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Aircraft noise detection using continuous wavelet transform

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Abstract. *This work aims to develop a method for aircraft events identifying from landing and takeoff procedures which eliminates the use of radar data. This method is crucial for monitoring aircraft noise; it allows determining the contribution of each aircraft through the metric SEL (Sound Exposure Level) and* LA_{MAX} *(maximum A-weighted noise sound). Data acquisition was performed using a sound pressure level meter installed at some critical receptors in the vicinity of the Rio de Janeiro International Airport. The sound events are characterized by the superposition of the aircraft noise together with the environmental noise of the area. The Mexican hat continuous wavelet transform was applied to time series obtained in measurements. The obtained results indicate a good performance of the wavelet transform of detection, and identification of the aeronautical events*.

Keywords: *aircraft noise, wavelet transform, sound event detection*.

1. INTRODUCTION

The airport noise is divided into noise sources (movement of aircraft during landing operations, takeoff, and overflights) and noise sources on the ground (taxiing aircraft, auxiliary power unit – APU, testing engine and support equipment in soil). The present study deals with the noise generated by the movement of aircraft in operation.

An aeronautical event is the passage of an aircraft during the procedure for landing, takeoff and flyby. These events have a significant impact, as they produce an intermittent sound field that directly affects the quality of life of a large number of people residing and / or pass near large airports. The airport noise has several adverse effects on the communities adjacent to airports. Among these effects, there is interference with communication, sleep and also the feeling of discomfort (Bentes, 2011).

Thus, the monitoring of airport noise around airport is an activity of great importance, especially in areas where urban settlement is consolidated.

The monitoring aims to determine the levels of sound pressure and characterization of the sound environmental impact generated by aircraft around the airport and provide subsidies for the guidance of the control actions of the impacts assessed from the results of the monitoring in some critical receptors.

Monitoring systems for aircraft noise adopted at major airports of the world are based on the intersection of noise levels that exceed certain value (trigger) with information from the flight path of the aircraft obtained radar data.

Thus, aeronautical sound events are identified by a threshold sound level detection, however, the problem is to ensure that the event detected is actually produced by any aircraft.

The RBAC 161 (2011) establishes that the operator of airports which annual average of the aircraft movements over the last three years exceeds 120,000 and having regions of residential or mixed use in over 50% of the areas defined by the curves defined noise thereof shall submit to ANAC (National Civil Aviation Agency) a noise monitoring project.

In this context, this paper aims to focus on the noise monitoring at airports in certain places, with emphasis on the identification and detection of aviation events based on processing of acoustic data recorded with the data logger.

DRESS and KERCEL (1994) used wavelet transform orthogonal Daubechies for recognition and identification of sound events. The wavelet coefficients were calculated from a simple recursive algorithm, which uses a bank of filters with tree structure proposed by Mallat (1989a and 1989b). The recorded signals were designed in subspaces orthogonal wavelet coefficients both in the details as approximations. The advantage of signal analysis in wavelet subspaces is that the time characteristic is not lost. The transform of Daubechies wavelet subspaces 12 provided for each aircraft event. In most cases, the coefficients of the detail of five to eight levels were sufficient to identify the event. However, for some events, such as jet aircraft, a significant portion of the energy resides in levels one to four. The results showed good performance in signal processing for recognition of aviation events.

Dufournet and Jouenne (1997) developed new instruments for noise analysis able to automatically identify and quantify, in real time, several outlets in a given environment and evaluate its impact effect. This project became known as Madras. The data base includes high-quality recordings of various noise sources such as cars, trucks, motorcycles, mopeds, aircraft, electric saws, industrial plants, etc. To characterize passing vehicles, it was trained a neural network with over a thousand different real standards by third octave spectra, in the range of 50 Hz to 5 kHz to distinguish cars, bikes, trucks. To treat occurrences of aircraft overflight, suggested an analysis using Daubechies wavelet.

The present work is to develop a method for segmentation of the sound signal events in the aeronautical and non-aeronautical origin. The sound events are characterized by the superposition of the noise movement of aircraft operating together with the local ambient noise. For such algorithms were built in Matlab, using the continuous wavelet transform (TWC) and applied in LAeq(t) time history obtained during a measurement procedure.

