

A Noisy Vehicle Surveillance Camera (NoivelCam) System

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ABSTRACT

Traffic noise is one of the main contributors to noise pollution near urban settlements. To keep a check on the vehicle noise emissions in Singapore, a pilot project has been carried out to identify offending vehicles that exceed the stipulated noise limit set by the environmental agency in Singapore. In particular, noise due to tail pipe emission and engine are the main concerns. The current law enforcement practice includes holding roadblocks, and measuring noise of stationary vehicle at different revolution per minute. However, this approach is highly manpower-intensive, costly and does not determine the actual driving pattern of drivers on highway. To provide an efficient and automated alternative to noisy vehicle monitoring, a standalone integrated vehicle noise tracking system, known as the "NoivelCam," is designed and built for a single lane monitoring in expressways. This system will be scaled up to multiple-lane monitoring in the next stage of the project. In this paper, we present the design and technical functioning blocks of the NoivelCam system and how it is currently being deployed in overhead bridge spanning highways to estimate the tail pipe level noise generated from individual vehicle passing through the overhead bridge. Vehicles that exceed the stipulated noise level threshold will be tracked and captured through the cameras. The collected evidences, which include audio and video clips of the captured footage, snapshots of the vehicle number plate, and data log files of sound pressure level with time stamp, serve as a mean to identify offending vehicles in an in-situ operation. In addition, we will also highlight some situations of false alarm or error detection, and how multimodal information can assist in filtering out these false detections.

Keywords: Road traffic noise, Noisy vehicle, Noise monitoring. I-INCE Classification of Subjects Number: 52.3

1. INTRODUCTION

With the rapid extensive industrialization and urbanization in the past few decades in major cities, especially in Asia, pollution to our environment is a great concern to our human health. Noise pollution has emerged as one of most cited pollution issues in the recent years. According to the world health organization (WHO) [1], "Noise is an underestimated threat that can cause a lot of short and long term health problems, such as sleep disturbance, cardiovascular effects, poorer work and school performance, hearing impairments, etc.". In particular, traffic noise is one of the main contributors to urban noise problem. Excessively loud vehicles plying at wee hours cause annoyance and poor quality of sleep to residents staying near highways or major traffic junctions. Every country has vehicle noise emission laws, which set the threshold for tail pipe emission noise for each category of vehicle based on ISO 362 vehicle pass-by noise test [2,3]. A vehicle with tail pipe emission noise exceeding the stipulated level is considered to violate the law and is liable for penalty.

The main reasons for excess noise in vehicles can be attributed to either vehicles' wear and tear or illegal exhaust pipe installation. The current law enforcement practice includes conducting roadblocks and manual checking of vehicle tail pipe noise level, which is costly due to additional manpower (noise engineers, traffic and auxiliary police), and may not effectively serve the purpose of enforcing considerate driving. Moreover, in this practice, the tail pipe noise is measured manually in a static

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condition with gradual increase in rpm, which is different from the actual noise level when vehicle is travelling at high speed and under hard acceleration. Growing complaints from urban dwellers have raised concerns to search for effective and efficient solutions to track noisy vehicles on road.

Study on works related to automated techniques for identification of noisy vehicles on road can be found as early as 1970. In [4], the design of a semi-automatic analog system deployed on road side for monitoring highway noise levels and tracking noisy vehicles with integrated camera was demonstrated. The system used a sensing microphone with analog amplification circuitry to compute A-weighted sound pressure level and record the value in chart recorder. With the help of an additional two microphones delay line positioned perpendicular to the road, the cross correlation of signals received at two ends of an acoustic delay line was computed to pinpoint the passage of vehicle past the optimum point for photography. The chart recorder image was also displayed alongside the captured vehicle image using split-image technique. However, the system usability was limited to monitoring only the nearest lane, delay in response due to analog circuitry and vulnerability to weather. Moreover, the system performance in dense traffic was not mentioned in the paper.

In [5], a passive acoustic dual microphone array that can utilize radiated acoustic energy to detect, localize, track and classify a sound source was proposed. The system arrangement included road side placement of 2 microphones at a certain distance from the center of the traffic lane. The system computed time delay between signals received at two microphones. A subset of time delays was then summed and moving average tracked. A significant magnitude change in time delay indicated the passage of a vehicle. The authors in [5] presented ways of estimating traffic parameters like traffic density, speed of vehicle and long hour noise level.

