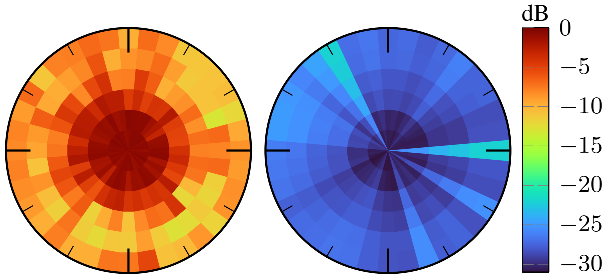
3.1 Measurement Equipment

The measurements were carried out in a controlled indoors environment that follows the base reference ITU-R BS.1116-2 [10], but is subject to adverse acoustic effects such as room echos. A DJI mini 2 SE is equipped with a DPA 4061 omnidirectional condenser type microphone with a pop-filter to protect against wind noise, placed directly on the bottom of the chassis. A RME 12-mic microphone amplifier was used together with the RME MAD-Iface USB as an audio interface running at a sampling frequency of 48 kHz. Six error microphones of the same make and model were placed in a linear array on top of a Head Acoustics HRT I high-precision turntable, to fa-



(a) Front view. (b) Top-down view.

Figure 3: Measurement setup.



(a) primary paths. (b) secondary paths.

Figure 4: Relative approximation error.

cilitate the measurement of $d(n)$ inside a disk directly underneath the DJI mini. These microphones allow to gather the required measurement data, but are unavailable in practice. Multiple independent measurements were performed with varying rotations of the turntable. As secondary sources five Fostex 6301b active studio monitors were placed in proximity to the DJI mini. The error microphones were spaced $20\,\mathrm{cm}$ apart. The DJI mini was placed $1.59\,\mathrm{m}$ above the microphone array (Fig. 3).

3.2 UAV Noise Measurements

During the UAV noise measurements the loudspeaker array was not present. Measurements were taken at multiples of $10°$ of turntable angle spanning the entire disk. Figure 3b shows the coordinate system used for the angles. The DJI mini was fixed by a construction mounted to its top, such that arbitrary rotational speeds could be utilized without requiring stable flight conditions. This way, scenarios such as hovering, take off and landing could be simulated by assigning the same rotational speed to all rotors. Here, 10 different rotational speeds were selected, such that the BPF varied between $93\,\mathrm{Hz}$ and $233\,\mathrm{Hz}$. For each configuration of angle and rotational speed the reference microphone and all six error microphones were recorded for two seconds. The estimated primary paths have been obtained using the MMSE method [11] and are available as FIR filters of length 8192 (corresp. $170\,\mathrm{ms}$).

3.3 Loudspeaker Measurements

The loudspeakers were placed in a cross-shaped arrangement tightly below the DJI mini. One central loudspeaker was placed directly underneath the DJI mini, with loudspeakers at each of its four sides angled away from the center at about $30°$. Exponential sweeps [9] with a duration of $10\,\mathrm{s}$ were played back over each of the five loudspeakers in individual measurements. Again, all measurements were repeated for each multiple of $10°$ of turntable angle. All secondary paths were obtained using the spectral division method with suitable regularization and are available as FIR filters of length 8192.

3.4 Analysis of Estimation Accuracy

One issue with the primary path estimate is the tonal characteristic of the UAV noise, visible in Fig. 2. With a narrow-band excitation signal it is generally not possible to obtain the underlying broadband transfer function. However, the transfer path estimates can be analyzed objectively by their relative estimation error. This measure has no issue with small band excitation, as the same frequencies used for identification are used in the evaluation. A high approximation error indicates insufficient model order or a general lack of applicability of linear models. Figure 4 shows the normalized approximation error in decibels for each primary path estimate at a BPF of $137\,\mathrm{Hz}$, as well as the accuracy of the secondary path estimates averaged over the five speakers. It clearly shows that the estimation of secondary paths is more accurate compared to the primary path. Rotor-induced wind noise is present at the error microphones but not in the reference microphone signal. This deteriorates the estimation accuracy underneath the UAV as can be seen in Fig. 4a, where the approximation error decreases with the radius.