2. WAVELET TRANSFORM

The wavelet transform is defined as the inner product of the function f (t) and, $\psi_{a,b}\ (t)$ according to Equation 1.

$$C_{a,b} = \langle f(t)\psi_{a,b}(t)\rangle = \int_{-\infty}^{\infty} f(t)\psi_{a,b}(t)dt \tag{1}$$

The function ψa, b (t) is defined by Equation 2.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi^*\left(\frac{t-b}{a}\right) \tag{2}$$

In which, and b are two real parameters and $\psi *$ denotes the complex conjugate of a function so-called wavelet. The term $(1 / | a |^{1/2)}$ is a normalization factor that ensures the energy $\psi_{a,b}(t)$ is independent of the parameters a and b, such that the Equation 3 is valid.

$$\int_{-\infty}^{\infty}\psi_{a,b}(t)dt = \int_{-\infty}^{\infty}|\psi(t)|^2 dt \tag{3}$$

The parameter b indicates that the function $\psi(t)$ was shifted to the t-axis a distance equivalent to b, and then, a translation parameter. Mathematically, delaying the function f (t) by b is represented by f (t - b). Thus, Continuous wavelet transform (CWT) can be rewritten as Equation 4.

$$C_{a,b} = \frac{1}{\sqrt{|a|}}\int_{-\infty}^{\infty} f(t)\psi^*\left(\frac{t-b}{a}\right)dt \tag{4}$$

By varying the values of scale (a), and translation (b), yields the wavelet coefficients of C (a, b).

2.1 Mexican hat wavelet transform

The Mexican hat wavelet is a function proportional to the second derivative function of the probability density function of Gaussian ($0.5e^{-t^2}$) (Mallat, 1998). The function is represented by equation 5 and graphically in Figure 1.

$$\psi(t) = (1-2t^2)e^{-t^2} \tag{5}$$

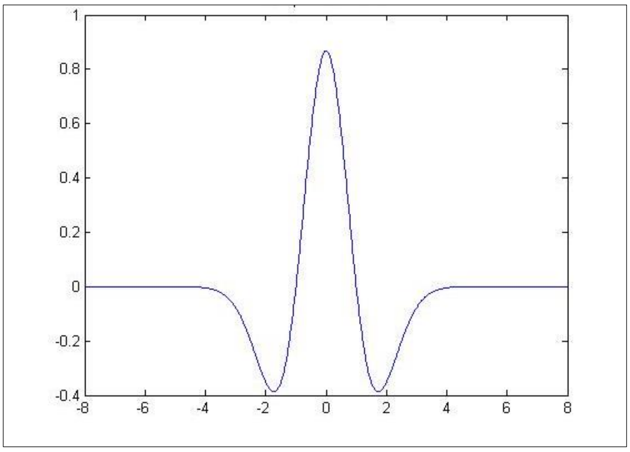

Figure 1. Mexican hat wavelet transform

Nevertheless, before applying the CWT to signal, you must choose a mother wavelet that presents good performance in detection of sound events. The choice of mother wavelet - mexican hat was proposed due to its similar to shape to the sound levels $L_A(t)$ generated by an aircraft overflight.

2.2 Aircraft sound pressure level

The aircrafts (landing and takeoff procedures) are considered a moving sound source. For the case of an omnidirectional source, considering that the mobile source moves along a linear path, the sound pressure level at a distance r(t) is given by Equation 6.

$$L_A(t) = L_W + 10\log\frac{1}{4\pi r_t^{\,2}} \tag{6}$$

In which, $L_A(t)$ is the sound pressure level; L_W is the sound power level; d is the distance between source and receiver. From the schematic drawing of Figure 2 has the relation 8.

