Measurement: Sensors 23 (2022) 100389

Contents lists available at ScienceDirect

Measurement: Sensors

journal homepage: www.sciencedirect.com/journal/measurement-sensors

Design of a beamforming antenna sensor for environmental noise detection to discriminate vehicle emission according to road conditions

John P. Djungha Okitadiowo [a,*], A. Lay-Ekuakille [b], T. Isernia [a], A. Massaro [c]

[a] Dept of Information Engineering, Infrastructure and Sustainable Energy (DIIES), University "Mediterranean" of Reggio Calabria, Reggio Calabria, Italy
[b] Dept of Innovation Engineering, University of Salento, Lecce, Italy
[c] LUM Enterprise -Università LUM "Giuseppe Degennaro", S.S. 100—Km 18, 70010, Bari, Italy

ARTICLE INFO

Keywords:
Beamforming
Antenna
Noise zoning
Environmental measurement
Noise measurement
Road
Condition
Pollution
Vehicle
Smart

ABSTRACT

The noise instance is unpleasant in the ears and leads to harmful or even dramatic consequences, and we all have this obligation to limit the extent of noise in a consistent way in our cities. It is very important and even crucial to underline that noise pollution has a negative impact on human health and activities, so this harmful environmental pollution coming from different sources must be seriously monitored with dedicated equipment that are able to discriminate, categorise and even give or display the noise level in terms of dB. From this, the antenna sensor, specifically oriented or dedicated for the detection of the quality and quantity of noise pollution, can be realized by using a sensor array. In this paper we propose a design and simulation of a Beamforming based antenna sensor to detect the direction of arrival (DOA) of the noise and how to differentiate between different noises that are in a single signal envelope. The system has the ability to record and store the noise for further processing.

From the signals (noise) we can deduce other events that are happening that are invisible to us, when these signals are processed, they reveal the hidden realities; the proposal of this Beamforming antenna and its system associated with algorithms can make the difference of a noise of a vehicle driving on a good road and on a destroyed one. This can bring many benefits for the protection of the environment, especially in the pollution, see also on the financial point, maintenance of the road and other.

1. Introduction

The main objective of the research is the reduction of noise pollution in cities, or areas close to transport infrastructures such as roads, railways, and airports, so the implication of the use of Beamforming antennas will lead us to solve the problem of monitoring and detecting noise pollution. The design of this device (antenna) will allow us to calibrate the filters to capture and record the sound signals emitted by the sources of noise (vehicles, planes, trains, industry, …) that will exceed the limits calibrated in the antenna, when the noise tends towards a harmful level to the human ear or becomes harmful.

It is important to emphasize that antenna sensors have enormous properties that we can use in the context of solving the problem of noise pollution detection from various simultaneous sources, the objective being to reduce the noise in certain environments to protect humans from noise pollution. The solution is to limit the decibel level of vehicle noise on roads passing through residential neighbourhoods [1] by installing roadside antennas at the entrance points to the neighbourhoods to collect sound signals from vehicles, trains, and other nuisance engines. The antennas are naturally equipped with sensors which will play the role of picking up sound signals produced by vehicles when the sound noise produced by the engine exceeds the dB level set in the filters of the system. The aim is to reduce noise pollution in residential areas, schools, hospitals, universities, retirement homes, research centres and other places sensitive to harmful noise which could disrupt the tranquillity, the concentration of actors and the smooth running of activities. For some places, the system is configured by time slots so it allows vehicles with interfering engines [2] to pass, since the monitoring system by its filters will allow a high noise level to pass through than expected. The design of complex antenna elements and arrays, with intelligent partitioning of beamforming systems to pick up sound signals and process it, checking whether the picked-up sound signal has a lower dB

* Corresponding author.
E-mail addresses: johnpdjungha@unirc.it (J.P. Djungha Okitadiowo), tommaso.isernia@unirc.it (A. Lay-Ekuakille), aime.lay.ekuakille@unisalento.it (T. Isernia), massaro@lum.it (A. Massaro).

https://doi.org/10.1016/j.measen.2022.100389
Received 24 April 2022; Received in revised form 20 June 2022; Accepted 5 July 2022
Available online 8 July 2022

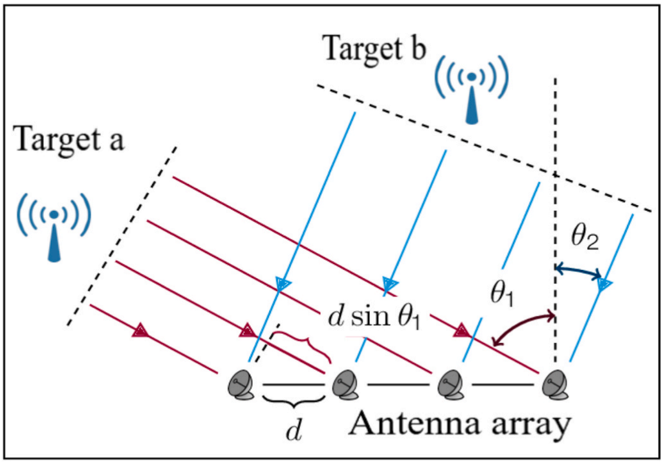

Fig. 1. A relationship between DOA and timing for the linear antenna array.

level, equal to or higher than that allowed to roll in the zone, is a crucial topic. We have used MatLab to do our simulations to provide a way to increase the sensitivity in noise pollution monitoring [3].

The condition of the road has an influence on the noise that the vehicle has to emit when moving, when we face road requirements, we are referring to two types of realities: the first one "Vehicle noise on road good condition (VNRGC)", and the second one "Vehicle noise on road poor condition (VNRPC)", when a vehicle is moving on the first type of road, the noise of the engine and the friction of the tyres are never when the vehicle is moving. This has an impact on the environment, as the pollution is high, and even very harmful to the population living close to the road. Monitoring and knowledge of the conditions of road degradation by differentiating from the sound of the vehicle can help to remedy the situation of noise pollution and also to make a reminder for the maintenance of the road, we can understand that from the monitoring of the noise can bring many benefits for the protection of the environment. The set of all its devices, software and hardware implemented in the road, introduces us to an intelligent road, that is to say a road that interacts with motorists, for the protection of the environment against noise pollution and also for the benefit of road maintenance [4].

