Wavelet Scalograms of Aircraft Noises at Tripoli Airport during Takeoff and Landing

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Abstract—The wavelet technique is used to analyze aircraft noises during takeoff and landing at Tripoli international airport (Libya). The noises from the airplanes A300-600, A320, B737-800 and C-130 are recorded around 20 sites on an area of 6km-east-west and 5km-sides from the runway thresholds. The calibrated microphone with Spectra-Lab software is used to obtain the noise level database. Overall, no obvious trends of noise energies are observed for maximum noise levels emitted by the planes with changes in frequency range from 20Hz and up whereas the active design is more suitable for the low-frequency below 400Hz.

The most well-known technique of signal analysis is frequency-based Fourier transform. It breaks down a signal into sinusoids of different frequencies [8]. However, time information is lost in the case of transitory characteristics such as drift, trends, abrupt changes, and beginnings and ends of events. Dennis Gabor in 1946 used short-time Fourier transform which maps a signal into a two-dimensional (2D) function of time and frequency by windowing the signal where the precision is limited by the size of the window [8]. Wavelet analysis represents a windowing technique with variable-sized windows.

Keywords—aircraft noises; wavelet analysis; Tripoli international airport; scalograms

I. INTRODUCTION

The noises generally refer to unwanted harmful reverberations as remarked from automobiles, airplanes and industrial workplaces. However, their effects cause an immediate annoyance on human emotion ranges from negligible to psychological disruptive and physiological wellbeing of people [1].

Aircraft noise is one form of pollutions produced by aircraft components during various phases of a flight running up from propeller and/or jet exhaust or on the ground during parking and/or taxing. Airport neighbors have increasingly complained about the influences of potential aircraft noise upon their normal life. Noise can also exert economic factors by decreasing worker efficiency, affecting turnover, and decreasing property values [2]. Aircraft sound sources produce a time-varying sound pressure level over periods of typically 10 to 100 seconds [3]. The noise generated in an aircraft cabin will have an uneven distribution of energy in the audible frequency range of 20Hz to 20KHz [3]. Day Night Level (DNL) is a standard for evaluating community noise exposure.

In 1973, the Federal Aviation Regulations (FARs) part 25 prescribes noise standards for all transport-category aircraft [3]. The main sources of the aircraft noise are the engines, fans, compressor and turbine blades [4]. The fan and compressor blade noise is radiated forward the engine while the turbine blades noise is radiated aft the engine. However, the new versions of aircraft engines are of high-bypass ratio which could have a noise reduction of 10%, i.e., about 15dB. Aircraft experiences higher noise during takeoff than landing [5]. Contemporary aviation noise abatement laws and ICAO regulations aim to control noise emissions [5]. Active and passive controls of noise are commonly used such as Helmholtz Resonators (HR) to minimize the sound propagation [6]. The passive noise reductions are effective for the frequency range from about 500Hz and up whereas the active design is more suitable for the low-frequency below 400Hz.

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Wavelet analysis uses long time intervals for more precise low-frequency information, and shorter regions for high-frequency information [9]. The wavelets were first presented by Jean Morlet at the Marseille Theoretical Physics Center in France [8]. The main algorithm dates back to the work of Stephane Mallat (1988) when a fast wavelet decomposition and reconstruction algorithm for discrete wavelet transform (DWT) was revealed [8].