$$r^2 = d^2 + x^2 \tag{7}$$

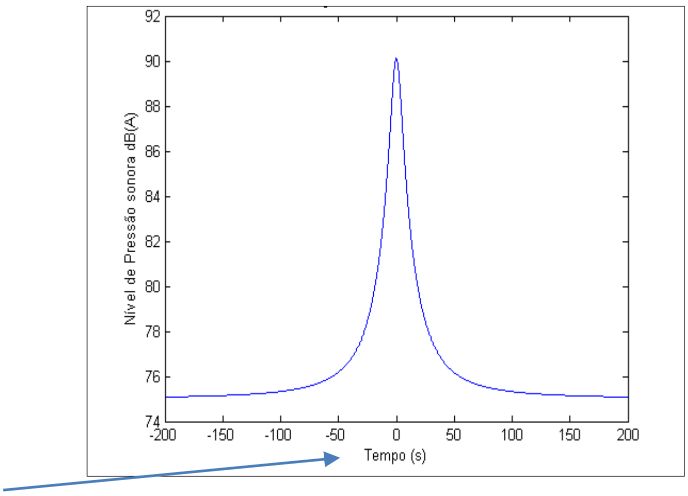

Figure 2: Representation of a flyover

$$L_A(t) = L_W - 10\log\left[d^2\left(1+\left(\frac{vt}{d}\right)^2\right)\right] \tag{8}$$

Substituting x = vt, we obtain the sound pressure level versus time according to Equation 8. Figure 3 shows the behavior of sound pressure levels for an aeronautical event.

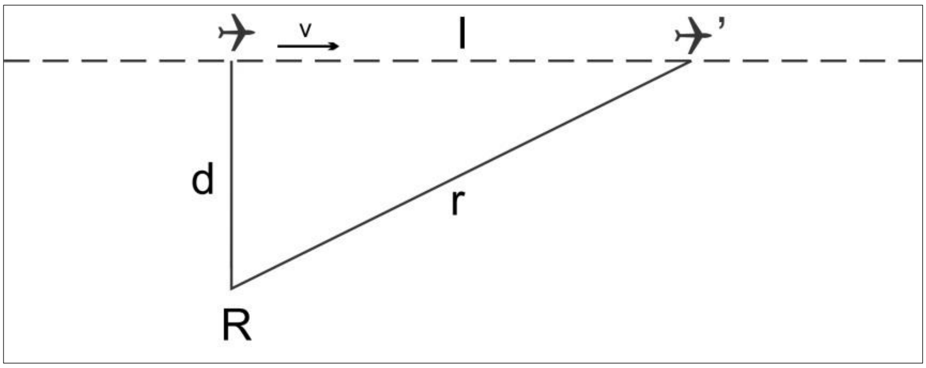

Figure 3. Representation of aeronautical event

3. METHODOLOGY

3.1 Data acquisition

The first stage of work consists of the acquisition of noise levels in receptors located in the vicinity of the Rio de Janeiro International Airport - Galeão. The experimental data were obtained using a sound pressure level meter with capacity to store audio data and sound levels (data logger). The equipment was configured to register the instantaneous pressure sound level - $L_A(t)$ over a 1 second period, during the measurement process. From these data it is possible to obtain the values of SEL and LA_{MAX}) corresponding to each aeronautical event. The sound pressure level meter was installed in the extension of the runway 15. In Figure 4 we can see their location relative to the airport.

3.2 Aircraft noise events detection method

For detection of aircraft sound events were adopted two procedures: a segmentation of data sound pressure level based on NF S31-190 and the continuous wavelet transform.

The detection consists in the analysis of sound levels recorded. When the level of L_{Aeq_1s} exceeds a chosen threshold an event is detected. The automatic classification is the process of identifying of the aircraft events among all registered events, associated with the data of sound pressure level. Usually, only the data $L_A(t)$ corresponding to overflying aircraft are stored, the rest of the measurement is considered as the local ambient noise.