2. Beamforming antennas for environmental monitoring

Technical beamforming, a name derived from directional antennas designed to form a pencil beam radiation pattern, is a spatial filtering process that can be implemented at the transmitter and receiver level. In general, beamforming performs a spatial filtering operation of signals whose frequency content overlaps but which are from different spatial locations. In general, beamforming requires the knowledge of the direction of arrival (DOA) of the desired signal or delay caused by the DOA and the characteristics of the transmission, as the complexity of transmission lies in changing the transmission channels. This parameter is not known, so an estimate can be made based on the data we have. Over time the parameters may change, the solution to the problem is that the parameters are determined by an adaptive beamforming algorithm.

These algorithms are subdivided into two basic classes which are: block adaptation and continuous adaptation. The block adaptation algorithm estimates the parameters charged from a temporal block of array data, where the continuous adaptation adjusts the parameters upon receipt of the data so that these converge to the optimum solution. Phased array versus delayed array [5] is an interesting dilemma; a wavefront arriving at an antenna array under an arrival direction (DOA) introduces an arrival delay to each individual antenna. This delay between two adjacent antennas, ΔT, depends on the DOA and the antenna spacing according to $d \sin(DOA) = c\Delta T$, d being the distance between the antennas, and c the speed of light.

Fig. 1 illustrates an example of DOA application. The beamforming is a delay compensatory method that implements an ideal delay element on the reception path, its elements are very difficult to implement, so to cope with this difficulty; it consists of translating the time difference into phase shift in the frequency domain [6]. When the signal we want consists of a single frequency the delay can be replaced with phase shift Δp using

$$\Delta p = 2\pi \Delta T f_0 \tag{1}$$

$$\Delta p = 2\pi \frac{d}{c} \sin(DOA) f_0 \tag{2}$$

With the above Eq. (1) and Eq. (2) we calculate the phase shift; a signal using only one frequency, when the desired signal consists of a larger bandwidth, using, Eq. (2) introduces a distortion phase. If the signal bandwidth is small compared to the carrier frequency, this distortion will remain limited. Signal representation of the relationship between DOA and antenna spacing, and the representation of the received signal can be derived; they give the complex envelope of the received baseband signal. In the updated and below equation, θ_k is the phase shift caused by the delay of the signal received at the antenna k. If $r_k(t)$ is the signal received at the antenna k under DOA β, θ_k can be expressed as:

$$\theta_k = \theta_1 + (k-1)2\pi \frac{d \sin(\beta)}{\lambda} \tag{3}$$

Beamforming antennas are a vital tool for telecommunication companies given the rapid development of their technology such as 5G one. This technology presents enormous potential that we will have to understand very quickly and exploit it in other fields, in this case the monitoring of the environment which is the objective of our writing of this paper, is essential to do well.

2.1. The rise of beamforming

Different from their traditional counterparts which could only transmit and receive [7] on fixed radiation patterns, the generation of beamforming antennas dynamically creates their main and null beam directions depending on the location of the users, and which are connected to the use of its radiation blanket. This technology which brings a new impetus is called: *antennas in beamformers.* They bring certain advantages to telecommunications in the world such as their ability to effectively reduce interference, improve Signal to Interference and Noise Ratio (SINR) and they provide a better end user experience. Beamforming antennas offer us a multitude of configurations and capacities; each is best suited to a certain environment. From a physical point of view, these antennas may seem very different, but all beamforming architectures share three main logics: an active or passive network structure; use of digital/analog or hybrid beamforming; equipped with several radio transceivers. Beam management is a very important part of beamforming technology, as well as its understanding; here is its connection with the 5G world.

The 5G NR specifications include new physical layer (PHY) and media access control (MAC) to support directional communications. Making use of 3GPP terminology, these procedures are called bundle management; comprising within it 4 different operations, which are: (i) beam scanning: the radiating pattern covers a spatial area, using multidirectional beam scanning and predefined time intervals; (ii) beam measurement: evaluation of the quality of the signal received at the level of the Node B (gNB) or from the user of the equipment (UE); (iii) determination of the beam: selection of the appropriate beam (s), at the level of the gNB or from the user of the equipment, and (iv) a report on the beam: feedback from the UE on the quality of the beam and the decision information to the radio access network (RAN).

A single antenna broadcasting a wireless signal scatter that signal in all directions (unless it is blocked by a physical object). This is the nature

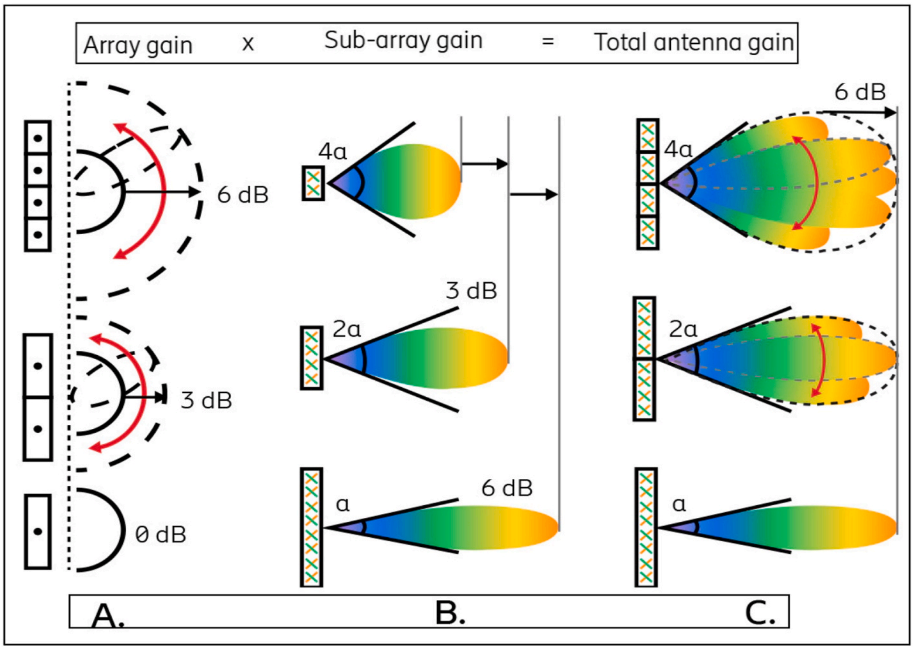

Fig. 2. Beamforming transmitting array with three beams in different direction.

