A Smartphone Application for Car Horn Detection to Assist Hearing-Impaired People in Driving

Cleyton Aparecido Dim(✉), Rafael Martins Feitosa, Marcelle Pereira Mota, and Jefferson Magalhães de Morais

Universidade Federal do Pará, Belém, Brazil
{cleytondim,rafaelmf,mpmota,jeffersonmorais}@ufpa.br

Abstract. This paper presents a smartphone application that displays an onscreen alert and emits a vibration if a car horn is triggered in the traffic, aiming to assist hearing impaired people in driving vehicles. The stages of the construction process are detailed and ways of obtaining the sound frequency of a real-time noise with algorithms using Fast Fourier Transform are discussed, as well as the crossing of these with usual frequency ranges in car horns. The paper also discusses the problems faced in the detection of frequency bands in real traffic, related to the Doppler effect. The testing methodology includes simulations and uses the application in a real traffic environment. As a result of this work we obtained a functional application, customizable by the user, capable of detecting automotive horns.

Keywords: Horn detection · Smartphone · Fast Fourier Transform

1 Introduction

In a society that aims to promote the social and digital inclusion of people with special needs, inclusive actions must extend to the transit system. People must have freedom and ease of movement, enjoying their right to come and go. A breakthrough in this regard is automobiles adapted for people with specific physical needs for mobility or motor coordination.

Several technological advances facilitate drivers' maneuvers through different types of sensors, such as parking sensors, reverse camera or 360° camera. These advances serve as a complement for people without special needs and as an aid for people who have some visual deficit that compromises a good view of the environment around the car in various maneuvers. In Brazil, for instance, the Brazilian Traffic Code [1] admits the inclusion of people with special needs in driving motor vehicles, when the specifics of each case are analyzed by commissions established by state and district transit councils.

However, when we think of hearing impairment, we do not have as many technological advances to assist a person driving a vehicle. Some researches [2]

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show the difficulties for the hearing impaired from the process of obtaining a driver's license in Brazil, passing the legal exams, until the act of driving itself, where it is reported that they can drive vehicles normally, but need a lot of attention around them during driving since they rely a lot on visual signals and little or nothing on ambient sounds.

Therefore, the hearing impaired person needs a sound-sensory complement that allows him to know if a horn was triggered in the surroundings and that, therefore, he must be more alert to his surroundings to avoid any accident. By analyzing the horn pattern it may also be possible to inform the driver of the direction of the sound source or even indicate what information the driver who triggered the horn is trying to pass to others, in traffic, as a green light alert, feelings of anger and thanks.

Thus, a person with hearing impairment can be assisted by a system that reports whether a horn has been blown, the direction of its origin, and, possibly, what is the intention of the emitting driver, making it possible to take the most appropriate measures in the direction. Some examples of initiatives to help the hearing impaired are works that are dedicated to alerting the driver about the occurrence of a siren in traffic [5], or that try to identify and classify sounds in the alarm category [3] (bell, horn, siren, among others). But none of them tries to specifically identify horns in the traffic environment using a common smartphone.

The purpose of this article is to present the development of a smartphone application that captures the sounds of the environment and identifies whether a horn has been triggered, informing the driver by displaying an alert on the screen and emitting a vibration.

The article is organized as follows. Section 2 deals with related works. Section 3 describes the methods developed for horn identification. Section 4 presents the developed application. Section 5 presents the test results of using the application and discusses open problems. Finally, Sect. 6 presents the final considerations and future work.

2 Related Works

Given the social relevance of the topic, efforts are being made to include people with hearing impairments in traffic. In the literature we found a proposal for a traffic sound detection of sirens [5] through the analysis of frequencies extracted with Fast Fourier Transform (FFT), embedding the system in a device of the MyRIO platform and counting on accuracy of around 90%. However, this work is limited to the detection of sirens for emergency vehicles such as ambulances and police cars and is not dedicated to the detection of specific horns

Also with the motivation to assist the hearing impaired, although not necessarily in an approach of driving vehicles in traffic, there is a work where two ways of detecting different sounds in the category of alarms are verified [3], such as horns, sirens, fire alarms, bells, and ringtones, among others. The first way is through a Neural Network trained with Backpropagation, and the second

with sinusoidal wave analysis in spectrograms. Both proposals resulted in high error rates of around 50%, with the neural network having more false positives and sinusoidal modeling more false negatives. Besides, there is no differentiation between the detected sounds, being categorized only as alarm or non-alarm, and there was no incorporation of the solution in mobile devices for effective use.

