



An acoustic data collection for speech enabled technologies in moving vehicles

DATASET DOCUMENTATION

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CAVEMOVE

1 Introduction

CAVEMOVE is a research project dedicated to the collection of audio data for the study of voice enabled technologies inside moving vehicles. The recording process involves (i) recordings of acoustic impulse responses, which are acquired at static conditions and provide the means for modeling the speech and car-audio components and (ii) recordings of acoustic noise at a wide range of both static and in-motion conditions. Data are recorded with two different microphone configurations and particularly (i) a compact circular microphone array or (ii) a distributed microphone setup.

This document provides a description of the audio recordings and acoustic impulse responses that comprise the open access dataset of CAVEMOVE. The open access dataset is available at 16 kHz sampling rate and 24 bits bit depth and is approximately 4.5 GB in size. The latest version can be downloaded from [zenodo](#).

Note that the open access dataset is only a subset of the full CAVEMOVE dataset.

It is recommended to use this dataset along with the corresponding python API that can be downloaded from [CAVEMOVE github](#). It is important to note that the CAVEMOVE API relies on specific naming conventions for obtaining the audio mixtures corresponding to specific scenarios, and this document lists all the naming conventions required for correct use of the API.

For any questions with respect to CAVEMOVE dataset or API, feel free to send an email to

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2 Data Acquisition Process

2.1 Microphone setups

All recordings are acquired using the M-audio M-Track Eight usb audio interface, at 48kHz sampling rate and at 24-bit sample size. Eight omnidirectional microphones (Shure SM93) placed at different locations are used for recording acoustic noise and IRs. These are lightweight lavalier microphones with a flat frequency response from 80 to 20000 Hz. Two different microphone configurations have been used until now, as described below.

1. Distributed setup: While there are slight variations in the setup between different cars, the microphones are distributed in a way so that six of the microphones are at the front part of the car, while the other two are placed on the headliner at the back of the car (see Figures 1, 6 and 10). This setup ensures that there is at least one microphone close to each passenger. All microphones were stabilized with blue tack and were covered with a windshield.
2. Microphone array: the eight microphones are mounted on a plastic circular case, forming a circular microphone array of radius equal to 5 cm. The circular array is placed on top of the dashboard, between the driver and the front passenger (see Figures 3 and 7). Microphones were mounted on the array without a windshield.

2.2 Measurement of IRs

Acoustic Impulse Responses (IRs) are measured for different passenger locations in each car. Basic locations covered include that of the driver, the front passenger, the rear-left, rear-middle and rear-right passenger, assuming that the passengers are at normal height and that they are facing in-front. In several cases, IRs are also measured for slight displacements, e.g. by assuming that the passenger's head is shifted a few centimeters from the nominal location, or assuming that the head is rotated. All IRs are captured using Room Eq Wizard with a sweep tone as the excitation signal. The loudspeaker used for these measurements is the Talkbox from NTi which is especially designed for resembling the frequency response and radiation characteristics of the human voice. The loudspeaker is calibrated and it has built-in excitation signals which allow us to excite the car interior with acoustic powers that correspond to specific speech effort, particularly normal speech effort (referenced as 60 dBA at 1 m) and high speech effort (referenced as 70 dBA at 1 m). This process is very important as it will allow us to calculate the signal levels that correspond to specific speech efforts, consequently allowing us to scale the speech components so that when mixed with the noise components, a realistic balance is achieved. Additionally to the acoustic paths from the passengers to the microphones, IRs are also measured for the built-in audio system, whenever available. This process involves recording the response from all car loudspeakers simultaneously.

It was accomplished by directly feeding the excitation signal required for IR estimation into the auxiliary input of the audio system, or by reproducing it through the CD player. Attention was paid so that any adjustments related to equalization settings or panning were neutralized.

2.3 Recorded conditions

As basic factors that affect the composition of noise in a car we considered the following: car speed, window aperture and ventilation/air condition level. With respect to these factors, it has been attempted to have them at fixed values for continuous temporal segments so as to achieve stationary noise conditions. A basic set of so-called “controlled” conditions is recorded in each car, spanning a specific range of driving speeds and window apertures. Particularly regarding window aperture, we consider four states designated as 0, 1, 2 and 3. Regarding the driving speeds, in each car we cover at least the range from 50 km/h to 110 km/h with steps of 10 km/h. All combinations of window apertures and driving speeds are covered in each case, excluding those that it was not possible. Additionally to these in-motion recordings, static recordings were obtained for capturing the noise produced by the built-in ventilation or air-conditioning system. Two or three different levels of ventilation power were considered in each car and microphone setup.

3 Synthesis Model

The ultimate goal of the data and python API delivered in the context of CAVE-MOVE is to allow the engineers and researchers to easily synthesize the microphone signals that correspond to a particular scenario. Assuming that a target car and microphone setup has been chosen, the synthesis process can be compactly described as:

$$Y = \mathbf{S}(p, L_s, w, \mathbf{x}) + \mathbf{A}(L_a, w, \mathbf{z}) + \mathbf{N}(s, w) + \mathbf{V}(l, w) \quad (1)$$

Briefly, each bold capital symbol is a $N \times M$ signal matrix, where M is the desired number of microphone channels and N is the duration of the synthesized sound excerpt in samples. \mathbf{S} represents the filtered speech components, \mathbf{A} represents the interference components produced by the built-in audio system (when available), \mathbf{N} are the noise components corresponding to the particular driving condition and \mathbf{V} are the noise components associated to the ventilation/air-condition functionality. Assuming that all these sound components are independent from one another, the final microphone signal can be synthesized as in Eq. 1, by means of simple superposition. As it can be seen, each component is produced as a function of user defined parameters. A brief explanation of these parameters is as follows;

- w : is an integer taking values in the range [0, 1, 2, 3], with each integer value representing a different condition with respect to the windows’

apertures, as described in more detail below.