In 2009, Houzu et al. [6] proposed a noise source localization method to detect noisy vehicles in a traffic stream. A hybrid method combining both beamforming and sound intensity mapping techniques was employed to sense and localize noisy source from a remote location. Their setup consisted of an array of 31 microphones arranged in patterns based on equilateral triangles and regular tetrahedrons, and hung in an overhead position above the traffic lane. Real-time implementation was carried out using FPGA, with a capability of handling a data block size of 40 milliseconds. In the actual field test, microphone array was hung 4 m above the traffic lane in the test track. Vehicles passing under the microphone array were localized with good accuracy under real road conditions. However, system performance in actual expressway conditions with multiple lanes, where interference from traffic in the neighboring lane can be significant, was not reported in [6].

In 2011, Houzu et al. [7] presented an extension of his work in the form of an integrated system, which continuously monitored noise levels of vehicles in search of high noise emissions and alerted the drivers of such vehicles via an electronic display on the roadside. The system also housed an onboard camera to gather image of the vehicle for processing on vehicle type and identification. It was tested in road side deployment setup on a test track followed by a public road test with two adjoining lanes under monitoring. Good localization accuracy was reported for cases when either of the lanes had a passing vehicle with speed within 50kmph. However, system performance with vehicles simultaneously parallel in both lanes and at high speed was not mentioned.

Jeffrey et. al [8] proposed an effective method for estimating vehicle speed based on wayside sound pressure onset rate using a single microphone mounted at road side. Shi et al. in [9] demonstrated an integrated vehicle type classifier using audio features. Audio based traffic density estimation proposed in [10] showed how audio based features could effectively be used to estimate traffic density in the monitored area. These preceding works indicate a need to continuously monitor the traffic noise and perform real-time data analytic to extract critical information on the offending vehicle.

In this work, we designed and built a high performance, standalone and automated traffic noise surveillance system for single lane monitoring in an overhead deployment setup. The system remotely estimates sound pressure level of each passing vehicle in the monitored lane, and has a high speed camera and a wide view video camera onboard to capture vehicle number plate and surrounding video evidence, respectively. The system is also capable of identifying and filtering false alarm triggering cases due to loud interferences from neighboring lanes. The system is calibrated in an outdoor test scenario with speakers emulating vehicle noise and further tested in a real traffic site with system deployed on an overhead bridge located on expressway.



Figure 1: System block diagram



Figure 2: System setup at overhead bridge

The paper is organized as follows. Section 2 describes system design and setup. System calibration experiment in an outdoor test scenario with results is explained in Section 3. Section 4 presents the system performance in a real traffic scenario. Finally, Section 5 concludes the paper with a discussion on the current merits and extension of the system for a multi-lane setup.



Figure 3: GUI front panel displaying the peak SPL reading, date & time stamp, number plate picture and video footage for latest captured case. SPL at Mic Array and extrapolated SPL at 0.5 meters from tail pipe level are also displayed in real time along with the set threshold SPL value.

2. DESIGN OF THE SYSTEM

Due to strict application needs, the main challenge in the NoivelCam system design is to choose the acoustic transducer array such that vehicle noise is picked up only from a narrow zone. A microphone array with phased array techniques would have offered a satisfactory solution with sharper polar pattern but with increased cost due to the number of microphones and high speed processing unit to achieve real-time processing in fast moving traffic. Instead, a pair of directional microphones was used to satisfy the zonal capture of fast moving noise sources, and using a two-stage (real-time and off-line) processing to track and analyze the noise signature of passing vehicle that exceeds the stipulated noise threshold. The first version of the NoivelCam was implemented using a fast prototyping (high speed data acquisition and processing) platform from National Instruments (NI) to achieve fast development and validation. Subsequently, in the next phase of this project, this platform will serve as a golden-reference platform for evaluating a lower-cost version that can be massively and more easily deployed in different overhead structures in the island. The system hardware design and algorithm implementation are described in following subsections.

2.1 Hardware Description & Setup

The system interconnection diagram and setup are depicted in Figure 1 and Figure 2, respectively. It consists of an array of two highly directional shotgun microphones (Audio Technica BP4071L) spaced 51 cm apart and attached to the end of a foldable structure for measuring noise directly below the overhead structure. An effective measurement zone of 3.5m in diameter (equivalent to the width of a single lane) is formed directly below the directional microphones. The foldable structure welded to a rugged aluminum casing houses a Gigabit Ethernet (GigE) enabled high-speed camera for capturing number plate and a wide-angled view camera for continuous video/sound recording of the surroundings, as shown in Figure 2. The high-speed camera is focused at a forward distance, which is a few meters away from the measurement zone in the monitored lane, while the wide-view camera is capturing continuous video/sound of the measurement zone and its surroundings. High speed data acquisition is facilitated by using a multi-channel DAQ module (NI 9234), which is interfaced to a high performance embedded controller (NI CRIO 9082). As shown in the lower right corner of Figure 2, the controller sits snugly inside the top compartment of the aluminum casing behind the screen and



Figure 4: Calibration experiment setup at premises of Nanyang Technological University, Singapore.

handles all real-time and off-line processing and triggering cameras in the system. The pre-amplifiers and power circuitry components are housed in the lower compartment of the casing. All externally exposed parts of the system have been waterproofed to withstand varied weather conditions.