Still in the line of neural networks, one research [4] presents a classifier of ambient sounds using the Convolutional Neural Network. This classifier distinguishes sounds between 10 specific classes in an urban environment, including music, dog barking, car horns, and sirens. The data used for the creation of the model and validation was a dataset of sounds related to each sound class. Despite having accuracy rates above 70%, it is not specifically applied for the detection of horns in a traffic environment to aid the hearing impaired, as it is also not proposed to use on smartphones.

Considering the direct analysis of audio in the frequency domain, a work [6] found in the literature that aims to monitor traffic conditions through a smartphone has the detection of horns as one of its components. Using the Discrete Fourier Transform (DFT), an efficient analysis is made to locate peaks at specific frequencies. However, as pointed out in the article itself, there is a great variation in accuracy depending on the environment, and the smartphones themselves, which can have considerable differences in microphone sensitivity. Thus, it was clear that an approach of direct analysis of frequencies, as is the case of our proposal, must be accompanied by the possibility of personalization of the application by the user, which may change the sound sensitivity, specific frequencies or even the algorithm variations which can produce different results in different situations.

In another work [7], the Short Time Fourier Transform (STFT) algorithm is used for better analysis of frequency oscillation, characteristic of sirens. A differential in this research was the application on smart cars, with central processing performed on smartphones. The results of the system evaluation were promising, with the detection being more accurate than the human hearing itself.

Despite having a good accuracy, these works do not include the set proposed in this research: a smartphone application for detecting automotive horns, which in a survey with different manufacturers in Brazil was found to be generally between 400 Hz and 500 Hz. Due to this gap, the system was developed and is detailed in the next sections.

3 Horn Identification

One way to identify automotive horns is to directly analyze the intensity of each frequency range in a beep interval. Since the sound signals are considered temporal functions in the temporal domain, they need to be converted into another domain: frequency, spectral. This conversion is performed through the Discrete Fourier Transform (DFT), which is obtained through the application of the FFT algorithm [8]. The difference between the two domains is shown in the Fig. 1, with the X-axis growing in time in the temporal domain and growing in frequency in the spectral domain.

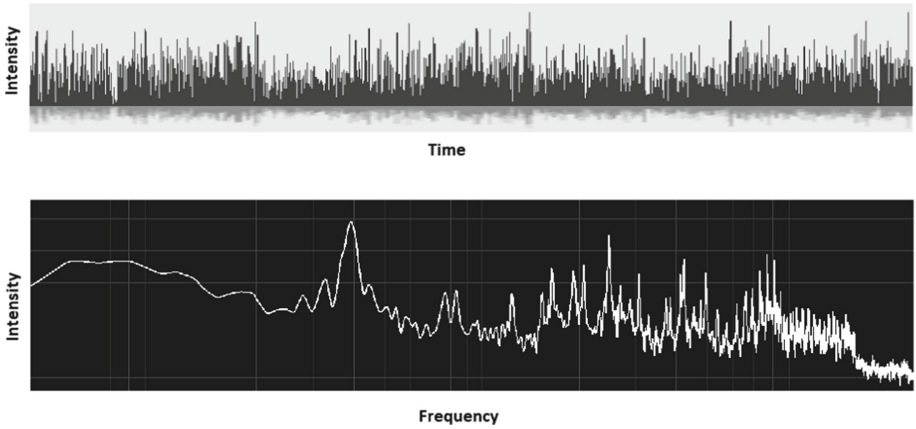

Fig. 1. Sound signal in time and frequency domain

An audio signal is represented computationally by an intensity vector. Applied in an FFT function, a vector is returned whose indexes correspond to a certain frequency range, and their values corresponding to the intensity of the sound in that frequency range. In this work, the JTransforms library of the Java programming language was used to apply the FFT function.