of how electromagnetic waves work. When we need to focus that signal just for one direction, as in our specific vehicle noise pollution monitoring, to form a targeted beam of electromagnetic energy? This is Beamforming, which is simply a technique of using several antennas near each other, all broadcasting the same signal at slightly different times. The overlapping waves produce interference which in some areas is constructive (makes the signal stronger) and in others destructive (makes the signal weaker or undetectable). If it is well done, the beamforming process can concentrate the signal where we want it to go, which is our objective, so that the antenna can keep the direction of arrival of the vehicle well, in order to collect as much as possible of the noise emitted by the engine, tyres, wind and other types of noise produced by the passage of the vehicle, and finally to allow us to have a strong signal, this is why we chose the beamforming technique, since it knows how to optimize the emission and reception of the signal.

2.2. Beamforming and 5G

To adapt our monitoring system to 5G, it is very important to look at the neighbourhood of beamforming and 5G, because this technology (beamforming) is especially used in 5G, so the system will evolve at the pace of 5G.

Until now, beamforming has been most likely to occur on local WiFi networks. But with the rollout of 5G networks, this situation is about to change. 5G uses radio frequencies in the 30–300 GHz band. While these frequencies can transmit data much faster, they are also much more susceptible to interference and have more difficulty penetrating physical objects. Many technologies are needed to overcome these problems, including decreasing cell size, massively increasing MIMO (multiple input multiple output) coverage, including increasing the number of antennas on 5G stations, and, of course, with beamforming. If 5G takes off as the operators hope, the day will come when we will be using beamforming every day, without knowing it.

It is clear and true that 5G offers a radical change in network performance from current 4G levels, with peak data rates up to 20 times faster at 20 GB/s and connection densities of 1000 devices per square kilometre, 100 times higher than 4G. This performance improvement is delivered by 5G New Radio (NR), which uses several advanced techniques, including millimetre wave (between 30 and 300 GHz), frequency transmissions, advanced signal coding techniques (OFDM), multi-access edge computing (MEC), and network slicing.

Two technologies in particular, Massive MIMO and beamforming, are fundamental to the enhanced throughput and capacity of 5G and work so closely together that they are often described interchangeably.

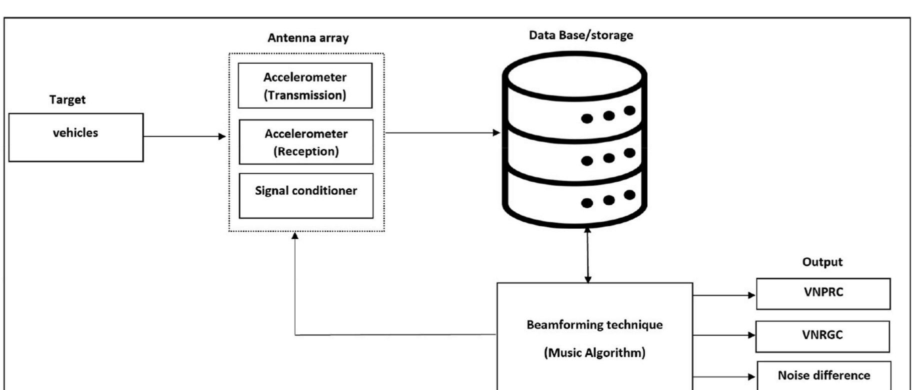

Fig. 3. System diagram.

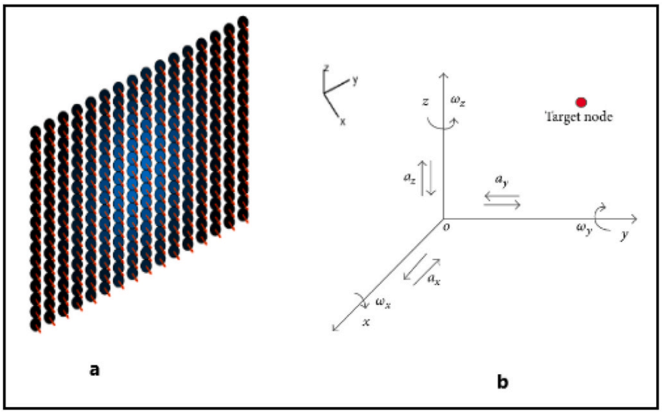

Fig. 4. (a) Array geometry, (b) Inertial sensors coordinate frame.

Both are, in fact, complex techniques, deserving of separate descriptions.

2.3. Beamforming and monitoring

Beamforming, as technology, has been developing in wireless communications to improve coverage, data rate and/or signal quality. For future monitoring, the same improvements are necessary. Beamforming monitoring simultaneously emits uncorrelated signals, for example in different directions, or in the same direction with orthogonal polarizations. This improves the coverage and quality of the information received. An example for the radiation of three simultaneous beams with beamforming is shown in Fig. 2.

In this case, the total bandwidth for each transmitting-receiving channel is kept so there is no degradation in the resolution of the antenna range, but the total radiated power is also interlaced, which means shared. It can be fully controlled.