4. CASE STUDY

The case study considers an ANC system which uses five secondary sources and is optimized for one error microphone directly underneath the UAV for a turntable rotation of $0°$. The two system models described in section 2, are tested and compared using different rotational speeds. The optimal filters $w(n)$ were determined using the well

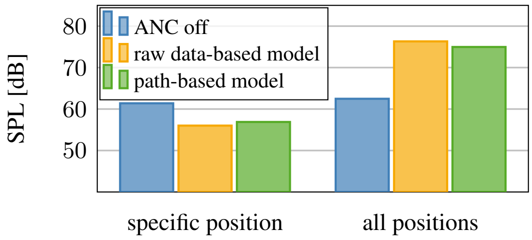


Figure 5: SPL comparison.

known minimum mean squared error approach [11] using a filter length of 8192 samples. The simulation results for a BPF of 137 Hz are presented in Fig. 5, showing the SPL in a third-octave band centered at the BPF at the target location and averaged over all virtual microphone positions. The data includes comparisons of both considered systems to the scenario without ANC. Peak SPL at the target location is reduced by 9 dB and 7 dB using the raw data-based and path-based models, respectively. This evaluation is likely more favorable than a real application, as the secondary path estimates employed for the filter design were also used in the subsequent simulation. Despite this success at the target location, the overall SPL is increased highly using any of the described methods.

5. CONCLUSION

This paper describes a database which contains spatially distributed quadrocopter noise for ANC applications. The data is available online and facilitates the design and simulation of UAV-ANC algorithms. Experiments on reducing the UAV noise within a region of interest were conducted. It was shown that a relatively simple system equipped with a single reference microphone and five secondary loudspeakers, designed to minimize the SPL at a single error microphone, can reduce drone noise at the target location, but is generally not suited for spatial noise reduction.

6. ACKNOWLEDGEMENTS

This work was part of the SILENce project, which was funded by the Federal Ministry of Digital and Transport as part of the mFUND innovation initiative.

Funded by:
Federal Ministry for Digital and Transport
on the basis of a decision by the German Bundestag
mFUND Das Startkapital für die Mobilität der Zukunft

7. REFERENCES

[1] M. Lotinga, M. Green, and A. J. Torija Martinez, "How do flight operations and ambient acoustic environments influence noticeability and noise annoyance associated with unmanned aircraft systems?," in *Quiet Drones*, (Manchester, UK), Sep. 2024.

[2] J. du Plessis, A. Bouferrouk, and A. Pontillo, "Numerical study of noise reduction on looped propeller blades with bio-inspired tubercles," in *Quiet Drones*, (Manchester, UK), Sep. 2024.

[3] F. Hilgemann, E. Chatzimoustafa, and P. Jax, "Data-driven uncertainty modeling for robust feedback active noise control in headphones," *J. Audio Eng. Soc*, vol. 72, pp. 873–883, Dec. 2024.

[4] D. Miljković, "Methods for attenuation of unmanned aerial vehicle noise," in *International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*, pp. 0914–0919, 2018.

[5] H. Bi *et al.*, "Spherical sector harmonics based directional drone noise reduction," in *International Workshop on Acoustic Signal Enhancement*, pp. 1–5, 2022.

[6] K. Brentner *et al.*, "Maneuvering rotorcraft noise prediction: A new code for a new problem," in *AHS Aerodynamics, Acoustics and Test Evaluation Specialist Meeting*, 2002.

[7] C. Dreier and M. Vorländer, "Drone auralization model with statistical synthesis of amplitude and frequency modulations," *Acta Acust.*, vol. 8, p. 35, 2024.

[8] S. Kuo and D. Morgan, "Active noise control: A tutorial review," *Proc. IEEE*, vol. 87, no. 6, pp. 943–973, 1999.

[9] S. Müller and P. Massarani, "Transfer-function measurement with sweeps," *J. Audio Eng. Soc.*, vol. 49, no. 6, pp. 443–471, 2001.

[10] ITU-R BS.1116-2, "Methods for the subjective assessment of small impairments in audio systems," recommendation, Geneva, CH, Jun. 2014.

[11] S. Haykin, *Adaptive Filter Theory*. Essex, UK: Pearson Education, 2014.