With the new vector, now in the frequency domain, a calculation must be applied to know which frequency range each index in the vector represents. For this, it is necessary to have the sampling rate at which the audio was captured and the vector size obtained by the FFT function, applying the following calculation to obtain a Frequency X Intensity matrix: For every element of the FFT Vector, there is a linked sound intensity with a frequency, such that

$$Frequency = (SampleRate * ElementIndex)/VectorSize. \quad (1)$$

The Frequency X Intensity matrix obtained is the object of analysis to verify if a horn was triggered in the environment. Two different approaches were used to perform the verification: analysis of average frequency intensity and analysis of maximum frequencies. For each approach, a frequency cancellation vector can be used to calibrate the system, removing the fixed noise that will occur throughout the driver's journey, for example, the noise of the car engine.

3.1 Average Frequency Intensity

In this approach, the general average intensity is obtained, considering each frequency range. The maximum available intensity in the matrix is also obtained. With these two values, it is verified if any frequency of the frequency range of Brazilian horns, 400 Hz to 500 Hz, with a tolerance of 30 Hz to more or less, then considering 370 Hz to 530 Hz, has: i) intensity greater than or equal to the general average; ii) intensity greater than or equal to half the maximum

intensity of the matrix; and iii) intensity greater than or equal to the sensitivity parameter, corresponding to the minimum intensity.

If it is verified only if the intensity in the target frequency range is equal or above the general average, a large number of false positives are obtained, since most of the frequencies have an intensity close to zero, reducing the average. As a result, it is checked whether the intensity is also equal to or exceeds half of the fundamental frequency of the sample, which is the frequency of greatest intensity.

Half of the intensity is considered because, in addition to the fact that horns operate in two different frequency ranges, there may also be background noise that exceeds the perceived intensity of the horn, especially when the source is more distant, which would increase the number of false-negative, with the system not detecting weaker horns or having two frequency ranges.

Finally, it is verified if the intensity in the target frequency range is higher than the sensitivity parameter (minimum intensity) so that very low noises, which may not be horns, are not considered since there are background noises in the target range, emitted by the car itself, which could be perceived as horns. The Fig. 2 illustrates the identification of horns by average frequency intensity, showing respectively a case in which a horn does not occur and is not detected by the system, and a case in which the horn occurs and is detected. Algorithm 1 shows the pseudocode of horn detection by average frequency intensity is shown.

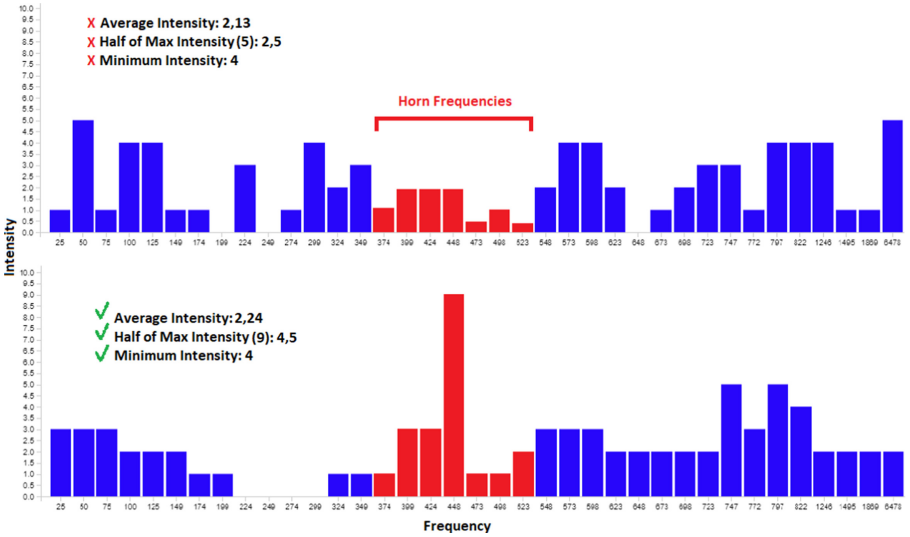

Fig. 2. Identification of horns by average intensity

Algorithm 1. Average Intensity Algorithm

```
Get Parameters (fmi, fma, i)
md = findAverageIntensity(Matrix)
mo = findHalfMaxIntensity(Matrix)
repeat
  Get next matrix element(fq, in)
  if fq ≥ fmi And fq ≤ fma And in ≥ md And in ≥ mo And in ≥ i then
    Return "Horn Detected"
  end if
until reading whole matrix
Return "Horn not Detected"
```

In the algorithm, the acronyms fq, fmi, fma, in, md, mo, i, are respectively the frequency under analysis, the minimum and maximum frequencies considered as horns, the intensity in the frequency, the average intensity, the medium of the maximum intensity and the minimum intensity to be considered.

