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A review of road traffic noise camera technologies

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ABSTRACT

Increased urbanisation, population density and vehicle ownership, coupled with the known impacts to human health and wellbeing, necessitates the need for effective management of the associated noise from road traffic. Increasingly, local and state government departments are exploring the use of recently developed noise camera technologies to assist with the process for noise mitigation. Carefully defined trials, both field and lab-based, will be required to evaluate the effectiveness and accuracy of the equipment and the operational resources needed to use the noise camera technology for such regulatory purposes. This paper will review the current state-of-the-art in: noise camera technologies, especially looking into differences between conventional and more contemporary noise measurement devices and associated signal processing approaches; the relevant and associated standard for calibration of the individual (arrays of) devices within the solution, as well as at the system level itself, including in particular determination of the localisation of the source; recent examples of deployment in other regions and contexts including challenges and successes. Ultimately, the intention of this review is to inform the development of a methodology for the lab-based assessment of excessive vehicle noise cameras in this context.

1 BACKGROUND AND INTRODUCTION

Road traffic noise is a significant and complex environmental pollutant that negatively affects human health and well-being. Understanding the interplay of many factors – acoustic in nature and otherwise – is essential for developing effective strategies to mitigate the negative impact of road noise in residential areas (Brown, 2023). Regulations, directives, and guidelines have been established to manage road noise, but they vary across geographic regions, such as Australia, Europe, and North America (Perna et al., 2021). These variations occur in terms of scope (e.g., emission vs. exposure), measurement protocols, acoustic indicators (overall and event-specific), and noise limits (Burgess & Macpherson, 2016; Peeters & Nusselder, 2019; Perna et al., 2021).

Effective management of road noise will differ depending upon whether the primary target is *traffic* or *vehicle* noise. The former is that which relates to a high volume of vehicles being on a normally functioning road with a mix of passenger and heavy vehicles being driven under normal operating conditions. The latter – the focus of this review – relates to individual vehicles within the traffic stream, specifically those that exhibit higher levels or more annoying characteristics for whatever reason than is statistically expected. Volume-related traffic noise is typically regulated with reference to dose/response may be effectively managed through noise control solutions. Excessive vehicle noise, conversely, is typically regulated in respect to the noise level generated as a result of the vehicle's pass-by which is in terms of exceedance vs. the acceptable level as defined by the Australian Design Rule 83/00 (Vehicle Standard 2005, 2021). Typically, these levels are 90 dB(A) for passenger cars and 94 dB(A) for motorcycles.

Sound level meter (SLM) based measurement systems are widely adopted and industrially robust and reliable solutions for the measurement of environmental noise and are applicable in the context of excessive vehicle noise detection. Such roadside microphone measurements have matured into a standard method for measuring traffic noise, yet they still suffer from key bottlenecks: complex acoustic environments, the need for extensive manual post-processing, and heavy reliance on expert interpretation. In such cases, as well as reliably triggering on excessive levels, effective solutions need to be also able to localise the source of the exceedance. Recent advances in acoustic-array technology have introduced the acoustic camera, making level estimation and source localisation and visualisation routine in industrial noise troubleshooting. As these systems grow increasingly automated and AI-enabled, their dual audio-visual capability positions them well for the next frontier—multimodal detection of complex sound sources under complex acoustic environments—an application that is emerging and is especially relevant in the context of excessive vehicle detection. Given the prominence of these two alternative approaches, prototype and commercially available solutions for the detection of excessive vehicle noise in a noise management context have generally implemented one or the other. This paper will, therefore, present a review of the current literature and state-of-the-art in the public domain on the topic of road traffic noise camera technologies from a number of regions around the world. Firstly, however, a brief review of vehicle pass-by noise measurements and standards is necessary and appropriate.