- \mathbf{x} : is a one-dimensional vector with the dry (ideally anechoic) speech recording that is used for the particular scenario. The user is responsible for providing an appropriate speech recording in PCM format. The audio recording can be of any length and sampling rate (it will be automatically converted to the target sampling rate).
- p : it can be selected from a given set of string values, each value corresponding to a particular location of the passenger inside the car cabin. For each combination of p and w the corresponding impulse response is automatically loaded and used to produce the filtered speech components by means of convolution with \mathbf{x} .
- L_s : it is a user defined value, in dBA, corresponding to the speech effort. While this can be any non-negative value, we recommend values in the range between 60 and 70, with 60 corresponding to normal speech effort and 70 to a high speech effort.
- L_a : is a user defined value, in dBA, corresponding to the mean A-weighted acoustic level of the audio program reproduced from the built-in audio system. The corresponding interference components are automatically scaled through this value so that the signal level at a reference microphone matches the desired sound level. Again, any non-negative value is applicable and it is up to the user to set it to a realistic value.
- \mathbf{z} : is a one-dimensional vector representing the audio program. The user is responsible for providing an appropriate audio file in PCM format. The audio file can be of any length and sampling rate. Audio files with more than one channel are accepted but will be automatically downmixed to a monophonic audio signal.
- s : is an integer value within a given range, where each value corresponds to a different speed in km/h. The noise components corresponding to particular speed, window aperture, car and microphone setup are automatically loaded.
- l : it is an integer with values in the range [1, 2, 3], each value corresponding to a different level of the ventilation/air-conditioning system, so that higher levels produce more noise. The synthesis approach is designed in such way that the resulting length N of the output signal \mathbf{Y} , as well as of all matrices in Eq.1 matches the length of the dry speech signal \mathbf{x} when converted to the target sampling rate. To achieve this, we have incorporated a mechanism that recycles the noise sequences inherent to the construction of \mathbf{A} , \mathbf{N} and \mathbf{V} as many times necessary in order to match the length of \mathbf{x} . Note that in most cases this will not be necessary if the dry speech signal does not exceed 25 seconds of duration.

4 Additional parameters and functions

An additional parameter that affects the returned microphone signals is the use of correction gains (or not), which will apply a scaling to the produced signals so as to compensate for slight deviations in the input channel sensitivities. The sensitivity values were measured with each microphone connected to a specific input channel in the sound card, subjecting it to a pink noise sound field produced inside a semi-anechoic chamber that we have in our facilities. Although the differences between minimum and maximum sensitivity do not exceed 3.5 dB, we recommend use of correction gains, which is also the default option in all relevant function calls.

Our API provides functions that are specific to each one of the aforementioned components (i.e. speech, noise, ventilation and built-in audio system) but there is also a function with which the user can synthesize all four different components with a single function call. Additional auxiliary functions are provided for example:

- to automatically crop or extend the duration of different components, so that they can be all added together to produce a mix,
- to derive the IRs associated to a particular passenger location and microphone setup,
- to derive the steering vector associated to a particular frequency and look direction with respect to the center of the circular array, which is handy for designing beamformers in the frequency domain.

5 Naming Conventions

5.1 Speaker Locations

Acoustic Impulse Responses are provided for at least the following locations inside the car:

- **d**: driver
- **pf**: front passenger
- **prl**: rear-left passenger
- **prr**: rear-right passenger
- **prm**: rear-middle passenger

5.2 Windows Condition

Regarding window aperture, we consider four states designated as 0, 1, 2 and 3:

- **w0**: corresponds to completely closed windows.

- **w1**: corresponds to windows of the driver and front passenger being slightly open (approx.10 cm).
- **w2**: corresponds to completely open front windows.
- **w3**: corresponds to all four windows being completely open.

5.3 Speed Condition

Regarding the driving speeds, in each car we cover at least the range from 50 km/h to 110 km/h with steps of 10 km/h. Speed condition is symbolized by the letter s followed by the speed e.g. **s70** or **s30**.

5.4 Different Versions

Some noise recordings come with more than one versions. To discriminate between different versions we append the file name with “*_ver1*”, “*_ver2*” etc. Also, some versions are obtained on coarse road surface, in which case we append the name with “*_coarse*”.

5.5 Ventilation Level

Two or three different levels of ventilation power were considered in each car:

- **v1**
- **v2**
- **v3**

6 Car Recordings

The open access dataset includes recordings from three different cars:

1. Volkswagen Golf (2011)
2. Alfa Romeo, 146 TS (2000)
3. Smart, forfour (2019)

6.1 Volkswagen Golf

6.1.1 Distributed Microphones

The locations and numbering of the distributed microphones inside the car’s cabin can be seen in Figure 1.



Figure 1: Locations and numbering of the distributed microphones inside the cabin. Six microphones are located in the front and two in the back.

6.1.1.1 Impulse Response Recordings

- | | |
|------------------------|------------|
| 1. d50_w0 ¹ | 13. prl_w0 |
| 2. d50_w1 | 14. prl_w1 |
| 3. d50_w2 | 15. prl_w2 |
| 4. d50_w3 | 16. prl_w3 |
| 5. d60_w0 ² | 17. prm_w0 |
| 6. d60_w1 | 18. prm_w1 |
| 7. d60_w2 | 19. prm_w2 |
| 8. d60_w3 | 20. prm_w3 |
| 9. pf_w0 | 21. prr_w0 |
| 10. pf_w1 | 22. prr_w1 |
| 11. pf_w2 | 23. prr_w2 |
| 12. pf_w3 | 24. prr_w3 |

¹d50: Driver position. 50cm distance from wheel (Figure 2).

²d60: Driver position. 60cm distance from wheel.



Figure 2: d50 speaker position.