3.2 Maximum Frequencies

In the detection by maximum frequencies, the 3 frequency bands of greater intensity are searched in the matrix, verifying next if one of these 3 frequencies is in the horn frequency range, 370 Hz to 530 Hz, including the tolerance. It is also checked whether the frequency considered reaches or exceeds the minimum intensity parameter.

It is not only analyzed the maximum frequency due to the possibility of some background noise reaching a higher intensity than the horn, as well as because of the operation in two frequency ranges in some horns. Thus, the three most intense frequencies are considered to reduce the occurrence of false negatives. Although reduced, false negatives can occur if the environment is loud with high-intensity noise at different frequencies when a horn is triggered. The Fig. 3 illustrates the identification of horns by maximum frequencies, showing, respectively, a case in which a horn does not occur and is not detected by the system, and a case in which the horn occurs and is detected. In Algorithm 2, the pseudocode for horn detection by maximum frequencies is displayed.

3.3 Frequency Cancellation Vector

Situations were found during tests in which the number of false positives was high, such as the operation of the vehicle's engine, affecting both detection modes: by the medium intensity and by the maximum frequencies, as the background noise activates many frequency bands.

To avoid false positives, it was necessary to decrease the sensitivity of the system, informing a higher parameter of minimum intensity. However, this solution can prevent the system from detecting more distant horns, which reach the smartphone with low loudness.

One solution found was to use a vector of initial frequencies to cancel, until its limit of intensities, the readings of the later frequencies. It is a system calibration

Algorithm 2. Maximum Frequencies Algorithm

```
Get Parameters (fmi, fma, i)
mxFqs = findMaxFrequencies(Matrix)
repeat
  Get next matrix element(fq, in)
  if fq ≥ fmi And fq ≤ fma And fq In mxFqs And in ≥ i then
    Return "Horn Detected"
  end if
until reading whole matrix
Return "Horn not Detected"
```

that when starting the sound verification, firstly the intensity of each frequency is captured. In the sound analysis phase, for each captured audio segment, the corresponding intensity that was captured at the beginning is subtracted from each frequency range. Thus, it is better to start the verification with the vehicle's engine running, so that the intensities of the frequencies emitted by the vehicle will be captured, being subtracted later in each verification.

With the use of the frequency cancellation vector, there is also the subtraction of intensities in the frequency range corresponding to the horns. Thus, the minimum intensity parameter must be reduced so that the most distant horns are detected.

4 Application Development

A smartphone application was developed to detect automotive horns, with adjustable parameters of minimum frequency, maximum frequency, minimum intensity and choice of algorithm to be used in the detection. This application emits a red visual alert and a vibration when a horn is detected. The .apk file to install on Android smartphones is initially available for testing at this address: http://www.filedropper.com/horncheck, to be later made available for free on GooglePlay Store.

The platform chosen for the development of the application was the Android operating system, due to the high participation in the smartphone market, reaching 86.6% in 2019 [9], with a growth trend in the coming years. For coding, this application, the Android Studio development environment with Java programming language was used. JTransforms were used as auxiliary libraries to apply FFT and Musicg functions for manipulating audio data in wave format. The other features such as audio capture and vibration activation were programmed with native Android libraries.

The application has three main screens: the home screen, the settings screen, and the detection screen. The home screen points to the others. In the settings, parameters allow the user to personalize the horn detection by changing, for example, the minimum intensity of the sound to be considered. The detection screen activates the system and emits red visual and vibration alerts if a horn is detected. Figure 4 shows the application screens.