2 VEHICLE PASS-BY NOISE MEASUREMENT METHODS AND STANDARDS

Extensive research has been conducted on vehicle pass-by noise measurement, with comprehensive reviews presented in studies such as (Braun et al., 2013) and (Li, 2018). Standardised methodologies like ISO 362 series (measurement of noise emitted by accelerating road vehicles) and ISO 11819 series (road surface influence) are widely used. These standards dictate how to position equipment and control environmental variables (National Transport Commission, 2006b), typically in a controlled roadside environment (ISO 10844:2021, Acoustics — Specification of test tracks for measuring sound emitted by road vehicles and their tyres). Key standards for the pass-by noise measurement include:

- ISO 362-1:2022, ISO 362-2:2009 and ISO 362-3:2022: Measurement of noise emitted by accelerating road vehicles.
- ISO 11819-1:2023, ISO 11819-2:2017 and ISO/TS 11819-3:2021: Measurement of the influence of road surfaces on traffic noise.
- Vehicle Standard (Australian Design Rule 83/00 – External Noise) 2005; which is based on:
  - ISO 5130:2019: Measurement of sound pressure levels emitted by stationary road vehicles.
- SAE J986/J1470 and SAE J366: North American standards for measurement of exterior sound levels for passenger cars, light trucks, and heavy trucks.
- United Nations Economic Commission for Europe (UN/ECE) Regulations 51.03 and 138: European regulations for exterior noise emissions and noise regulations for quiet road transport vehicles.
- Federal Motor Vehicle Safety Standard (FMVSS) 141: Minimum sound requirements for hybrid and electric vehicles.
- Additional Sound Emission Provisions (ASEP): Measures to ensure production vehicles comply with pass-by noise test results.

The above standards specify the procedure to measure the emitted noise level of road vehicles but are not designed to pinpoint noise sources using noise cameras, especially when multiple vehicles on the road. According to this review of the literature, there is only one recently established standard for noise cameras in vehicle noise measurement, primarily focused on horn detection applications:

- China T_SCJA 2-2019 'Vehicle Honking Detection System'. (Association, S. P. R. T. S., 2019)

Recent research involves developing portable and mobile devices for noise monitoring in everyday environments (Dutta et al., 2023; Maity et al., 2023). However, these devices are not equipped to monitor sudden exposure to loud noises caused by reckless driving behaviour, which significantly contributes to traffic noise affecting local communities (Moudon, 2009) and the ecological environment (Meillère et al., 2024). The instrumentations to measure the vehicle noise must also comply with national or international standards. Key standards for electroacoustic measurements used in the evaluation and verification of acoustic instruments include:

- IEC 61672-1:2013: Specifies requirements for sound level meters (IEC, 2013).
- IEC 60268-4:2018: Specifies methods for measuring microphone performance in sound systems.
- IEC 60942:2017: Specifies requirements for sound calibrators.