3. Design and simulations

The design of the monitoring antenna is done in MatLab environment, for the detection of high level of dB, and to make an evaluation of

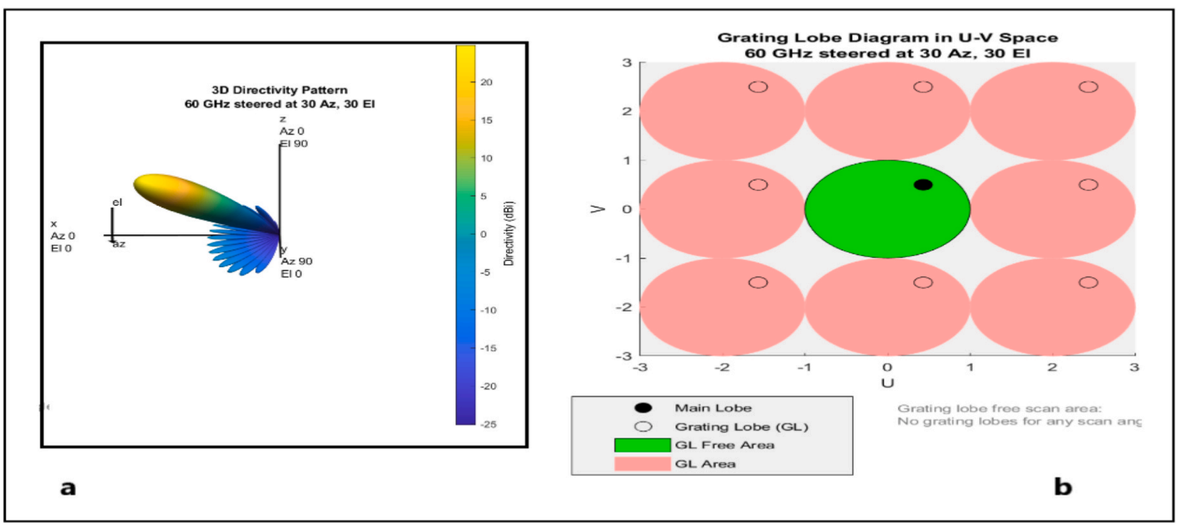

Fig. 5. (a)beam pattern and grating lobe diagram element design, (b) Grating lobe diagram with element spacing larger than half a wavelength.

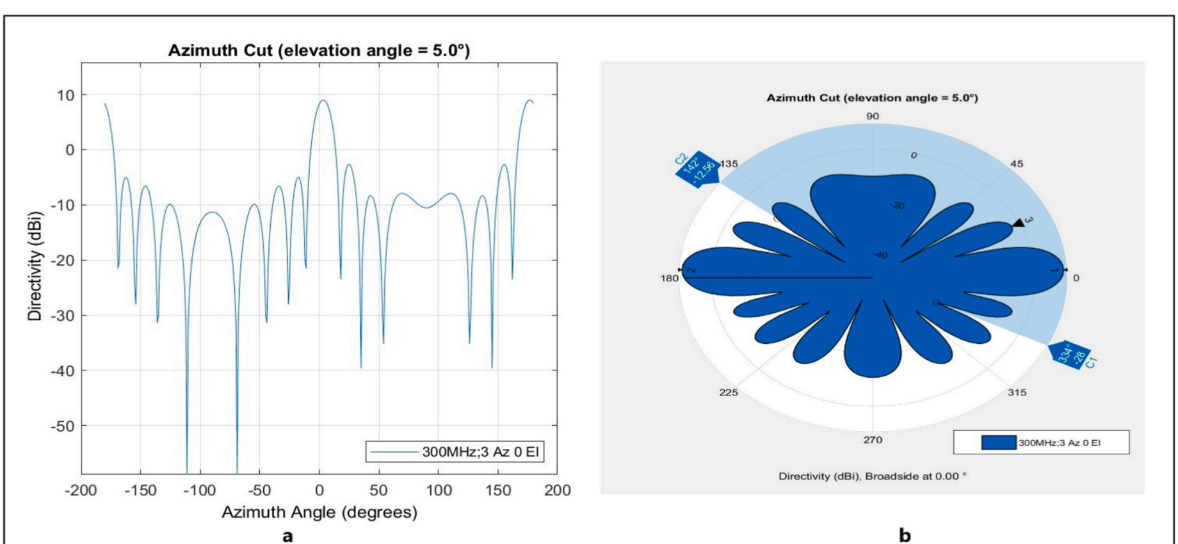

Fig. 6. (a) Azimuth cross rectangular coordinate, (b) azimuth cross polar coordinate.

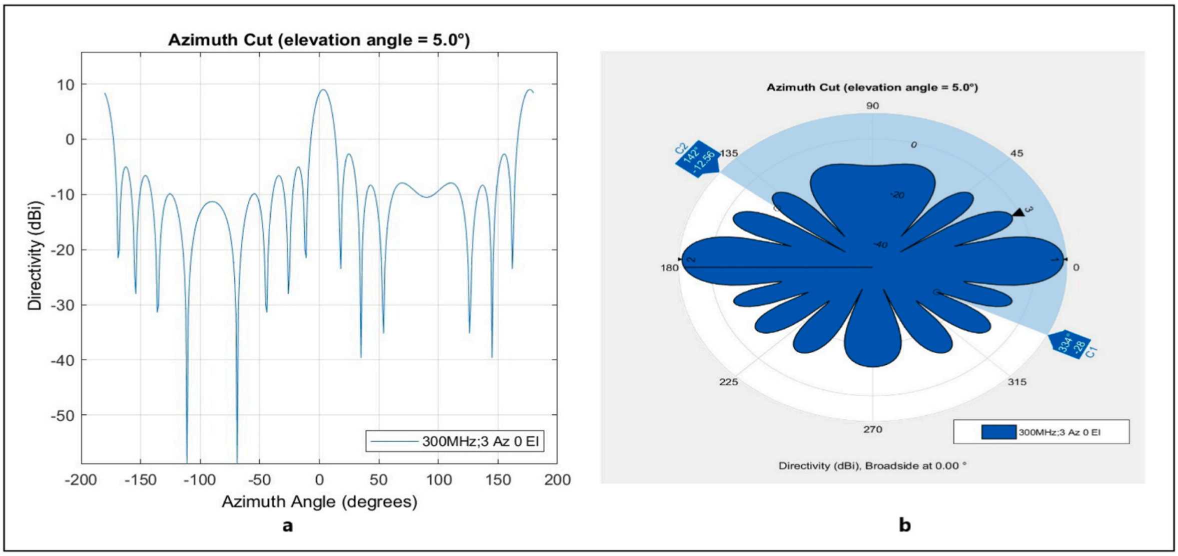

Fig. 7. Monitoring system scenario.

its impact on the environment, knowing that the Beamforming technique has this ability to focus on the targeted node; a multitude of schemes can be used to realize the Beamforming technique. In this section the results are presented for the proposed simulations. To verify the effect of the scheme proposed in this paper, the simulations are carried out under the conditions of regular vehicle noise, i.e., under these conditions, the vehicle movements are assumed to be swaying along the axis, lifting along the axis, and rotating around the axis, as shown in Fig. 4. The steps of the simulation are as follows.