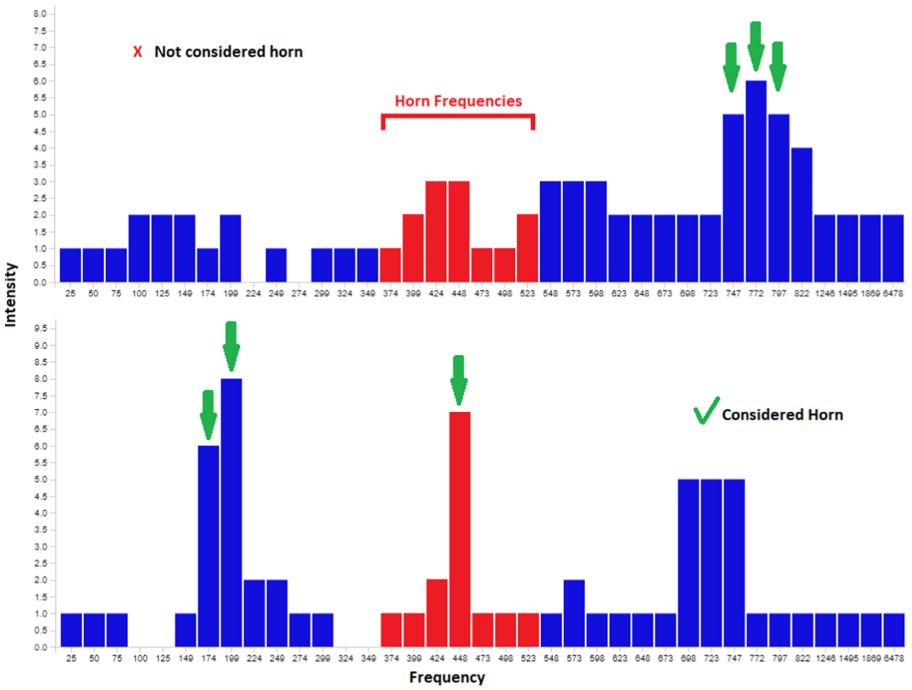

Fig. 3. Horn identification by maximum frequencies

Customizing the application with parameters on the settings screen allows the user to change the frequency range and the minimum intensity, and select the type of calculation to be performed in the detection of the horns. He can choose the calculation based on the average intensity by checking the corresponding option, otherwise, the algorithm used will be the one that considers the maximum frequencies. Also, he can select the option of using the vector of canceling initial frequencies, which will be used in the chosen algorithm.

During the testing phase, a results evaluation module was temporarily incorporated into the application. This module consisted of a screen where the horn detection operated in the background without triggering alerts, with the occurrence of a horn being recorded in an internal file with the time of the event and the configuration parameters used. At the same time, the tester pressed a button on this screen when a horn was heard, and this event was recorded in a second internal file with the time it occurred. There was a third button to record anomalous occurrences in this last file, such as an unusual noise inside the vehicle. Thus, for later evaluation, two files were obtained: one with the occurrences of horns detected by the application, and another with the occurrences of horns heard by the tester, in addition to the anomalies recorded by him. Figure 5 shows this evaluation screen, later removed from the application.

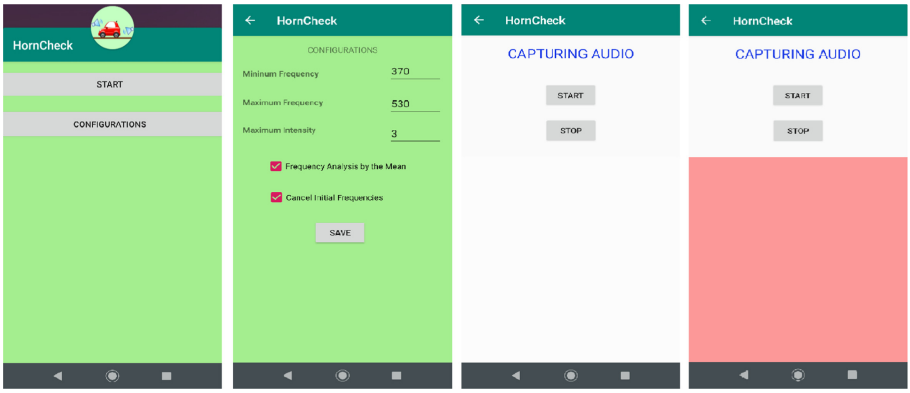

Fig. 4. Application screens

5 Results Obtained

Three simulated scenarios and a real traffic scenario were tested. Each scenario was tested for all the combinations of algorithms available in the application: average intensity without frequency cancellation vector, the average intensity with cancellation vector, maximum frequencies without cancellation vector and maximum frequencies with cancellation vector, adding up to a total of eight different tests performed. Each scenario had several events analyzed ranging from 80 to 100.