3 EXCESSIVE VEHICLE NOISE MEASUREMENT IMPLEMENTATION

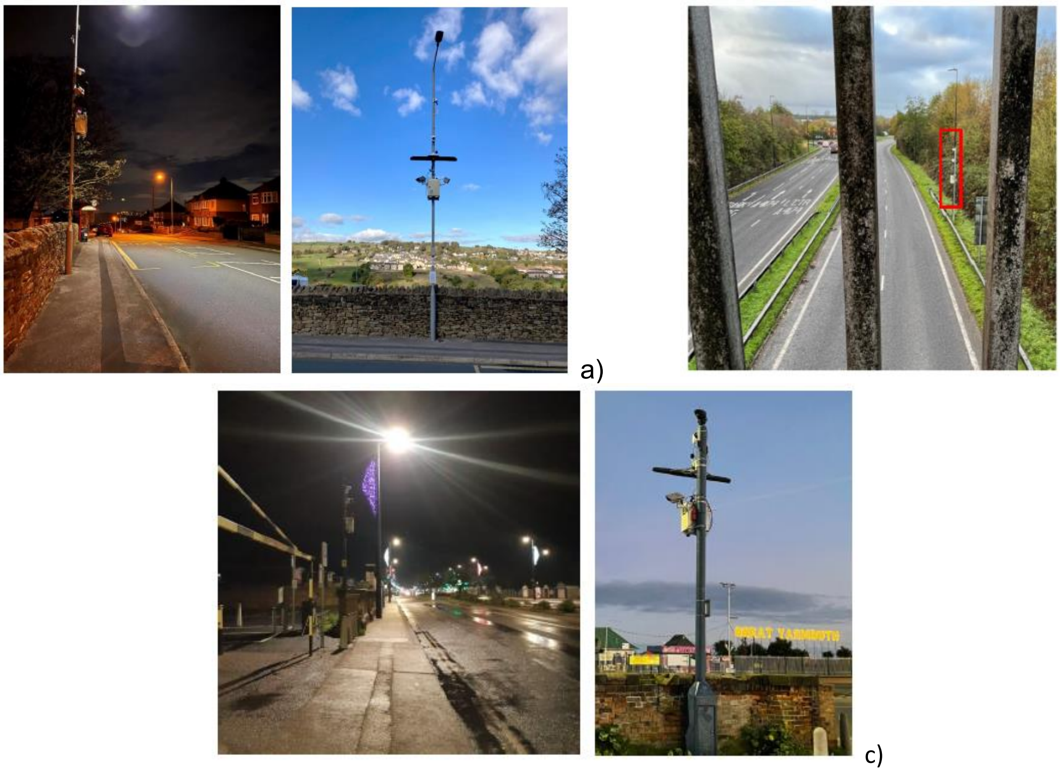
Advancements in audio and image processing technologies and hardware have led to further developments in acoustic cameras for vehicle monitoring and traffic regulation. An acoustic camera integrates a microphone array and a camera to identify and characterise sound sources. The array captures acoustic signals simultaneously, which are then processed using techniques such as beamforming (Cox et al., 1987) and acoustic holography (Maynard et al., 1985) for sound visualization (Kim & Choi, 2013). Acoustic cameras have been used to investigate noise emissions in various industries, such as i) the transportation industry for the monitoring of road vehicle noise, train pass-by noise, aircraft fly-over noise etc., ii) the energy industry for a wind turbine noise measurement (Ginn & Newton, 2011; Yang et al., 2011), and iii) the manufacturing industry for noise measurement of heavy machinery (Fiebig & Dąbrowski, 2020), engines, tyres, gearboxes, exhausts, and so on.

The application of acoustic cameras for traffic noise detection represents a relatively new area of research and application. Initial attempts have been made regarding the efficacy of noise camera technology for the measurement of vehicle noise events. This technological evolution has progressed from basic roadside noise monitoring systems to noise cameras with a single microphone, and more recently, to advanced noise cameras incorporating arrays of microphones.

A clear distinction exists between such “acoustic cameras” and “noise cameras”. Several countries, including The UK, France, Austria, the USA, Canada (Reniak, 2016), Singapore (Agha et al., 2017), the United Arab Emirates and, more recently, Australia, have trialled noise cameras designed to identify vehicles producing excessive noise. These systems typically consist of at least one microphone, Automatic Number Plate Recognition (ANPR), and a video feed, with timestamped outputs forming an evidence package. In contrast, acoustic cameras employ an array of microphones to construct a two-dimensional representation of noise sources, often overlaid onto a video image. This approach may provide a more comprehensive method for identifying and analysing noise sources. Some of these implementations will be reviewed by geographical location in this section.

3.1 United Kingdom

The UK Department for Transport has been conducting trials of noise camera technology to evaluate its effectiveness in automatically detecting excessively noisy vehicles. The project has evolved through several phases, each focusing on different aspects of the technology's development and real-world applicability. The most recent final phase – 3C – involved real-world testing of the noise camera technology, as shown in Figure 1 (Atkins Jacobs Joint Venture, 2023). This phase assessed the cameras’ performance under normal traffic conditions and validated the noise threshold levels proposed in Phase 3A. The goal was to determine the viability of using noise cameras for automated enforcement of noise regulations in everyday traffic scenarios.


a) b) c)

Source (Atkins Jacob Joint Venture, 2023)

Figure 1 – UK Phase 3C: a) “Figure 3-2 Noise camera installed at Fell Lane, Keighley”;
b) “Figure 3-4 Noise camera installed at the A4174 Bristol Ring Road”;
c) “Figure 3-6 Noise camera installed at the Great Yarmouth trial site.”