The standard NF S31-190 proposes a segmentation algorithm for the time series of $L_A(t)$ based on the moving average, and then, applies the squares least method to determine the maximum. The change of sign from positive to negative coefficient indicates the slope of the presence of a maximum in the curve $L_A(t)$. Locating the maximum, determines the energy associated with the passage of an aircraft. The moving average is calculated using Equation 9.

$$y(m) = \frac{1}{2n+1} \sum_{n-8}^{n+8} x(m+n) \qquad (9)$$

In this equation x (n) is the time series of levels L_{Aeq_1s}. The maximum detection is performed on the curve y (m). The slope of the line is determined by the least squares method, where a sequence of series marked by the slope of the line is associated with an aeronautical event.

In parallel, the wavelet analysis of the time series of noise levels was made to improve the possibility of detection and localization of sound events. The wavelet chosen must have a close curve that represents the sound event during the passage of an aircraft so why we have chosen a Gaussian mother wavelet family. The program for analysis and detection of aircraft noise events was developed in MATLAB, version 7.10 (R2012a) based on wavelet algorithm implemented in the Toolbox, which has the *cwtft* function to calculate the Continuous Wavelet Transform via inverse Fourier transform. The calculation of the TWC using the FFT algorithm favors the computational calculation of inverse TWC. By calculating the TWC, there are obtained the wavelet coefficients and escalograma indicating a mapping of sound events.

3.3 Validation of aircraft events

The validation of sound events from aeronautical origin was based on crossing data movement operating from the airport provided by Infraero (Brazilian Airport Infrastructure Company) and aeronautical events recorded during the measurement process.

3.4 Sound levels of the aircraft event

Firstly, the sound levels were calculated in SEL, and LAmax metrics. The calculation of these variables was developed from A-weighted sound pressure level time history of an aircraft noise event.

The Maximum Noise Level (LA_{MAX}) is an instantaneous peak noise level measured at an observer location during the time period in consideration as a critical measure of noise level. (Baird, Harder, and Preis, 1997).

The Sound Exposure Level (SEL) is generally used for the assessment of environmental noise such as aircraft, train and road traffic noise. The SEL (sound exposure level) is calculated according to equation 10.

$$SEL_i = 10\log_{10}\sum_{1}^{n} 10^{L_A(t)/10} \tag{10}$$

SELi refers to the passage of each aircraft

After that, obtained sound levels in different metrics were associated with all aeronautical events during the period of analysis.

4. RESULTS

In this section, are presented the wavelet analysis measurements. A receptor characterized the aircraft takeoffs that occurred during the period 09:00 to 11:00. The parameters chosen were: Mexican hat mother-wavelet and linear scaling. The chosen receiver was Sergio Franco Laboratory, located in Duque de Caxias. Figure 4 shows the receiver location.

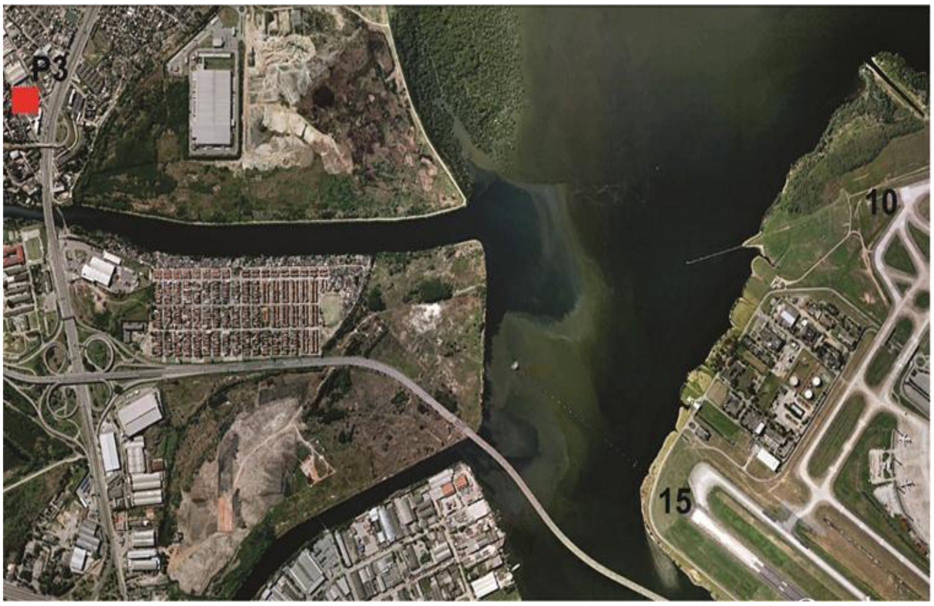

Figure 4. Receiver location

The highest wavelet coefficients are marked by a concentration of energy and are, locally, indicated by area, called cone of influence, which represent the highest noise levels emitted by aircraft overflight. Table 1 lists the events during the measurement period associated to aircraft flights with SEL and LA_{MAX} values , respectively.