The first simulated scenario refers to the verification in real audios of horns of different vehicles on a computer. The second scenario was to check the horns emitted by the vehicle parked with the engine running, with the tester inside this vehicle. The third scenario involved checking horns emitted by a collaborator's vehicle parked at different distances from the tester's vehicle also parked, with a range of distances between vehicles varying from 10 to 80 m. The last scenario was real traffic, with the tester being in the passenger seat while an assistant was driving the vehicle. Table 1 lists the percentage of the accuracy of the horn detector in each scenario, considering the horns heard by the tester.

It is observed in the results table that the accuracy of the simulated scenarios is significant. In the identification of horns emitted by a computer, 95% was achieved with the medium intensity algorithm, reaching 98% when the frequency cancellation vector was used. The algorithm that deals with the identification of maximum frequencies obtained 76% of correct answers with and without the use of the null vector.

In the scenario of own horns, being emitted by the vehicle where the tester is located, both algorithms reach a 95% or more hit rate, reaching 100% in both when using the frequency cancellation vector.

The third scenario, of two cars parked at variable distances in each horn event, has a drop in the hit rate, but maintaining a level above 70%, reaching 80% or more when using the cancellation vector, in both algorithms.

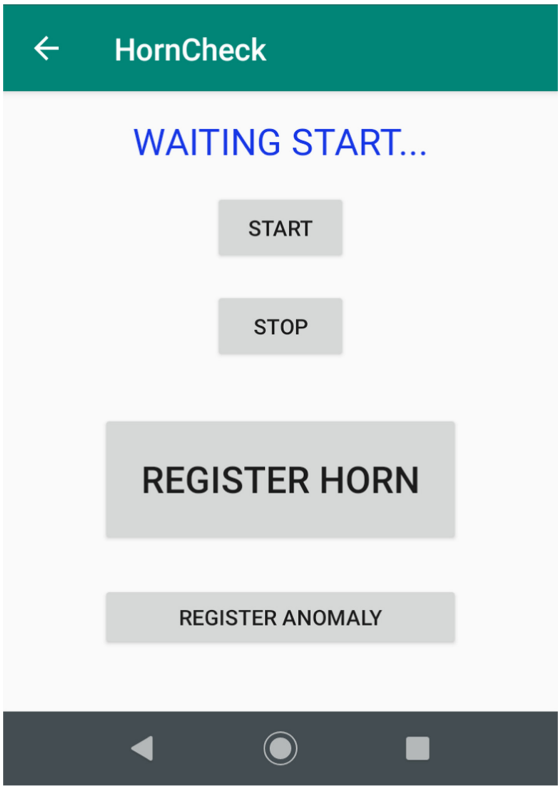

Fig. 5. Evaluation module screen

In the real traffic scenario, accuracy has dropped considerably across all algorithms available in the app, ranging from 35% to 45%. After a temporal analysis of the frequencies in the occurrences of horns, it was found that in real traffic the frequency ranges of the horns oscillated in a proportional displacement pattern when reading their intensities.

From the oscillation pattern, it was realized that it was the Doppler effect [10], which occurs when the source of the sound waves is in motion to an observer. In the Doppler effect when a sound-emitting object is moving, the sound that propagates in the direction of its movement is more bass than the sound that propagates in the direction opposite to its movement. This effect is verified in several works, with one [11], in particular, having presented an experiment on this frequency variation.

Since in real traffic the vehicles are in motion, the sound frequencies perceived by the detector will not always correspond to the frequency originally emitted by the horn. This occurs, for example, when a vehicle is honking behind the tester's car as it approaches. The perceived frequency of this horn will be more treble,

Table 1. Accuracy in each scenario for each algorithm

Scenario	Avr.	Avr. vector	Max.	Max. vector
Computer	95%	98%	76%	76%
Own horn	97%	100%	95%	100%
Parkeds	72%	80%	75%	82%
Real traffic	35%	42%	41%	45%

higher than the original frequency and likely to be outside the range established in the application.

It also occurs in the opposite situation, in which the vehicle is honking its horn in front of the tester's car while moving away from it. In this case, the perceived frequency of the horn will be more severe, lower than the original frequency, also likely to be outside the established range. Figure 6 shows this decrease in the frequency of the sound of a vehicle's horn in front of the tester as it moves further away, showing the shift of frequencies to the left.