6.1.1.2 Noise Recordings

- | | |
|-------------------------------|-----------------|
| 1. s30_w0_coarse ³ | 18. s50_w2_ver4 |
| 2. s30_w1_coarse | 19. s50_w2_ver5 |
| 3. s30_w2_coarse | 20. s50_w2_ver6 |
| 4. s30_w3_coarse | 21. s50_w3_ver1 |
| 5. s40_w0_ver1 | 22. s50_w3_ver2 |
| 6. s40_w0_ver2 | 23. s50_w3_ver3 |
| 7. s40_w1_ver1 | 24. s60_w0 |
| 8. s40_w1_ver2 | 25. s60_w1_ver1 |
| 9. s40_w2 | 26. s60_w1_ver2 |
| 10. s40_w3 | 27. s60_w1_ver3 |
| 11. s50_w0_ver1 | 28. s60_w1_ver4 |
| 12. s50_w0_ver2 | 29. s60_w2_ver1 |
| 13. s50_w0_ver3 | 30. s60_w2_ver2 |
| 14. s50_w1 | 31. s60_w2_ver3 |
| 15. s50_w2_ver1 | 32. s60_w2_ver4 |
| 16. s50_w2_ver2 | 33. s60_w3_ver1 |
| 17. s50_w2_ver3 | 34. s60_w3_ver2 |
| | 35. s70_w0_ver1 |
| | 36. s70_w0_ver2 |

³coarse: Coarse road surface.

- | | |
|-----------------|------------------|
| 37. s70_w1_ver1 | 57. s90_w2 |
| 38. s70_w1_ver2 | 58. s90_w3 |
| 39. s70_w1_ver3 | 59. s100_w0 |
| 40. s70_w1_ver4 | 60. s100_w1 |
| 41. s70_w2_ver1 | 61. s100_w2_ver1 |
| 42. s70_w2_ver2 | 62. s100_w2_ver2 |
| 43. s70_w3 | 63. s100_w2_ver3 |
| 44. s80_w0_ver1 | 64. s100_w3_ver1 |
| 45. s80_w0_ver2 | 65. s100_w3_ver2 |
| 46. s80_w1_ver1 | 66. s110_w0 |
| 47. s80_w1_ver2 | 67. s110_w1_ver1 |
| 48. s80_w1_ver3 | 68. s110_w1_ver2 |
| 49. s80_w2_ver1 | 69. s110_w2_ver1 |
| 50. s80_w2_ver2 | 70. s110_w2_ver2 |
| 51. s80_w3_ver1 | 71. s110_w2_ver3 |
| 52. s80_w3_ver2 | 72. s110_w3_ver1 |
| 53. s80_w3_ver3 | 73. s110_w3_ver2 |
| 54. s90_w0 | 74. s120_w0 |
| 55. s90_w1_ver1 | 75. s120_w2 |
| 56. s90_w1_ver2 | |

6.1.1.3 Ventilation Recordings

- | | |
|----------|-----------|
| 1. v1_w0 | 7. v2_w2 |
| 2. v1_w1 | 8. v2_w3 |
| 3. v1_w2 | 9. v3_w0 |
| 4. v1_w3 | 10. v3_w1 |
| 5. v2_w0 | 11. v3_w2 |
| 6. v2_w1 | 12. v3_w3 |

6.1.1.4 Car Audio

Impulse responses from the car audio were obtained for all four window apertures in Volkswagen distributed microphone setup.

1. w0
2. w1
3. w2
4. w3

6.1.2 Microphone Array

The location of the microphone array inside the car and numbering of the microphones can be seen in Figure 3.

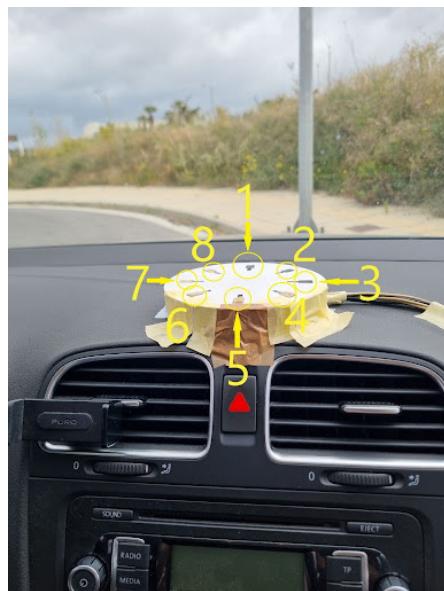


Figure 3: Position of the microphone array inside the car's cabin and numbering of the microphones.

6.1.2.1 Impulse Response Recordings

- | | |
|------------------------|-----------|
| 1. d50_w0 ⁴ | 3. d50_w2 |
| 2. d50_w1 | 4. d50_w3 |

⁴d50: Driver position. 50cm distance from wheel.

- | | |
|-------------------------|------------|
| 5. pf60_w0 ⁵ | 15. prl_w2 |
| 6. pf60_w1 | 16. prl_w3 |
| 7. pf60_w2 | 17. prm_w0 |
| 8. pf60_w3 | 18. prm_w1 |
| 9. pf80_w0 ⁶ | 19. prm_w2 |
| 10. pf80_w1 | 20. prm_w3 |
| 11. pf80_w2 | 21. prr_w0 |
| 12. pf80_w3 | 22. prr_w1 |
| 13. prl_w0 | 23. prr_w2 |
| 14. prl_w1 | 24. prr_w3 |

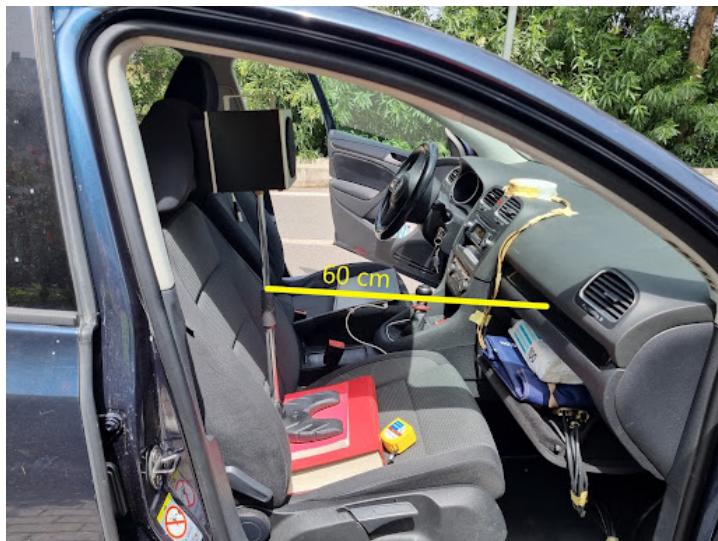


Figure 4: Speaker position pf60.