Fig. 3 shows the interaction between the different parts of the system, the noise coming from the different targets (vehicle) taking into account the road condition is measured by the antenna arrays (Beamforming) connected to accelerometers and a dedicated unit that allows a good noise conditioning, the MUSIC algorithm interacts with the antenna arrays for a good orientation towards the target, thanks to the Euler parameters that are obtained using the orientation filter knowing the attitude error and the antenna array pattern after beamforming, the power gain over time for control is obtained. The details of the other elements are shown in Figs. 4 and 5 (see Fig. 6).

As the vehicles on the road do not have the same positioning, some of them are in the centre and others tend to be towards the edge of the road, this can be seen clearly in Fig. 7; then the data is saved to our database/storage which will send them back to the MUSIC algorithm to perform the decomposition and classification of the vehicle noise to give us the outputs (VNRC, VNRGC, noise difference). These data are then sent back to the second part of the database for post processing.

Fig. 5 a and Fig. b show the different parameters of the antenna on the azimuth point, the azimuth degree and angles as well as the directivity in dB.

3.1. Sizing

If the thickness of the substrate is small, the electric field is oriented along the z axis and independent of z. As a summary, here is a procedure for designing an antenna. This can be used for a first dimensioning. Maybe, we can optimize by using an electromagnetic simulator. The input data are the substrate, electrical permittivity, loss tangent, thickness, and operating frequency. The thickness of the substrate should be such that it satisfies certain constraints. We consider a perfect and infinite ground plane. The calculation of the patch width is:

$$W = \frac{\lambda_0}{2}\sqrt{\frac{2}{1+\varepsilon_r}}; \lambda_0 = \frac{c}{F_{res}} \tag{4}$$

in which the effective wavelength is λ_e, the effective dielectric constant is ε_e, and the calculation of the patch length extension ΔL is given by:

$$\Delta L = 0.412h\frac{(\varepsilon_e + 0.3)}{(\varepsilon_e - 0.258)} + \frac{\frac{W}{n} + 0.264}{\frac{W}{h} + 0.8} \tag{5}$$

In practice, we find: $0,005\frac{\lambda_e}{2} \leq \Delta L \leq 0.01\frac{\lambda_0}{2}$
and the calculation of the patch length L is given by

$$L = L_e - 2\Delta L = \frac{\lambda_0}{2}2\Delta L \tag{6}$$

A typical configuration of measuring the environmental noise is illustrated in Fig. 7.

4. Signal processing

The signal processing: a sub-field of electrical engineering concerned with the analysis, modification, and synthesis of signals such as sound, images, and scientific measurements [8]. Signal processing techniques can be used to improve transmission, storage efficiency and subjective quality, as well as to highlight or detect the internal components of a measured signal. To make this possible we chose the MUSIC algorithm which we found to be the best among other signal processing algorithms; the below subsection briefly explains the MUSIC algorithm.

MUSIC (MUltiple SIgnal Classification) is one of the algorithms used for frequency estimation and transmitter location. This algorithm allows to determine the direction of signals incident on a sensors network even when the signal-to-noise ratio is very low; the reason why we chose this algorithm, since we work with compound signals coming from antennas and the antennas are sensors, so its signals are composed by small signals and each one must have its own frequency [9], so the MUSIC algorithm is well suited for such kind of works the results of its work for the classification separation or separation of the signals are demonstrated on Figs. 8 and 9.

To exploit the MUSIC, for the signal processing part, precisely for the highlighting of signals, we have used the MUSIC algorithm, which also has similarities with the maximum method, the likelihood method and is fundamental with a representation having the one-dimensionality of the maximum entropy. The general approach of the MUSIC algorithm is based on separating the signal from the noise by making use of the eigenvalue decomposition of the covariance matrix of the received signal. The algorithm uses the orthogonal property of the signal and noise space.