2.2 Software Implementation

The algorithms have been implemented using NI LabVIEW graphical programming interface to develop a simple and user-friendly GUI, as shown in Figure 3. The system programming framework is divided into two stages that are described below:

- 1) First stage program continuously running in real-time for the entire duration of intended noise monitoring. Noise signals are acquired at a high sampling rate (Fs= 51.2 kHz) and processed in blocks of size 100 milliseconds each. Incoming data block is low-pass filtered and processed to compute an A-weighted exponentially averaged sound pressure level (SPL) in fast mode $(\tau = 125 \text{ msec})$. The computed SPL value at the directional microphones is further extrapolated to 0.5 meters from vehicle tail pipe level based on sound propagation model in air. The extrapolated SPL is compared with the threshold SPL (specified at 0.5 meters from tail pipe) for each data block. A threshold crossing event is asserted if extrapolated SPL exceeds the threshold SPL for 3 consecutive data blocks. Subsequently, a trigger signal is sent to the high-speed camera to start the process of capturing the vehicle number plate in burst mode and save them on the storage drive. Besides, the system also continuously records the received signals at each microphone in raw data format, and computes the SPL value at each microphone, their differential amplitude and saves these values with timestamp in a log file. In addition, continuous video acquired from wide view camera is compressed, overlaid with date and time stamp and saved on the storage drive. This stored data is utilized later in the second stage program.
- 2) Second stage program is run in an off-line manner (during the non-monitoring mode of the NoivelCam), where triggered data are further analyzed and verified to ascertain the offending vehicle with valid proof. The main purpose of this program is to evaluate all the captured cases and identify the false alarms due to loud interference from neighboring lanes. Time difference of arrival (TDOA) and differential SPL based decision algorithms are employed to identify and filter out the cases of false alarm. At the end of this stage, an evaluation report is generated for each captured case with its sound, video and number plate evidence along with logged SPL values with

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Table 1: Showing results for first objective of the calibration experiment.

SPL meter reading

(dBA)

81.16

Extrapolated SPL

(dBA)

80.36

Figure 5: SPL at microphone array vs source positions for shotgun and omnidirectional array.

date and time stamp for government agency to issue an inspection notice to the vehicle owner. In addition, further data analytics can also be performed on the stored data for generation of long hour SPL patterns, traffic density for specified duration, and vehicle speed, etc.

3. OUTDOOR CALIBRATION EXPERIMENT

Trial number

Trial 1

In order to calibrate the system, an outdoor experiment was performed in a test scenario using speakers to emulate the vehicle noise. The main objectives of this experiment are defined as follows:

- 1. To measure the accuracy of system computed extrapolated SPL value at 0.5 meters from speaker's emitter (emulating the vehicle tail pipe) by comparing with Class A type SPL meter reading.
- 2. To demonstrate signal suppression capability of highly directional Shotgun microphone array as source moves away from the measurement zone.
- 3. To measure threshold values of delta SPL and TDOA for identifying false alarm cases.

The experiment setup, analysis and results are described in the following subsections.

3.1 Experiment Setup

The system was deployed on an overhead location in the premises of Nanyang Technological University, Singapore, as shown in Figure 4. It was positioned such that the two shotgun microphones were symmetrically placed directly above the center of monitored lane. The height of microphones from the ground is 4.15 meters and width of each lane is 3.5 meters. One omnidirectional microphone was also temporarily attached near each shotgun microphone. Loud speaker placed on the ground, with emitter facing towards the sky and playing a white noise signal, was used to emulate the vehicle tail pipe noise. Two trials were taken for each position of the speaker starting from center of the monitored

Distance from	Absolute	Absolute value of	
center of	value of	Delta SPL (dB)	
monitored lane	TDOA		
(meters)	(milliseconds)		
0.00	0.0000	0.3000	
0.50	0.1953	1.1396	
1.00	0.3906	3.1163	
1.50	0.5664	3.6252	
1.75	0.6250	3.9524	

Table 2: TDOA and delta SPL values for five source positions within the monitored lane.

lane, moving along the line just below the microphones and perpendicular to lanes, till the end of neighboring lane in steps of 0.5 meters. In each trial, a white noise signal with constant amplitude was played from the speaker and recorded at all the 4 microphones (2 shotgun and 2 omnidirectional microphones).