⁵pf60: Front passenger position. 60cm distance from dashboard (Figure 4).

⁶pf80: Front passenger position. 80cm distance from dashboard.

6.1.2.2 Noise Recordings

- | | |
|-------------------------------|-----------------|
| 1. s0_w0 ⁷ | 26. s70_w0_ver1 |
| 2. s0_w1 | 27. s70_w0_ver2 |
| 3. s0_w2 | 28. s70_w0_ver3 |
| 4. s0_w3 | 29. s70_w1_ver1 |
| 5. s30_w0_coarse ⁸ | 30. s70_w1_ver2 |
| 6. s30_w1_coarse | 31. s70_w2_ver1 |
| 7. s30_w2_coarse | 32. s70_w2_ver2 |
| 8. s30_w3_coarse | 33. s70_w3_ver1 |
| 9. s40_w0 | 34. s70_w3_ver2 |
| 10. s40_w1_ver1 | 35. s80_w0 |
| 11. s40_w1_ver2 | 36. s80_w1 |
| 12. s40_w2 | 37. s80_w2_ver1 |
| 13. s40_w3 | 38. s80_w2_ver2 |
| 14. s50_w0 | 39. s80_w2_ver3 |
| 15. s50_w1_ver1 | 40. s80_w2_ver4 |
| 16. s50_w1_ver2 | 41. s80_w2_ver5 |
| 17. s50_w1_ver3 | 42. s80_w3_ver1 |
| 18. s50_w2 | 43. s80_w3_ver2 |
| 19. s50_w3_ver1 | 44. s80_w3_ver3 |
| 20. s50_w3_ver2 | 45. s90_w0_ver1 |
| 21. s60_w0 | 46. s90_w0_ver2 |
| 22. s60_w1_ver1 | 47. s90_w1_ver1 |
| 23. s60_w1_ver2 | 48. s90_w1_ver2 |
| 24. s60_w2 | 49. s90_w2_ver1 |
| 25. s60_w3 | 50. s90_w2_ver2 |
| | 51. s90_w2_ver3 |

⁷s0: Idle conditions, stopped car.

⁸coarse: Coarse road surface.

- | | |
|------------------|------------------|
| 52. s90_w3_ver1 | 63. s100_w3_ver1 |
| 53. s90_w3_ver2 | 64. s100_w3_ver2 |
| 54. s100_w0_ver1 | 65. s110_w0 |
| 55. s100_w0_ver2 | 66. s110_w1_ver1 |
| 56. s100_w0_ver3 | 67. s110_w1_ver2 |
| 57. s100_w0_ver4 | 68. s110_w2_ver1 |
| 58. s100_w1_ver1 | 69. s110_w2_ver2 |
| 59. s100_w1_ver2 | 70. s110_w3 |
| 60. s100_w2_ver1 | 71. s120_w0 |
| 61. s100_w2_ver2 | 72. s120_w1 |
| 62. s100_w2_ver3 | 73. s120_w2 |

6.1.2.3 Ventilation Recordings

- | | |
|----------|-----------|
| 1. v1_w0 | 7. v2_w2 |
| 2. v1_w1 | 8. v2_w3 |
| 3. v1_w2 | 9. v3_w0 |
| 4. v1_w3 | 10. v3_w1 |
| 5. v2_w0 | 11. v3_w2 |
| 6. v2_w1 | 12. v3_w3 |

6.1.2.4 Car Audio

Impulse responses from the car audio were obtained for all four windows apertures.

1. w0
2. w1
3. w2
4. w3

6.1.2.5 Steering Vector

Angles for the different locations of passengers required to construct the steering vector are provided Figure 5.

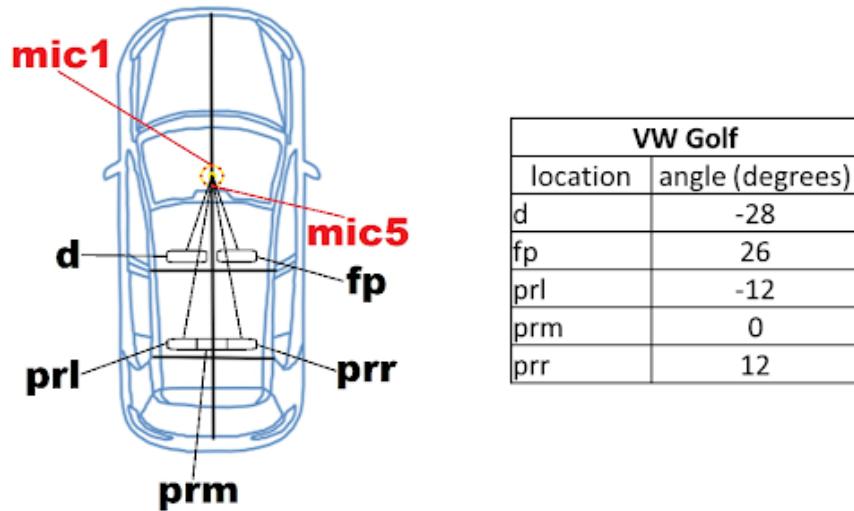


Figure 5: Angles for the different locations of passengers.

6.2 Smart forfour

6.2.1 Distributed Microphones

The locations of the microphone array inside the car and numbering of the microphones can be seen in Figure 6.



Figure 6: Locations and numbering of the distributed microphones inside the cabin. Six microphones are located in the front and two in the back.