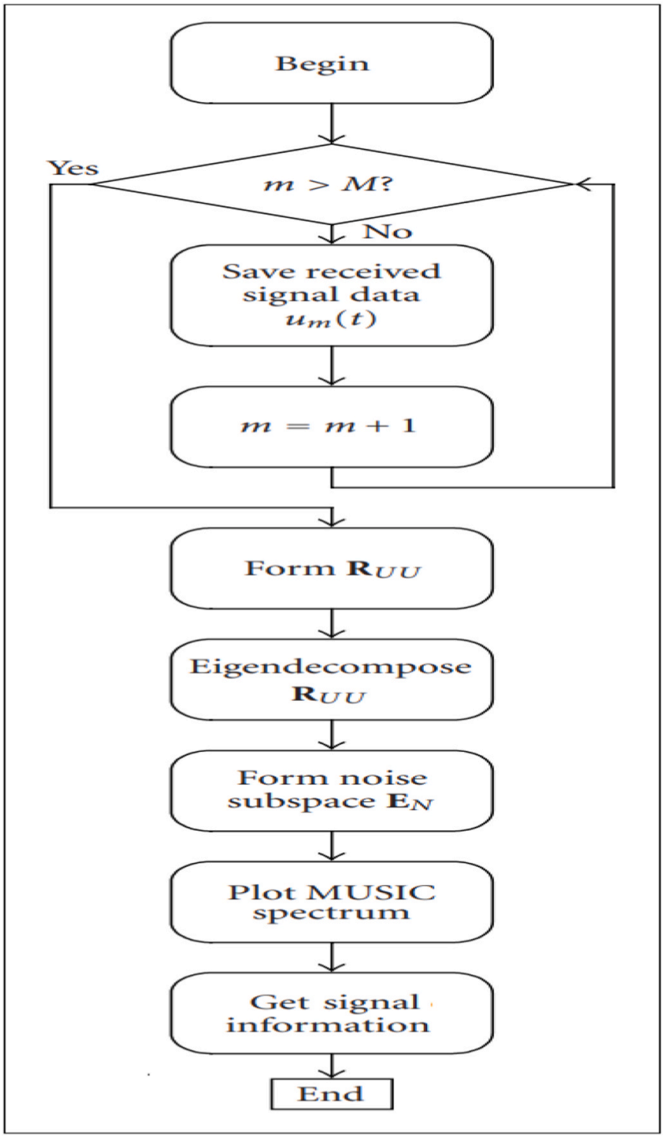

Fig. 8. MUSIC algorithm flowchart
a) Construct the signal sample vector given by $U(t) = [u_1, ..., u_m(t), ..., u_m(t), m = 1, ..., 6$, which is the signal sample when the antenna is at sampling period $\#m$. With U(t), we form the signal correlation matrix R_{ss}
b) Eigendecompose the signal correlation matrix R_{ss} , and form the noise subspace E_N with eigenvectors corresponding to the small eigenvalues.
c) Evaluate the MUSIC spectrum P_{MU} versus the signal direction φ.

We used a subspace of the signal to produce the estimate, when we come to the consideration that the noise and the signal are almost identical, and that the noise of each channel has no correlation. It is important to note that the MUSIC algorithm considers the noise uncorrelated with, and the covariance matrix generated is diagonally natural.

The matrix algebra allows the subsets (other internal signals) of the signal and noise to be separated and found to be orthogonal to each other. Therefore, the MUSIC algorithm exploits the property of orthogonality to isolate (separate) the signal and noise subsets.

4.1. MUSIC algorithm in subspace signal processing

Noise subspace methods are popular for differentiating the diverse parameters or components contained in a complex signal envelope in the presence of uncorrelated noise and have applications in modelling the decomposition of signals and noises. One of these algorithms, MUSIC, can provide solutions or solve this situation.

So, the computational efficiency of MUSIC is relatively low, as it requires an explicit eigenvalue decomposition of an autocorrelation signal from an autocorrelation matrix, followed by a linear search in a large space. Within the MUSIC algorithm, a pseudo-spectrum is generated on the projection of a complex sinusoid onto the entire spectrum of a complex sinusoid onto all eigenvectors of the noise subspace, which define the peaks where the amplitude of this projection is minimal.

We want to make a decomposition of the parameters or components of a composite signal. Let $y(n)$ be the noisy signal, consisting of a deterministic part, $x(n)$, consisting of r real sinusoids and a random noise, $w(n)$. We assume that $w(n) \sim N(0, \sigma^2)$, and that $w(n)$ and $x(n)$ are uncorrelated. The sinusoidal phases φ_i are assumed to be i.i.d.(independent, identically distributed) and uniformly distributed

$$\varphi_i \sim U(-\pi, \pi) \tag{7}$$

$$y(n) = \sum_{i=1}^{r} A_i \cos(\omega_{in} + \varphi_i) + \omega(n) \tag{8}$$

$$y(n) = x(n) + \omega(n) \tag{9}$$

From (8) the vector notation, the signal $y \in \mathbb{R}^M$ takes the character $M \times M$ of the autocorrelation matrix $K_y = E(yy^T)$ As a signal, the autocorrelation matrix coincides with the covariance matrix. Because this matrix is Toeplitz and positively symmetrically defined and see even its eigenvalues are real and non-negative (and positive when $\partial > 0$). We can perform an eigenvalue decomposition on this matrix to get a diagonal matrix $\wedge$ consisting of the eigenvalues, and an eigenvector matrix Q.

The 2_r eigenvectors corresponding to the 2_r largest eigenvalues, Q_x, contain more information about the signal than about the noise, while the remaining $M - 2_r$ eigenvectors, Q_w, represents only the noise subspace. Thus, we can have this relationship:

$$K_y = K_x + K_w + \sigma^2 I \tag{10}$$

$$K_y = Q \wedge Q^H \tag{11}$$

$$K_y = [Q_x Q_w] \begin{bmatrix} \wedge' & 0 \\ 0 & \sigma^2 I_{M-2_r} \end{bmatrix} \begin{bmatrix} Q_x^H \\ Q_w^H \end{bmatrix} \tag{12}$$

Consider a vector of M harmonic (12) frequencies written $b(\omega)[1, e^{jw}, e^{2jw} ... e^{(M-1)jw}]^T$ projecting the vector onto Q_ω, let be the subspace occupied by the noise (where there is no signal component); the below spectrum is a function of a set of ω's:

$$P(\omega) = \frac{1}{b(\omega)^H Q_w^H b(\omega)} \tag{13}$$

$$P(\omega) = \frac{1}{||Q_w^H b(\omega)||^2} \tag{14}$$

For a particular (14) value of ω which is present in the signal, the sum of the projections of b onto the eigenvectors covering the noise subspace will be zero. This is because the subspace occupied by the signal is orthogonal to that occupied by the noise since they are uncorrelated. Thus, we see that $P(\omega)$ will take a very high value in such cases. In conclusion, we can find peaks of the corresponding frequencies of each element contained in the signal, so peaks that are very close together can be found or will appear thanks to the MUSIC algorithm.

MUSIC algorithm flowchart details**:** the details related to the flowchart; the correlation matrix of the output signals has a similar representation: R_{uu}

$$R_{uu} = E\left(U\left(t\right)U^U\left(t\right)\right) = \frac{1}{Ns} UU^H. \tag{15}$$