3.2 Europe

In the UK study (Phase 1), a noise camera system called AKUT (AKUT Tunnel, 2025) developed in Austria, is mentioned as a potential solution. This system uses beamforming technology with an array of microphones to detect noise sources and analyse the spectral profile of vehicle noise. It is primarily designed for use in tunnels – refer to Figure 11 – and on multi-lane roads for incident detection but may be adapted to identify vehicles with illegal exhaust modifications. The technology is noted for its potential use of artificial intelligence (AI) to learn and recognise the noise characteristics of different roads, improving accuracy in identifying excessively noisy vehicles. However, it still requires further development before it can be deployed in trials for roadside noise.

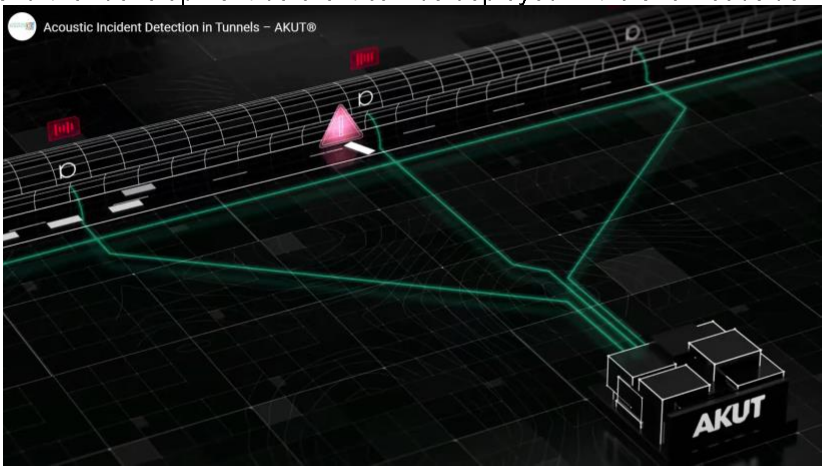


Figure 2 – Illustration of the AKUT system as a distributed microphone network within a tunnel, designed to receive sound signals and perform acoustic signature analysis for incident detection.

A further camera system from Bruitparif named Hydra is mentioned and was trialled in the earlier stages of the UK study. Hydra, under development since 2016, incorporates a two Class 2 microphone array, arranged vertically, two ANPR cameras and a wide-angle camera, in addition to other environmental sensors, all installed in a single, pole-mountable unit. Integrated algorithms appear to extract the details of the vehicle source responsible for the exceedance, i.e. the license plate which identifies the vehicle make and model. An article of Law was voted for in 2019 to enable the experimentation of “noise radars” as an instrument to punish significant noise caused by driver behaviour. An evaluation process including “track trials, roadsite tests and a final phase with fines” (EUR135) was foreseen which would evaluate the Hydra system alongside solutions from two other manufacturers. Deployed in the 20ème department in Paris, as well as in Toulouse, Nice and elsewhere, average exceedances range from 44 at 83 dBA to 7 at 90 dBA. A particular challenge identified include the uncertainty in a single noise source level from a measurement taken in scenarios where multiple sources were simultaneously contributing (Bernfeld et al., 2023).

The dBflash system from microdB – another French manufacturer, renowned for their acoustic camera solutions, was also evaluated earlier in the UK study. dBflash claims to include a Class 1 equivalent SLM and directional array with 5 m detection resolution up to vehicle speeds from 30-130 kph for a 5 m control zone and vehicle classification based on ANPR.