6.2.1.1 Impulse Response Recordings

- | | |
|-----------|---------------|
| 1. d48_w0 | 9. pf_w2 |
| 2. d48_w1 | 10. prl10r_w0 |
| 3. d48_w2 | 11. prl10r_w1 |
| 4. d58_w0 | 12. prl10r_w2 |
| 5. d58_w1 | 13. prl_w0 |
| 6. d58_w2 | 14. prl_w1 |
| 7. pf_w0 | 15. prl_w2 |
| 8. pf_w1 | 16. prm10d_w0 |
| | 17. prm10d_w1 |

- | | |
|---------------|---------------|
| 18. prm10d_w2 | 23. prr10l_w1 |
| 19. prm_w0 | 24. prr10l_w2 |
| 20. prm_w1 | 25. prr_w0 |
| 21. prm_w2 | 26. prr_w1 |
| 22. prr10l_w0 | 27. prr_w2 |

6.2.1.2 Noise Recordings

- | | |
|--------------------------------|-----------------|
| 1. s0_w0 ⁹ | 21. s60_w1_ver2 |
| 2. s0_w1 | 22. s60_w2_ver1 |
| 3. s0_w2 | 23. s60_w2_ver2 |
| 4. s30_w0_coarse ¹⁰ | 24. s70_w0_ver1 |
| 5. s30_w1_coarse | 25. s70_w0_ver2 |
| 6. s30_w2_coarse | 26. s70_w1_ver1 |
| 7. s40_w0 | 27. s70_w1_ver2 |
| 8. s40_w1_ver1 | 28. s70_w2_ver1 |
| 9. s40_w1_ver2 | 29. s70_w2_ver2 |
| 10. s40_w2 | 30. s80_w0_ver1 |
| 11. s50_w0_ver1 | 31. s80_w0_ver2 |
| 12. s50_w0_ver2 | 32. s80_w1_ver1 |
| 13. s50_w1_ver1 | 33. s80_w1_ver2 |
| 14. s50_w1_ver2 | 34. s80_w2_ver1 |
| 15. s50_w2_ver1 | 35. s80_w2_ver2 |
| 16. s50_w2_ver2 | 36. s90_w0_ver1 |
| 17. s60_w0_ver1 | 37. s90_w0_ver2 |
| 18. s60_w0_ver2 | 38. s90_w0_ver3 |
| 19. s60_w0_ver3 | 39. s90_w1_ver1 |
| 20. s60_w1_ver1 | 40. s90_w1_ver2 |
| | 41. s90_w2_ver1 |

⁹s0: Idle conditions, stopped car.

¹⁰coarse: Coarse road surface.

- | | |
|------------------|------------------|
| 42. s90_w2_ver2 | 52. s100_w2_ver5 |
| 43. s90_w2_ver3 | 53. s110_w0_ver1 |
| 44. s100_w0_ver1 | 54. s110_w0_ver2 |
| 45. s100_w0_ver2 | 55. s110_w1_ver1 |
| 46. s100_w1_ver1 | 56. s110_w1_ver2 |
| 47. s100_w1_ver2 | 57. s110_w1_ver3 |
| 48. s100_w2_ver1 | 58. s110_w2 |
| 49. s100_w2_ver2 | 59. s120_w0 |
| 50. s100_w2_ver3 | 60. s120_w1 |
| 51. s100_w2_ver4 | 61. s120_w2 |

6.2.1.3 Ventilation Recordings

- | | |
|---------------|----------------|
| 1. v1_w0_ver1 | 8. v2_w1_ver2 |
| 2. v1_w0_ver2 | 9. v2_w2_ver1 |
| 3. v1_w1 | 10. v2_w2_ver2 |
| 4. v1_w2_ver1 | 11. v3_w0 |
| 5. v1_w2_ver2 | 12. v3_w1 |
| 6. v2_w0 | 13. v3_w2_ver1 |
| 7. v2_w1_ver1 | 14. v3_w2_ver2 |

6.2.1.4 Car Audio

Impulse responses from the car audio equipment were obtained for all three window apertures, state 0, 1 and 2.

1. w0
2. w1
3. w2

6.2.2 Microphone Array

The locations of the microphone array inside the car and numbering of the microphones can be seen in Figure 7.



Figure 7: Location of the microphone array inside the car and numbering of the microphones.

6.2.2.1 Impulse Response Recordings

- | | |
|------------|-----------------------------|
| 1. d_w0 | 11. prl_w1 |
| 2. d_w1 | 12. prl_w2 |
| 3. d_w2 | 13. prm10l_w0 ¹¹ |
| 4. pf_w0 | 14. prm10l_w1 |
| 5. pf_w1 | 15. prm10l_w2 |
| 6. pf_w2 | 16. prm10r_w0 ¹² |
| 7. pfr_w0 | 17. prm10r_w1 |
| 8. pfr_w1 | 18. prm10r_w2 |
| 9. pfr_w2 | 19. prm_w0 |
| 10. prl_w0 | 20. prm_w1 |
| | 21. prm_w2 |

¹¹prm10l: Rear middle passenger. Moved 10 cm towards the left (Figure 8).

¹²prm10r: Rear middle passenger. Moved 10 cm towards the right (Figure 8).

22. prr_w0

23. prr_w1

24. prr_w2



Figure 8: Locations prm10l (left) and prm10r (right).

6.2.2.2 Noise Recordings

- | | |
|--------------------------------|-----------------|
| 1. s0_w0 ¹³ | 15. s50_w2_ver2 |
| 2. s0_w1 | 16. s60_w0 |
| 3. s0_w2 | 17. s60_w1_ver1 |
| 4. s30_w0_coarse ¹⁴ | 18. s60_w1_ver2 |
| 5. s30_w1_coarse | 19. s60_w2 |
| 6. s30_w2_coarse | 20. s70_w0_ver1 |
| 7. s40_w0 | 21. s70_w0_ver2 |
| 8. s40_w1 | 22. s70_w1_ver1 |
| 9. s40_w2 | 23. s70_w1_ver2 |
| 10. s50_w0_ver1 | 24. s70_w2 |
| 11. s50_w0_ver2 | 25. s80_w0_ver1 |
| 12. s50_w0_ver3 | 26. s80_w0_ver2 |
| 13. s50_w1 | 27. s80_w1 |
| 14. s50_w2_ver1 | 28. s80_w2_ver1 |
| | 29. s80_w2_ver2 |

¹³s0: Idle conditions, stopped car.