3.2 Analysis and Results

For the first objective, Class A type SPL meter was fixed at 0.5 meters above the speaker's emitter with the help of a tripod stand. Extrapolated SPL values at shotgun microphone array was computed and logged, while SPL meter reading was manually noted. Two trials were taken with speaker placed at the center of the monitored lane and playing a white noise signal of constant amplitude. The result in Table 1 highlights that the system estimation of the extrapolated SPL value is accurate within ± 0.8 dB.

In the second objective, high signal suppression capability of shotgun microphones is shown using the SPL values computed at the microphone array and comparing with that of omnidirectional microphone array. A shotgun microphone due to its hollow interference tube structure normally picks up signal without attenuation for source position along its axis and offers high attenuation for sources from other directions. To demonstrate this phenomenon, we recorded SPL at both microphone arrays by playing a white noise signal at each speaker positions starting from center of the monitored lane till the end of neighboring lane in steps of 0.5 meters. The computed SPL values at each array for various speaker positions are shown in Figure 5. Also, it is observed that the computed SPL values are same for both the arrays when source is at the center of the monitored lane. However, as source moves away from the center of monitored lane, significant signal attenuation is found for shotgun microphone array as compared to omnidirectional microphone array. As shown in Figure, at least 10 dB suppression is observed for sources outside the monitoring lane. This directional behavior of shotgun microphone helps in suppressing the interferences due to loud vehicles in neighboring lane in a real traffic scenario at expressways. However, it is noted that directional microphone alone is not sufficient in eliminating false trigger and differential signal processing approaches are implemented in our system.

In the third objective, delta SPL and TDOA values for shotgun microphone array is computed for five source positions starting from the centre till the border of the monitored lane. TDOA value corresponding to each source position is computed using cross correlation of the two audio signals. Similarly, delta SPL value corresponding to each source position is computed by taking difference of SPL readings recorded at individual microphones. The values for delta SPL and TDOA corresponding to various speaker positions are shown in Table 2. From the table, it is observed that the values of TDOA and delta SPL increase as source moves away from the center. It has also been observed that the values of TDOA and delta SPL further increase as the source moves farther in the neighboring lanes. Therefore, the threshold values for TDOA and delta SPL in this experimental setup have been found to be 0.625 milliseconds and 3.95 dB, respectively.

In actual traffic scenario, where one of the lanes in a multi-lane expressway is under surveillance, peak of the SPL contour for any vehicle occurs at the closest point of approach to the microphones. This is valid assuming that the SPL at receiver is above the environment SPL. In such a scenario, the closest point of approach to microphones will always be on the line just below the microphones and perpendicular to lanes. Hence, the threshold found from above calibration test set up can be used in the actual traffic scenario.

To detect and filter out false alarm cases in the second stage program, the system scrutinizes each of the registered threshold crossing events. The date and time stamp corresponding to each threshold crossing event is logged in a file during surveillance operation. For a particular threshold crossing



Figure 6: Images (a) to (d) have been extracted from wide view footage depicting various traffic scenarios.

event, the recorded noise file at each microphone is extracted at ± 0.5 seconds from the instant at which SPL peak was detected. The computed TDOA and delta SPL values for extracted part of data are compared to the threshold values. If both the computed values exceed their respective thresholds, it indicates the presence of a strong interference from the neighboring lanes and the case is marked as a false alarm and excluded from the final report. However, if only one of the computed values exceeds their respective thresholds, it indicates a possibility of a false alarm but not with high confidence. Such cases are dealt manually and require audio-visual inspection of the wide view footage to reach a conclusion.

4. ONSITE TESTING

To test the performance of system in a real traffic site, we deployed our NoivelCam system on an overhead bridge spanning one of the busy expressways in Singapore. Threshold SPL values equal to 95 dBA and 80 dBA were set for day and night time monitoring, respectively. Several data collection and testing sessions were performed at different times of the day, collecting a total of 300 gigabytes of data for over 4 hours of monitoring. The captured cases were later processed by running the second stage program to identify the false alarms. In-situ testing results for four different cases have been selected and presented below.