3.3 Australia

Driver behaviour is a major source of excessive noise, such as playing loud music, spinning wheels, excessive acceleration, and misuse of truck engine brakes in urban areas without steep descents. Meanwhile, Victoria's road safety regulations prohibit “unnecessary noise,” enforcement is difficult due to challenges in defining it” (VicRoads, 2015). Some Australian states have conducted extensive early research into heavy vehicle engine brake noise, evaluating various metrics and acoustic signatures to quantify noise levels and their effects (Parnell & Dowdell, 2007). A-weighted measurements and modulation characteristics were identified as key factors in determining both the noise source and perceived annoyance (Austroads, 1993; National Transport Commission, 2006a). Among these, the root mean square (RMS) of the modulation characteristic proved to be the most effective metric for assessing annoyance levels. To validate this approach, a panel test was conducted, rating different engine brake noises using a combination of acoustic and psychoacoustic measures (Parnell & Dowdell, 2007). Additionally, a specialised noise camera system was developed to support monitoring efforts (Klos, 2006).

Building on this research, the South Australian Department for Transport, Energy, and Infrastructure developed an integrated camera system incorporating acoustic measurement software and a modified RMS algorithm (Parnell & Dowdell, 2007). Similarly, the New South Wales Roads and Traffic Authority established a permanent monitoring station at Mount Ousley, integrating number plate recognition with acoustic analysis. However, public resistance – driven by concerns over perceived "revenue collection" and associations with speed cameras – posed significant challenges. These concerns, combined with technological limitations, ultimately led to the indefinite suspension of engine brake noise camera enforcement. Although the Mount Ousley station collected valuable data, it was never used for regulatory purposes.

Over time, industry shifts, including fleet consolidation and the adoption of advanced management systems, contributed to a natural decline in engine brake noise complaints. A key finding from these initiatives was that sound pressure levels alone are insufficient for evaluating noise-related annoyance and should only serve as an initial screening tool. Additionally, ensuring consistent placement of roadside monitoring equipment proved challenging, particularly on multi-lane roads. To improve regulatory effectiveness, minimising false positives and incorporating verification measures were essential. Collaboration among researchers, government agencies, and road authorities resulted in improved noise control strategies, including optimised muffler systems and road infrastructure modifications. These efforts helped shape national and international noise management standards.

3.4 China and Singapore

In densely populated cities, excessive honking significantly contributes to noise pollution, leading to public health issues like stress, hearing loss, and sleep disturbance. To address this, many Chinese cities, especially major metropolitan areas like Beijing, Shanghai, and Shenzhen, have introduced regulations to limit horn usage. This has led to the development of automated horn detection and capture systems, which use acoustic arrays, high-definition cameras, and algorithms to detect illegal horn use, capture vehicle information, and issue fines.

One known currently available product for excessive vehicle noise monitoring, primarily designed for monitoring vehicle horns, from KeyGo Tech is included in the last rows of Table 2 and Table 3. The system precisely identifies honking vehicles by locating the sound's source through microphone arrays and triggers cameras to capture evidence. A group standard, T/SCJA 2-2019 'Motor Vehicle Horn Detection and Capture System', has been developed to outline and assess the key specifications of this device.

Figure 3 – Example of the Motor Vehicle Horn Detection and Capture System in Beijing, China
["Figure 1: Composition of the Horn-Capturing System for Motor Vehicles" in (Niu et al., 2020)]

Vehicle horns typically operate within a frequency range of approximately 1 kHz to 4 kHz. Motor vehicle horns usually have a fundamental frequency of 400–500 Hz with inevitable higher order harmonics present. Studies in the literature, such as (Braun et al., 2013), indicate that low-frequency sounds, such as the fundamental frequencies of exhaust noise, often coexist with mid- and high-frequency vehicle noises. This suggests the potential to adapt existing products for broader applications by focusing on noise components in the middle- and high-frequency ranges for noise source detection (Niu et al., 2020). However, such products may have limitations in some scenarios, e.g. involving modified vehicles with super woofers.

However, this detection system focuses solely on the presence or absence of horn sounds, without taking into account the overall sound levels of vehicle noise. In contrast, the UK and most other studies address broader issues of excessive vehicle noise by developing an appropriate 'blanket-level threshold,' which significantly impacts the setup and evaluation of noise cameras. In essence, this approach encompasses both the measurement of sound pressure levels and the detection of the sound source but at the roadside.