¹⁴coarse: Coarse road surface.

- | | |
|-----------------|------------------|
| 30. s90_w0_ver1 | 37. s100_w1_ver1 |
| 31. s90_w0_ver2 | 38. s100_w1_ver2 |
| 32. s90_w1_ver1 | 39. s100_w2 |
| 33. s90_w1_ver2 | 40. s110_w0 |
| 34. s90_w2_ver1 | 41. s110_w1 |
| 35. s90_w2_ver2 | 42. s110_w2 |
| 36. s100_w0 | 43. s120_w1 |

6.2.2.3 Ventilation Recordings

- | | |
|----------|----------|
| 1. v1_w0 | 6. v2_w2 |
| 2. v1_w1 | 7. v3_w0 |
| 3. v1_w2 | 8. v3_w1 |
| 4. v2_w0 | |
| 5. v2_w1 | 9. v3_w2 |

6.2.2.4 Car Audio

Impulse responses from the car audio equipment were obtained for all three window apertures, state 0, 1 and 2.

1. w0
2. w1
3. w2

6.2.2.5 Steering Vector

Angles for the different passenger locations required for constructing the steering vector are provided in Figure 9.

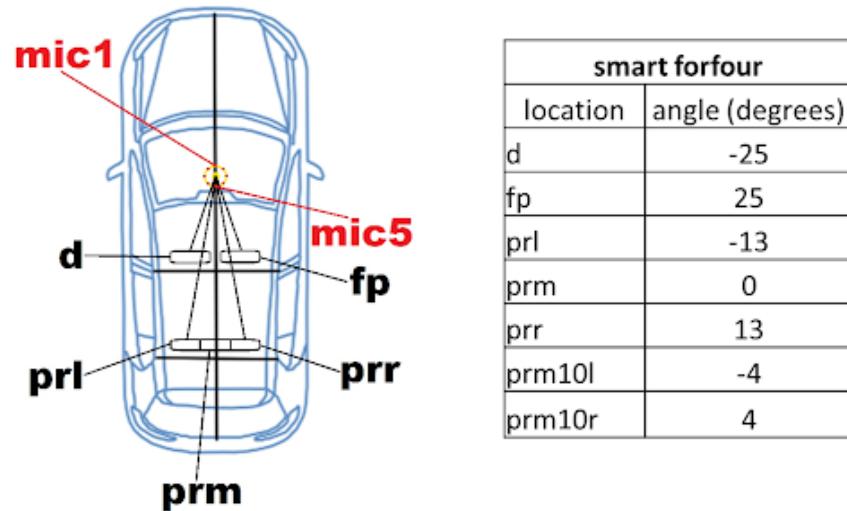


Figure 9: Angles for the different locations of passengers.

6.3 Alfa Romeo 146 TS

Recordings with microphone array are not provided.

6.3.1 Distributed Microphones

The locations and numbering of the distributed microphones inside the car's cabin can be seen in Figure 10.

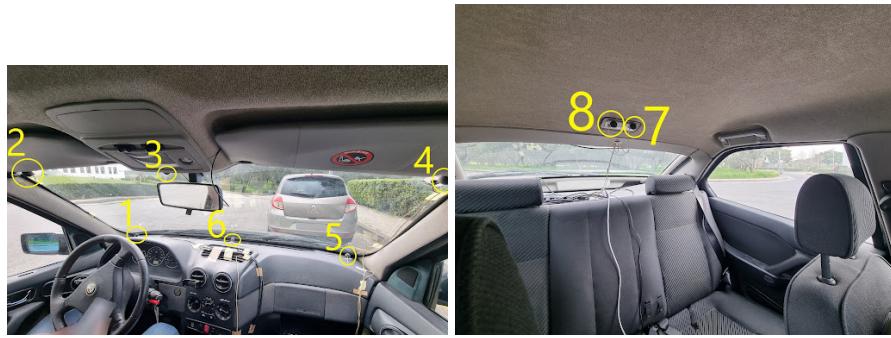


Figure 10: Locations and numbering of the distributed microphones inside the cabin. Six microphones are located in the front and two in the back.

6.3.1.1 Impulse Response Recordings

- | | |
|-------------------------|----------------------------|
| 1. d45_w0 ¹⁵ | 10. pfr90_w0 ¹⁷ |
| 2. d45_w1 | 11. pfr90_w1 |
| 3. d45_w2 | 12. pfr90_w2 |
| 4. d55_w0 ¹⁶ | 13. prl66_w0 ¹⁸ |
| 5. d55_w1 | 14. prl66_w1 |
| 6. d55_w2 | 15. prl66_w2 |
| 7. pf_w0 | 16. prl_w0 |
| 8. pf_w1 | 17. prl_w1 |
| 9. pf_w2 | 18. prl_w2 |

¹⁵d45: Driver location. 45cm distance from wheel.

¹⁶d55: Driver location. 55cm distance from wheel.

¹⁷pfr90: Front passenger location. Rotated 90 degrees to the left towards the driver (Figure 11).

¹⁸prl66: Rear left passenger location. Height: 66cm from seat base (Figure 11).

¹⁹prm10l: Rear middle passenger location. Moved towards the left (Figure 12).

- | | |
|-----------------------------|----------------------------|
| 19. prm10l_w0 ¹⁹ | 27. prm_w2 |
| 20. prm10l_w1 | 28. prr67_w0 ²¹ |
| 21. prm10l_w2 | 29. prr67_w1 |
| 22. prm10r_w0 ²⁰ | 30. prr67_w2 |
| 23. prm10r_w1 | 31. prr_w0 |
| 24. prm10r_w2 | 32. prr_w1 |
| 25. prm_w0 | 33. prr_w2 |
| 26. prm_w1 | |



Figure 11: Locations pfr90 (left) and prl66 (right).