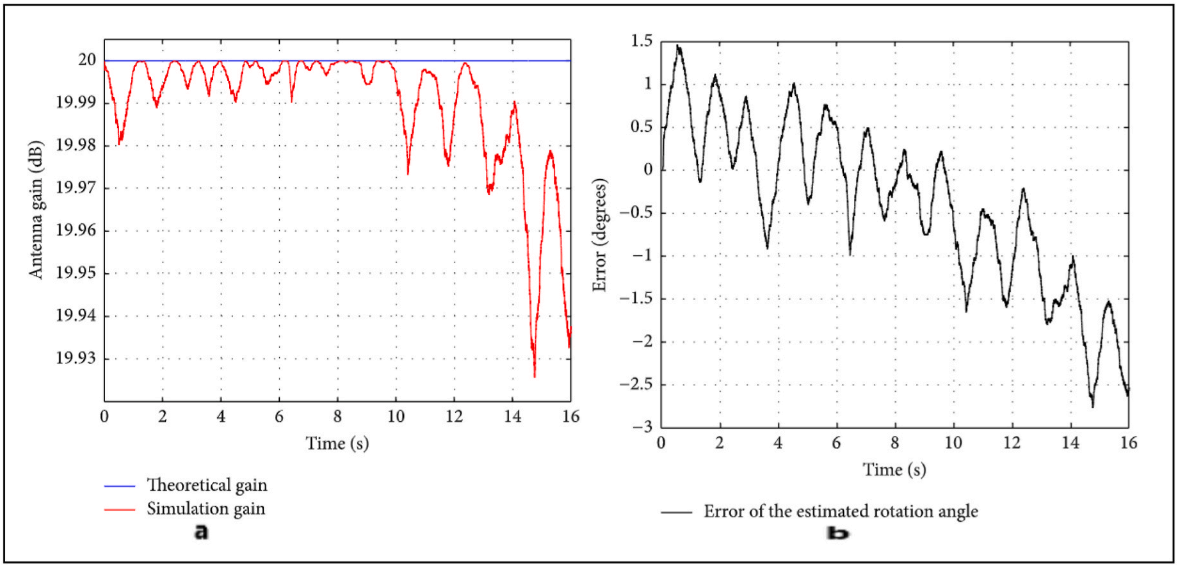

Fig. 9. (a) Typical results for power gain monitoring system block, (b) typical results error.

$E(.)$ is the expected value operator. U Without time argument represents discrete samples with a sample block length N_S. The exponent H denotes the conjugate transposition. We assume that all noise components $n_m(t) = 1, \ldots, 6$ at each sampling period $\#m$ are independent, identically distributed (i.i.d.) with power σ^2. R_{ss} Is then represented as:

$$R_{uu} = [\vec{\alpha}(\varphi_1)\vec{\alpha}(\varphi_2)\ldots\vec{\alpha}(\varphi_K)] \times R_{ss} \quad (16)$$

$$\times[\vec{\alpha}(\varphi_1)\vec{\alpha}(\varphi_2)\ldots\vec{\alpha}(\varphi_K)]^H + \sigma^2 I_{(6)} \quad (17)$$

(17) $I_{(6)}$ is a (6×6) dimensional identity matrix, the correlation matrix of the R_{ss} source signal is:

$$R_{ss} = E([s_1(t)s_2(t)..s_k(t)] \times [s_1(t)s_1(t)..s_k(t)]^H) \quad (18)$$

Based on (15), the MUSIC algorithm is executed according to a similar classical procedure see the flowchart of the MUSIC algorithm. The directional vector is used to obtain the MUSIC spectrum, the algorithm requires that the signals are periodic. Its procedure is described below.

$$P_{MU} = \frac{1}{|E_N^H \vec{\alpha}(\varphi)|^{2,}} \quad (19)$$

where $\vec{\alpha}(\varphi)$ α(φ) is the directional vector that corresponds to the azimuthal viewing direction φ.

Data storage for post-processing: for post-processing, the data are stored in the database as a result of the simulation, once the data are stored, a number of things can be done with them: review the data, display the data on the screen to see an overview of the decomposition of the different signal components.

Antenna arrays characterization and calibration, the procedure consists of four steps: in the first step, the selection of the appropriate calibration technique based on uncertainty analysis and mutual coupling assessment; in the second step, the evaluation of the measurement requirements from the calibration technique to define the measurement campaign; in the third step, the measurement procedure itself; and the last step, the post-processing of the measurement results for the calibration and characterization of the antenna array.

This procedure can be applied to select the appropriate calibration technique and derive the measurement requirements for the calibration of any antenna array. In addition, measurements of the active element patterns are included in the automated campaign for the analysis and characterization of mutual coupling performance.

5. Results and conclusions

We have made use of beamforming during our research for the improvement of environmental monitoring of sources (vehicles, trains,

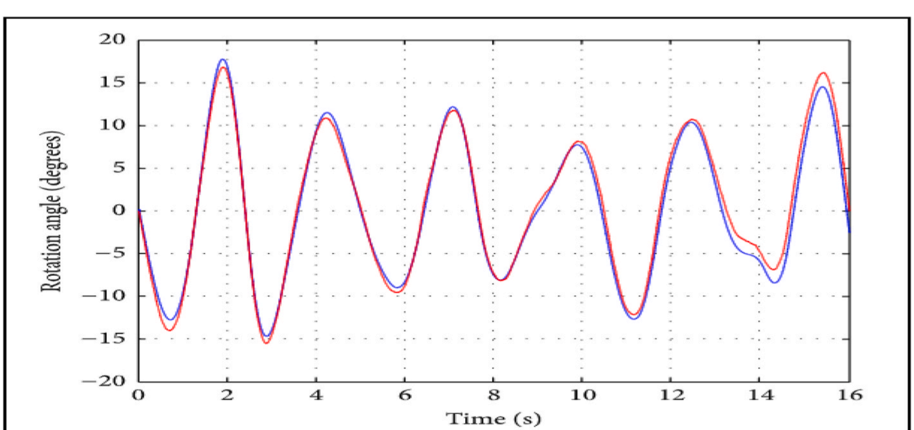

Fig. 10. Typical results for actual and estimation angle φ.