1) Loud motorbike in the monitored lane, no vehicle in the neighbouring lane:

A loud motorbike travelling at high speed was tracked with 112 dBA peak SPL, as shown in Figure 6(a). Bike number plate image, wide view footage, noise clip and logged SPL values were recorded and compiled in the form of a report.

2) Truck in the neighbouring lane, no vehicle in the monitored lane:

The SPL peak was registered at 97 dBA. However, in the second stage program, it was detected as a False alarm with high confidence. To further validate on the accuracy of detection, the presence of interference from neighbouring lane was also verified manually by inspecting the wide view footage as shown in Figure 6(b).

3) A passenger car in the monitored lane and loud truck in the neighbouring lane travelling parallel to each other:

In this case, the SPL peak was recorded at 96.8 dBA. However, it was detected as a false alarm with high confidence. Although the system claims a false alarm with high confidence (which has been tested in the outdoor calibration experiment) but we cannot truly validate this until we know the actual SPL values of car and truck in the scene shown in Figure 6(c).

4) A loud bike travelling on the edge of the monitored lane:

In this case, the system tracked the bike with 97.6 dBA peak SPL. However, in the second stage program, the system marked this case with a possibility of false alarm with less confidence. These types of cases as shown in Figure 6(d) are normally dropped to avoid any state of confusion.

5. CONCLUSION & FUTURE WORK

In this paper, we described the design and functioning of an overhead mounted automated noise monitoring system for single lane monitoring in expressways. It was shown how an array of two highly directional shotgun microphones can be effectively used to enable zonal signal pick as compared to conventional techniques of using large arrays with beamforming techniques, which are computationally intensive and increase overall system cost. System calibration tests were performed in an outdoor setup, followed by several sessions of onsite testing in real traffic scenario covering different times of day and traffic conditions. The collected data was processed in an offline manner to analyze and verify the triggered data and ascertain offending vehicles with valid proof. Post-processing results for several real traffic scenarios were described to show how TDOA and differential SPL based algorithms can help filter out the false alarms with confidence. The system is currently under rigorous testing and data collection phase. It will be further scaled to a modular multi-lane setup in the next stage of the project with additional features like 3G connectivity to continuously stream recorded data onto a server, data analytic tools to generate useful information like vehicle speed, traffic density and sound level pattern over long hours.

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REFERENCES

- 1. http://www.euro.who.int/en/health-topics/environment-and-health/noise/data-and-statistics
- 2. Braun, M. E., et al. "Noise source characteristics in the ISO 362 vehicle pass-by noise test: Literature review." *Applied Acoustics* 74.11 (2013): 1241-1265.
- 3. T. J. Copeland, "Noise measurement system meets new ISO standards in Pass By Noise with unique global positioning and triggering capabilities", in *Proc. InterNoise 2009*, Ottawa, Canada, 2009.
- 4. Allen, Richard G., Thomas P. Owen, and Emil L. Torick. "An Automatic Highway Noise Monitor." *Audio Engineering Society Convention 39*. Audio Engineering Society, 1970.
- 5. Duffner, Orla, et al. "Road traffic monitoring using a two-microphone array." *Audio Engineering Society Convention 118*. Audio Engineering Society, 2005.
- 6. H. Houzu, T. Tanaka, I. Sakamoto, T. Murakami, M. Ishihama, and K. Sawatari, "Hybrid source localization method to detect noisy vehicles traveling on the road. in *Proc. InterNoise 2009*, Ottawa, Canada, 2009.
- 7. H. Houzu, I. Sakamoto, T. Tanaka, T. Murakami, M. Ishihama, and K. Sawatari, "Development of sound source localization system to detect noisy vehicles from traffic flow", in *Proc. InterNoise 2011*, Osaka, Japan, 2011.
- 8. Zapfe, Jeffrey A., Eric W. Wood, and Marc S. Newmark. "Estimation of vehicle speed using wayside sound pressure onset rate." *The Journal of the Acoustical Society of America* 126.6 (2009): 2991-2997.
- 9. Shi C., Woon-Seng G., Yong-Kim C., Agha A, and Kin-San S "A vehicular noise surveillance system integrated with vehicle type classification." In *Signal and Information Processing Association Annual Summit and Conference (APSIPA), 2013 Asia-Pacific*, pp. 1-5. IEEE, 2013.
- 10. Nagy, György, Rene Rodigast, and Danilo Hollosi. "Energy Based Traffic Density Estimation Using Embedded Audio Processing Unit." *Audio Engineering Society Convention 136*. Audio Engineering Society, 2014.