Figure 12: Locations prm10l (left) and prm10r (right).

¹⁹prm10r: Rear middle passenger location. Moved towards the right (Figure 12).
²¹prr67: Rear right passenger location. Height: 67cm from seat base(Figure 13).



Figure 13: Location prr67.

6.3.1.2 Noise Recordings

- | | |
|--------------------------------|-----------------|
| 1. s0_w0 ²² | 15. s60_w1 |
| 2. s0_w1 | 16. s60_w2 |
| 3. s0_w2 | 17. s70_w0 |
| 4. s30_w0_coarse ²³ | 18. s70_w1 |
| 5. s30_w1_coarse | 19. s70_w2_ver1 |
| 6. s30_w2_coarse | 20. s70_w2_ver2 |
| 7. s40_w0 | 21. s70_w2_ver3 |
| 8. s50_w0_ver1 | 22. s80_w0_ver1 |
| 9. s50_w0_ver2 | 23. s80_w0_ver2 |
| 10. s50_w0_ver3 | 24. s80_w1 |
| 11. s50_w1_ver1 | 25. s80_w2 |
| 12. s50_w1_ver2 | 26. s83_w2 |
| 13. s50_w2 | 27. s90_w0_ver1 |
| 14. s60_w0 | 28. s90_w0_ver2 |
| | 29. s90_w1 |

²²s0: Idle conditions, stopped car.

²³coarse: Coarse road surface.

- | | |
|------------------|------------------|
| 30. s90_w2_ver1 | 35. s100_w1_ver2 |
| 31. s90_w2_ver2 | 36. s100_w2 |
| 32. s100_w0_ver1 | 37. s110_w0 |
| 33. s100_w0_ver2 | 38. s110_w1 |
| 34. s100_w1_ver1 | 39. s110_w2 |

6.3.1.3 Ventilation Recordings

- | | |
|----------|-----------|
| 1. v1_w0 | 4. v2_w0 |
| 2. v1_w1 | 5. v2_w1 |
| 3. v1_w2 | 6. v2_w2. |

6.3.1.4 Car Audio

Impulse responses from the car audio equipment were not obtained for Alfa Romeo.

6.4 Honda CR-V

6.4.1 Distributed Microphones

The locations and numbering of the distributed microphones inside the car's cabin can be seen in Figure 14.



Figure 14: Locations and numbering of the distributed microphones inside the cabin. Six microphones are located in the front and two in the back.

6.4.1.1 Impulse Response Recordings

- | | |
|-------------------------|------------|
| 1. d53_w0 ²⁴ | 11. pf_w2 |
| 2. d53_w1 | 12. pf_w3 |
| 3. d53_w2 | 13. prl_w0 |
| 4. d53_w3 | 14. prl_w1 |
| 5. d62_w0 ²⁵ | 15. prl_w2 |
| 6. d62_w1 | 16. prl_w3 |
| 7. d62_w2 | 17. prr_w0 |
| 8. d62_w3 | 18. prr_w1 |
| 9. pf_w0 | 19. prr_w2 |
| 10. pf_w1 | 20. prr_w3 |

²⁴d53: Driver position. 53cm distance from wheel.

²⁵d62: Driver position. 62cm distance from wheel.

6.4.1.2 Noise Recordings

- | | |
|------------------------|------------------|
| 1. s0_w0 ²⁶ | 29. s80_w0_ver1 |
| 2. s0_w2 | 30. s80_w0_ver2 |
| 3. s40_w0 | 31. s80_w1_ver1 |
| 4. s40_w1 | 32. s80_w1_ver2 |
| 5. s40_w3 | 33. s80_w2_ver1 |
| 6. s50_w0_ver1 | 34. s80_w2_ver2 |
| 7. s50_w0_ver2 | 35. s80_w3_ver1 |
| 8. s50_w1 | 36. s80_w3_ver2 |
| 9. s50_w2 | 37. s90_w0_ver1 |
| 10. s50_w3_ver1 | 38. s90_w0_ver2 |
| 11. s50_w3_ver2 | 39. s90_w1_ver1 |
| 12. s60_w0_ver1 | 40. s90_w1_ver2 |
| 13. s60_w0_ver2 | 41. s90_w2_ver1 |
| 14. s60_w1_ver1 | 42. s90_w2_ver2 |
| 15. s60_w1_ver2 | 43. s90_w2_ver3 |
| 16. s60_w2_ver1 | 44. s90_w2_ver4 |
| 17. s60_w2_ver2 | 45. s90_w3_ver1 |
| 18. s60_w3_ver1 | 46. s90_w3_ver2 |
| 19. s60_w3_ver2 | 47. s100_w0 |
| 20. s60_w3_ver3 | 48. s100_w1 |
| 21. s70_w0_ver1 | 49. s100_w2 |
| 22. s70_w0_ver2 | 50. s100_w3_ver1 |
| 23. s70_w1_ver1 | 51. s100_w3_ver2 |
| 24. s70_w1_ver2 | 52. s110_w0 |
| 25. s70_w2_ver1 | 53. s110_w1 |
| 26. s70_w2_ver2 | 54. s110_w2 |
| 27. s70_w3_ver1 | 55. s110_w3 |
| 28. s70_w3_ver2 | |

²⁶s0: Idle conditions, stopped car.

6.4.1.3 Ventilation Recordings

- | | |
|----------|----------|
| 1. v1_w0 | 4. v2_w2 |
| 2. v1_w2 | 5. v3_w0 |
| 3. v2_w0 | 6. v3_w2 |

6.4.1.4 Car Audio

Impulse responses from the car audio were obtained for all four window apertures in the distributed microphone setup.

1. w0
2. w1
3. w2
4. w3

6.4.2 Microphone Array

The location of the microphone array inside the car and numbering of the microphones can be seen in Figure 15.