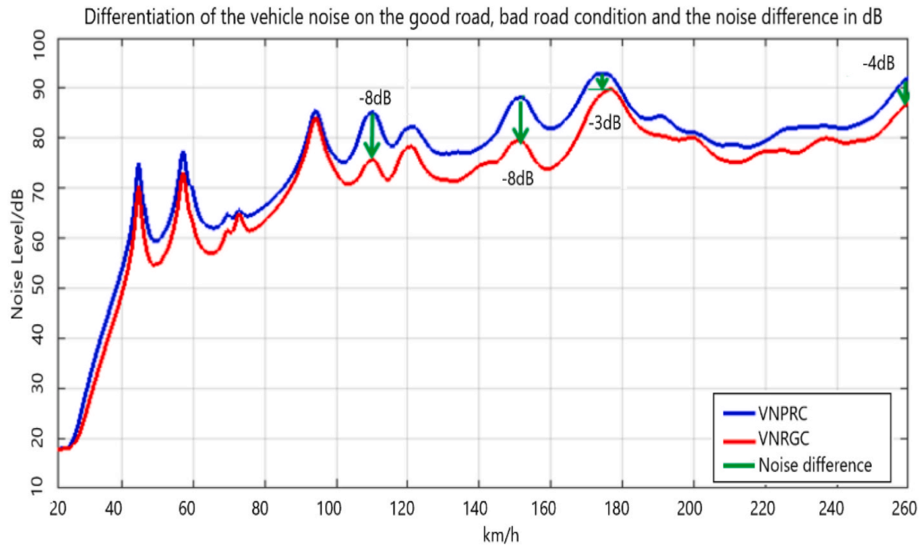

Fig. 11. Differentiation of the vehicle noise on the good road, bad road condition and the noise difference in dB.

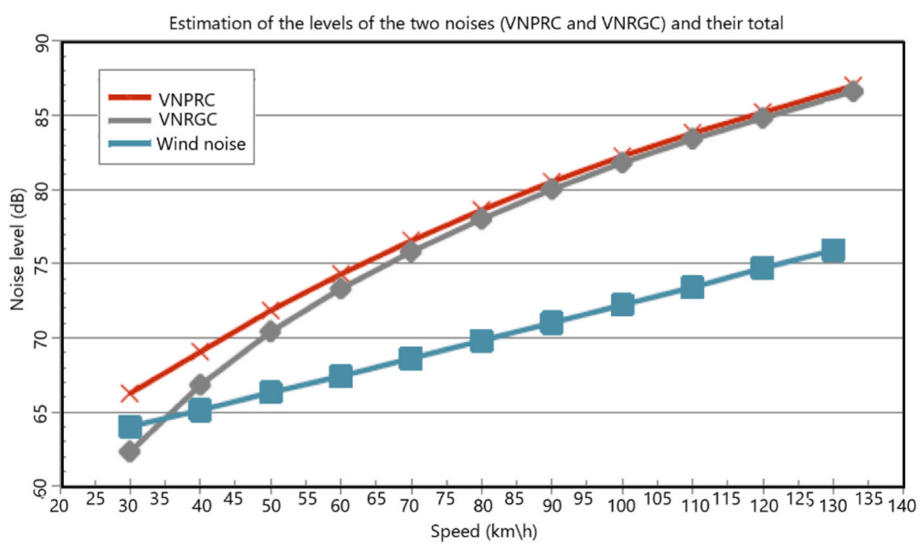

Fig. 12. Estimation of the levels of the two noises (VNPRC and VNRGC) and their total.

aeroplanes, …) of noise in cities and cases like research centres, schools, hospitals, so this approach is illustrated here as results. Considering the real time attitude calculated on some patterns, the relative direction of the target node with respect to the antenna array is obtained; thus, the selection of a method to perform beamforming. Subsequently, the test of the scheme is verified under regular wave conditions. The results show us that beamforming [10] effectively improves the antenna gain. The innovative aspect of this paper is that it uses a method to obtain the relative direction of the target node with respect to the antenna array installed alone outside the antenna array, which permits better monitoring of the area and then performing channel less beamforming.

We can see the results on the graph below, representing the actual and estimated angles. As we can see in Fig. 9, a trace that represents the calculated error in the estimated angles, and in Fig. 9 (a), 9 (b) and Fig. 10, a consideration is made just the trace that represents the estimated angles of the filter follows closely the trace representing the real angles, so the error is included in the interval of −3 and 1.5°.

In view of the simulation results, we emphasize that the beamforming technique can effectively achieve significant power gains. Thus, the same plot also indicates that the gain of the antenna, between 19.93 and 20 dB, is obviously higher than that of the non-beamforming antenna. Thus, the quality and quantity of environmental noise is better discriminated using beamforming.

As the vehicle passes the road near the Beamforming antennas for environmental monitoring system, the vehicle noises are recorded, as the system is equipped with a storage unit and the signals are retrieved and processed to make a difference between the noise of the vehicle driven in the road of good conditions as illustrated with the red colour and the vehicle driven in the road of bad conditions illustrated with the blue colour in Fig. 8; we used the MUSIC algorithm to make this difference of the noises when a vehicle is driven on its two roads of different conditions.

Between the two noises we have a difference in terms of dB which is represented in Fig. 9, hence, the highest difference is -8dB, and the lowest is -3dB, which proves that the parts of the road, either the good or the bad one, we can evaluate with regard to the differences of dB and conclude that the bad part of the road was not destroyed much, because the difference between the two signals is not too high.

In Fig. 11, we have detected on the same signal a third noise during the movement of the vehicle, it is the wind noise, the vehicle that is driving faces the wind's resistance during its advance. The wind hitting the vehicle produces noise and this noise does not come from the engine, it is the external noise, which may not have the same number of dB as the engine noise, the wind noise is still lower than the engine noise, Fig. 12 shows this difference on the plot.

6. Future work

In the future we plan to continue with the research to associate, in the monitoring system, how to interact with the motorist in real time throughout his journey by informing him regularly of certain parameters produced by his vehicle and those of the road: firstly on the number of dB that his vehicle is emitting in terms of noise when he is driving in the good road and also in the bad (wrong) road conditions, secondly to warn the motorist of the road conditions that he is going to drive in the next hours to minutes, that is to say the state of the road that awaits him; all this with the objective of decreasing the noise pollution in cities with environmental protection. As part of the new research and implementation, we plan to implement the algorithm and store the data in the cloud for easy and remote access. The main goal is to make a gradual migration to smart roads, i.e., a road that interacts in an intelligent way with users.

CRediT authorship contribution statement

John P. Djungha Okitadiowo: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Visualization, Investigation, Writing – review & editing. **A. Lay-Ekuakille:** Supervision, Writing – review & editing. **T. Isernia:** Validation. **A. Massaro:** Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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