Table 1. Aircraft sound events associated to noise metrics

Departure time	**Aircraft model**	**LA_{MAX} dB(A)**	**SEL dB(A)**
09:05	A319	66,3	76,0
09:09:06	E190	68,3	81,0
09:18:50	B738	72,5	84,2
09:29:45	B738	71,8	79,7
09:32:48	A320	77,2	84,5
09:38:08	A320	78,4	88,9
09:42:07	B738	77,7	85,9
09:47:12	A320	80,0	89,5
09:51:14	B737	74,7	85,1
09:55:03	A320	80,6	89,4
09:58:59	B738	78,2	88,3
10:00:43	A320	79,5	89,9
10:05:06	B738	73,8	85,2
10:07:06	A320	77	86,2
10:09:39	C130	83,0	91,8
10:13:08	A320	77,7	89,0
10:15:26	E190	77,3	87,5
10:17:19	A320	81,1	88,7
10:19:14	B738	76,1	85,6
10:26:44	A330	77,8	89,4
10:29:33	B737	68,4	79,3
10:34:02	A320	79,2	88,4
10:45:47	C130	83,6	91,8
10:52:18	A320	79,1	88,9
10:55:49	A319	81,0	90,2
10:58:17	B738	73,2	81,9

The Figure 5 illustrates the wavelet coefficients at different scales. It is observed that the smaller scales (5-15) already contain the location of the peaks associated with aircraft events, thus, it is unnecessary the calculation of the TWC at larger scales. The representation of the coefficients in different scales indicates the shape of the signal resulting of the scalar product of the L_A (t) function for the Mexican hat wavelet with variable width. Comparing the results obtained bulletin airport operation is found that 26 events were detected by the methodology developed by wavelet transform - Mexican Hat.