Rather than directly identifying the location of a noise source from the roadside, research has also explored detecting the specific lanes where the noise originates from overhead. Researchers in Singapore conducted preliminary setups and trials to develop an automatic noisy vehicle surveillance camera system called NoivelCam (Agha et al., 2017). This system identifies the lanes of noisy vehicles by analysing the measured Time Difference of Arrival (TDOA) of sound signals. However, its implementation required an overhead-mounted system rather than a roadside setup to ensure sufficient TDOA for accurate lane identification. In contrast, researchers in China conducted trials with a roadside setup, using a microphone array consisting of up to 48 microphones for lane detection (Na et al., 2015).

3.5 United States

The SLEEP Act (Stop Loud and Excessive Exhaust Pollution), signed by New York State Governor Kathy Hochul on October 29, 2021, addresses vehicle noise pollution in New York City by deploying noise cameras that detect vehicles emitting sounds typically over 85 decibels from 50 feet or more away. These cameras use sound meters paired with automatic number plate recognition (ANPR) to identify offending vehicles. Fines from US$150 to $1000 are reported to be applicable for exceedances from 76 to 90 dBA, depending upon speed and vehicle type (Maldonado, 2022). Furthermore, it is stated that in the City's Noise Code (New York City Environmental Protection, 2018), vehicles less/over than 10,000 lbs. in mass are not to make noise that can be heard from 150/200 ft. Otherwise, however, it is quite vague stating that "The Noise Code prohibits excessive sound from the muffler or exhaust of motor vehicles operating on a public right-of-way where the speed limit is 35 mph or less.". It is reported that the Police issued 14 or 26 summonses from 2018 to 2022 for excessive vehicle noise with exceedances of over 85 dB from 50 ft. Fines of US$220 were reported for a first offence, increasing to US$800 from spring 2022. A senate bill was tabled in 2021 to "establish a noise camera demonstration program for motor vehicles in the City of New York.".

SoundVue was deployed in Sacramento, CA among five other cities across the state from January 2023 to December 2027 (White, 2022). Exceedances are defined as being < 95 dB for cars and >80 dB for motorcycles built since 1985. Here, it is reported that first-time offenders will not be fined, only repeat offenders. It is noted that not only modified vehicles but those direct from the factory if driven in a certain manner will easily exceeds the threshold levels. Comments also note that measurements made according to SAE J1492 at 0.5 m are considerably different to measurements made from pole-based systems at several m distance from the source.

4 CONCLUSIONS

The studies reviewed in this paper examine various noise camera systems, from single microphones to small arrays, dense arrays, and distributed systems. Each differs in availability, practical readiness, and the extent of research or trials conducted. The existing studies provide valuable references and cover practical considerations, such as real-world scenarios, enforcement challenges, and stakeholder perspectives, offering a broad understanding of noise camera systems for roadside vehicle noise measurement.

However, it is observed that gaps remain between real-world studies and academic research, particularly in:

- Laboratory testing for controlled analysis and validation,
- Performance evaluation in both controlled and simulated real-world environments,
- Robustness testing under numerous simulated cases,
- Benchmarking performance, using single measurement microphones as a lower limit and advanced acoustic cameras as an upper limit, ensuring measurement standards and limitations are clearly determined,
- Comparative analysis of candidate solution(s) against these benchmarks from technical aspects to assist the determination of the effective and suitable candidate(s).

- Information on advanced techniques in microphone arrays, electro-acoustics, and signal processing within the research domain can enhance the development of existing products, improving their effectiveness for this specific practical application. Key objectives include:
  - Identifying and localizing noise sources,
  - Accurately measuring sound levels of identified sources,
  - Investigating suitability for multi-lane and complex ambient scenarios, and
  - Exploring simplified microphone array systems that offers comparable and acceptable performance.

Advanced technologies like RADAR or LIDAR can detect the presence and speed of vehicles, and these data can be synchronised with sound measurement equipment to more accurately correlate noise levels with specific vehicles. However, as mentioned in the UK Study (Atkins Jacobs Joint Venture, 2023), such technologies are not so commonly used within the acoustics domain. It is recommended that future trials of noise camera systems should include filed-based and laboratory-based trials for the rigorous performance assessment of the technology.

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