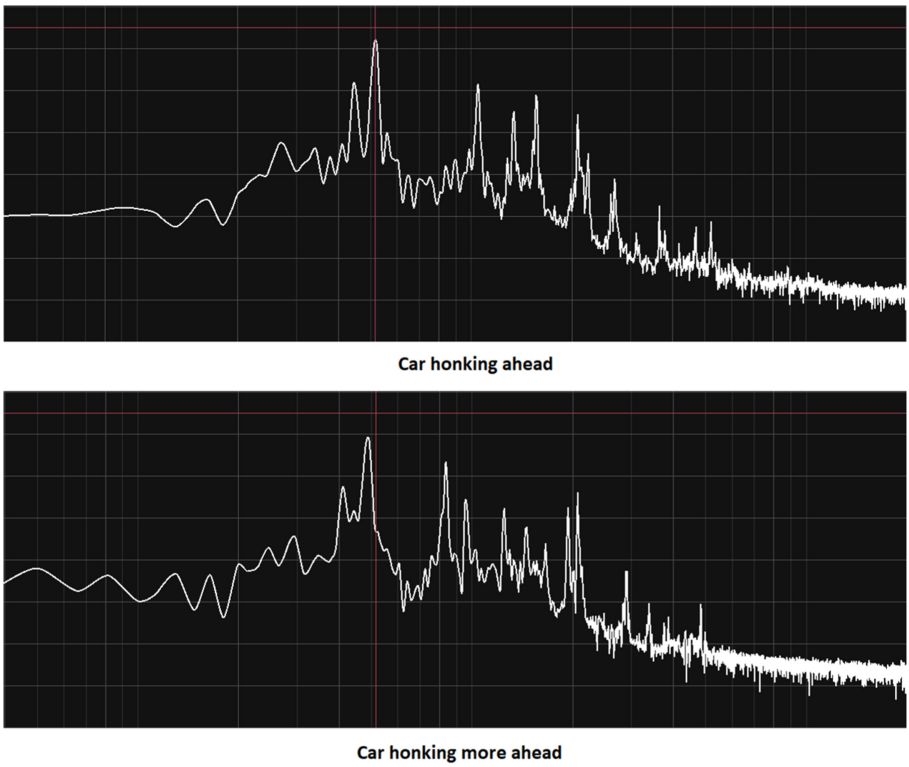

Fig. 6. Doppler effect on a moving vehicle's horn

A solution to improve the accuracy of the detector to face the problem of the Doppler effect could be to expand the frequency range considered as a horn. However, this expansion could result in a high number of false positives, with the system interpreting as background horns that might not be horns. Therefore, the Doppler effect must be analyzed and treated in future works to enable the effective use of the application in real transit, with the least possible number of false positives and false negatives.

6 Final Considerations and Future Work

An application for Android smartphones was developed, capable of detecting whether a horn was blown in traffic, to assist people with hearing impairments when driving a car. This application is parameterized by the user, who can choose the frequency bands, the minimum intensity and the algorithm that will perform the verification.

The application uses the Fast Fourier Transform to obtain the frequencies of the sounds and different algorithms to detect the occurrence of automotive horns.

The horn detection system was evaluated with a temporary internal application module, for recording and later analysis of the detected and heard horns. In the evaluation it was found that in real transit, due to the Doppler effect, the accuracy of detection drops considerably, being considered low. The immediate possibility of circumventing the problem that arose due to the Doppler effect would be to increase the frequency range considered as a horn, which could have the negative effect of increasing false horn detection.

For this reason, it is proposed as a future work the improvement of the horn detection system through the treatment of the Doppler effect. A possible way to solve this problem is to analyze sound frequencies temporarily, looking for the proportional and linear increase and decrease patterns of frequencies to detect vehicle horns approaching or moving away from the user.

Another possibility for improving the detection system is the incorporation of machine learning algorithms to analyze the characteristics of sound stretches. Among the possible classifiers can be investigated: decision trees, k-Nearest Neighbors, support vector machine, neural networks, among others.

As a complement to a horn detection approach with the aid of machine learning, the separation of sound sources can be investigated for the analysis of the events separately, as proposed in a paper [12], which presents a method of distinguishing sound sources and performs individual detection through statistical models. This separation of sound events can contribute to the reduction of false positives and deserves to be investigated for incorporation in the horn detection system developed.

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