Figure 15: Position of the microphone array inside the car's cabin and numbering of the microphones.

6.4.2.1 Impulse Response Recordings

- | | |
|-------------------------|------------|
| 1. d55_w0 ²⁷ | 13. prl_w0 |
| 2. d55_w1 | 14. prl_w1 |
| 3. d55_w2 | 15. prl_w2 |
| 4. d55_w3 | 16. prl_w3 |
| 5. d63_w0 ²⁸ | 17. prm_w0 |
| 6. d63_w1 | 18. prm_w1 |
| 7. d63_w2 | 19. prm_w2 |
| 8. d63_w3 | 20. prm_w3 |
| 9. pf_w0 | 21. prr_w0 |
| 10. pf_w1 | 22. prr_w1 |
| 11. pf_w2 | 23. prr_w2 |
| 12. pf_w3 | 24. prr_w3 |

6.4.2.2 Noise Recordings

- | | |
|--------------------------------|-----------------|
| 1. s0_w0 ²⁹ | 11. s40_w1_ver1 |
| 2. s0_w1 | 12. s40_w1_ver2 |
| 3. s0_w2 | 13. s40_w2_ver1 |
| 4. s0_w3 | 14. s40_w2_ver2 |
| 5. s30_w0_coarse ³⁰ | 15. s40_w3_ver1 |
| 6. s30_w1_coarse | 16. s40_w3_ver2 |
| 7. s30_w2_coarse | 17. s40_w3_ver3 |
| 8. s30_w3_coarse | 18. s50_w0 |
| 9. s40_w0_ver1 | 19. s50_w1 |
| 10. s40_w0_ver2 | 20. s50_w2_ver1 |
| | 21. s50_w2_ver2 |

²⁷d55: Driver position. 55cm distance from wheel.

²⁸d63: Driver position. 63cm distance from wheel.

²⁹s0: Idle conditions, stopped car.

³⁰coarse: Coarse road surface.

- | | |
|-----------------|------------------|
| 22. s50_w2_ver3 | 45. s90_w1_ver2 |
| 23. s50_w3 | 46. s90_w2_ver1 |
| 24. s60_w0_ver1 | 47. s90_w2_ver2 |
| 25. s60_w0_ver2 | 48. s90_w3_ver1 |
| 26. s60_w0_ver3 | 49. s90_w3_ver2 |
| 27. s60_w0_ver4 | 50. s90_w3_ver3 |
| 28. s60_w1_ver1 | 51. s100_w0_ver1 |
| 29. s60_w1_ver2 | 52. s100_w0_ver2 |
| 30. s60_w2_ver3 | 53. s100_w1_ver1 |
| 31. s60_w3 | 54. s100_w1_ver2 |
| 32. s70_w0 | 55. s100_w2_ver1 |
| 33. s70_w1_ver2 | 56. s100_w2_ver2 |
| 34. s70_w2_ver1 | 57. s100_w3_ver1 |
| 35. s70_w2_ver2 | 58. s100_w3_ver2 |
| 36. s70_w3_ver1 | 59. s110_w0 |
| 37. s70_w3_ver2 | 60. s110_w1_ver1 |
| 38. s80_w0 | 61. s110_w1_ver2 |
| 39. s80_w1_ver1 | 62. s110_w1_ver3 |
| 40. s80_w2_ver1 | 63. s110_w2_ver1 |
| 41. s80_w2_ver2 | 64. s110_w2_ver2 |
| 42. s80_w3 | 65. s110_w3_ver1 |
| 43. s90_w0 | 66. s110_w3_ver2 |
| 44. s90_w1_ver1 | |

6.4.2.3 Ventilation Recordings

- | | |
|----------|----------|
| 1. v1_w0 | 4. v1_w3 |
| 2. v1_w1 | 5. v2_w0 |
| 3. v1_w2 | 6. v2_w1 |

- | | |
|----------|-----------|
| 7. v2_w2 | 10. v3_w1 |
| 8. v2_w3 | 11. v3_w2 |
| 9. v3_w0 | 12. v3_w3 |

6.4.2.4 Car Audio

Impulse responses from the car audio were obtained for all four windows apertures.

1. w0
2. w1
3. w2
4. w3

6.4.2.5 Steering Vector

Angles for the different locations of passengers required to construct the steering vector are provided Figure 16.

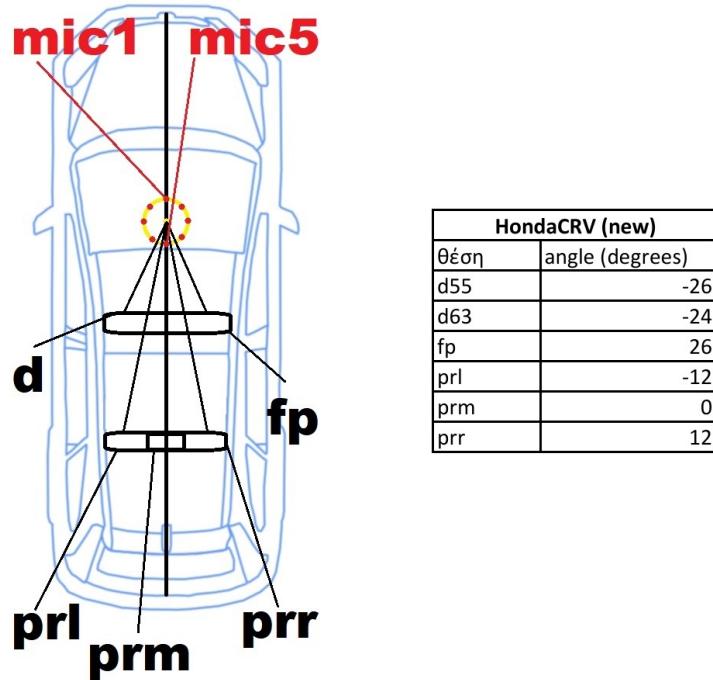


Figure 16: Angles for the different locations of passengers.