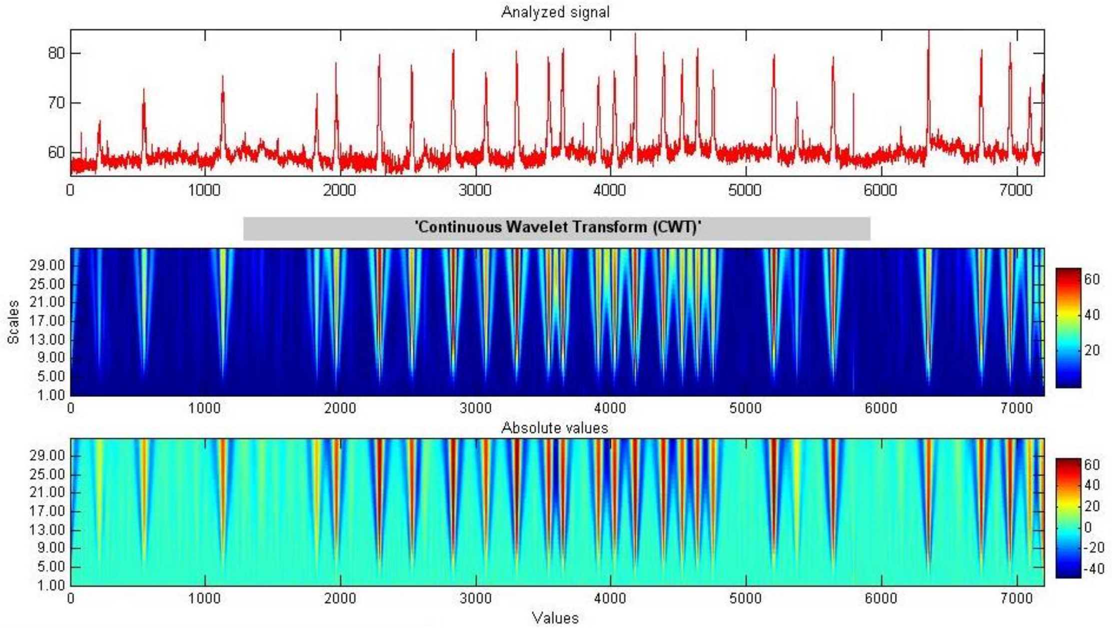

Figure 5. Time series and wavelet coefficients in different scales

5. CONCLUSION

In order to detect and characterize sound events coming overflying aircraft was developed a method for the segmentation of time A-weighted sound pressure level time history of an aircraft noise event from wavelet transform and Standard NF S31-190.

We observed that the wavelet transform – mexican hat was very useful for detecting abrupt transitions in the signal, producing relatively large wavelet coefficients (in absolute value) centered around the discontinuity of the signal at all scales. The better location of the aeronautical events is marked by of the discontinuity of the signal based on the obtained coefficient wavelets at smaller scales. The measurements conducted in the Sergio Franco Laboratory were characterized only aircraft landing procedure. The events associated to aircrafts were validated with information of the operational movements from the airport during the analysis period.

The results show good performance in the detection of sound events aeronautical origin. We observed that the events were well marked in spectrogram and signal representation at different scales facilitate the detection process, so the representation of the wavelet coefficients at smaller scales is sufficient to characterize such sound events.

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7. REFERENCES

AFNOR, *French Standard NF S31-190 Acoustique - Caractérisation des bruits d' aéronefs perçus dans I'environnement,* France, Mars 2008.

ANAC, *RBAC 161 Regulamento Brasileiro de Aviação Civil*, *Resolução Nº 202*, de 28 de setembro, 2011.

BAIRD, J. C, HARDER, K, and PREIS A., "Annoyance and community noise: Psychophysical model of dose-response relationships". Journal of Environmental Psychology, 17 (4):333{343, December 1997.

BENTES, F. M., SLAMA, J. G., "Sensitivity analysis of airport noise using computer simulation". *Journal of Aerospace Technology and Management*, São José dos Campos, Vol.3, No.3, pp. 295-300, Sep. - Dec., 2011.

DRESS., W. B., KERCEL., S. W., "Wavelet-based acoustic recognition of aircraft". In: *SPIE International Symposium on Optical Engineering and Photonics in Aerospace sensing. Conference on Wavelet Applications*, Orlando, Florida, 1994.

DUFOURNET., D., JOUENNE., P., "MADRAS, an intelligent assistant for noise recognition". In: *Internoise 1997*, Budapest, Hungary, Aug. 1997.

INFRAERO - EMPRESA BRASILEIRA DE INFRAESTRUTURA AEROPORTUÁRIA, *Disponível em* < http://www.infraero.gov.br/ > *Acesso em* novembro de 2012.

MALLAT, S. G. "Multiresolution approximation and wavelets orthonormal bases of $L^2(R)$". In: *Transactions of the American* Mathematical. Society, vol. 315, pp. 69 – 88, 1989a.

MALLAT, S. G., "A theory for multiresolution signal decomposition: The wavelet representation". In: *IEEE Trans. Pattern Analysis and Machine Intelligence*, vol. 11, pp. 674 – 693, 1989b.

MALLAT, S. G., *Wavelet tour of signal processing wavelet analysis & its applications.* Los Angeles: Academic Press-Elsevier, 1998. 577 p.

MALLAT, S. G, A Wavelet Tour of Signal Processing, 2^{nd} ed., Academic Press -Elsevier, San Diego 1999.

MORLET, J.; GOUPILLAUD, P.; GROSSMAN, "A. Cycle-octave and related transforms in seismic signal analysis". In: *Geoexploration*, v.23, pp. 85-102, Amsterdam, 1984.

MATLAB, version 7.10 (R2012a), The Math Works, "*User's Guide"*.

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