This work aims to study the noise generated by crowded aircraft at Tripoli international airport. It is the main busiest air transportation station located at 34km south of the capital city Tripoli. The runway length is 3.6Km and is made of asphalt and concrete. The airport receives 25 airlines from many destinations. The terminal capacity is about 3 million passengers a year [10]. The calibrated microphone with spectra lab software installed on portable computer is used to obtain the database. The system is oriented carefully for accurate maximum sound received as practically as possible. The microphone is placed at approximately 1.2m above the ground, and the 2238 mediator integrated sound level is used to measure sound pressure noise level in dB. Fig. 1 shows the distributions of 20 sites used to probe the aircraft noises around Tripoli airport’s runway.
In this study wavelet transform technique is used to analyse nature of aircraft noises measured at 20 sites around the Tripoli International Airport. Different types of planes, A300-600 at 86dB, A320 at 88dB, B737-800 at 90dB and turboprop Hercules C-130 at 98dB have been considered. However, no extremely high noise planes such as B52 and Concorde had been seen at the Tripoli Airport. These extraordinary designs could emit noises with power as high as 118dB [3]. Wavelet analyze is a new and promising set of techniques for analyzing the noises [8]. Wavelet Toolbox™ software which is a collection of built-in pseudo functions in the MATLAB® provides tools for the analysis and synthesis of signals [9]. This part is devoted to 2D scalograms analysis while three-dimensional (3D) representations to be shown in the future work in order of preventing extensive analyses being given in a lengthy paper.

II. ANALYSIS TECHNIQUE

A. Noise Measurements

Sound pressure level (SPL) based on logarithmic scale is given by:

\[
SPL = 10 \log \left( \frac{P_{\text{rms}}}{P_{\text{ref}}} \right)^2 = 20 \log \left( \frac{P_{\text{rms}}}{P_{\text{ref}}} \right)
\]

(1)

where \( P_{\text{rms}} \) is a root mean square pressure and \( P_{\text{ref}} \) is air reference sound pressure of \( 2 \times 10^{-5} \) Pa which is widely used to compare acoustic quantities on dBA scale.

Sound intensity meters are becoming increasingly popular for determining the quantity and location of sound energy emission. Sound intensity level (SIL) in a specified direction at a point is given by:

\[
\text{SIL} = 10 \log \left( \frac{I_{\text{avg}}}{I_{\text{ref}}} \right) \text{ dB}
\]

(2)

where \( I_{\text{ref}} \) is a reference sound intensity of \( 1 \times 10^{-12} \) W/m². The intensity of a wave \( I \) is simply given by:

\[
I_{\text{avg}} = \frac{P_{\text{avg}}}{4\pi r^2} = \frac{p^2}{2\rho c} = 2\rho c A^2 \pi^2 f^2
\]

(3)

where \( P_{\text{avg}} \) is the power emitted by the source and \( r \) is the distance from the source. \( P \) is the pressure, \( \rho \) is the average density of the air, \( A \) is the maximum amplitude and \( c \) is the speed of sound. Equation of the cusp signal with very quick local variation is represented by \( A = r^t \) with \( t \) close to 0 and 0 < \( r \) < 1. The lower value of parameter \( r \) results in a sharper signal.

B. Radial Basis Function Neural Network

Radial Basis Function Neural Network (RBFNN) is a class of feed-forward network. It comprises two layers: output and hidden layers (HL). The hidden layer is a fixed functional mapping that pre-processes \( t(x_i) \) and \( P_{\text{ave}}(x) \) before passing it to the output layer to generate the response \( f(A) \). The resulting networks have adjustable parameters that are updated till a reasonable convergence seen [11]. Fig. 2 represents the architecture of Gaussian Radial basis function neural network (GRBFNN).

The Gaussian activation level of the \( i^{th} \) receptive field units (hidden units) is [12],

\[
w_i = R_i(X) = \exp \left( -\frac{|x - u|^2}{2\sigma^2} \right), i = 1,2,\ldots,n.
\]

(4)

where \( u_i \) is the Gaussian centre vector, \( n \) is the number of RBFs, \( \sigma \) is variances, and \( R_i(X) \) is the \( i^{th} \) RBFs. Fig. 3 a and b show scalar and surface GRBFs’ plots based on \( u = 0.5 \) and \( \sigma = 0.2 \) respectively.

RBFNN training process approximates smooth continuous function as a combination of simple basis functions. The RBF output can be computed by taking the weighted average of the output associated with each receptive field [13],

\[
d(X) = \sum_{i=1}^{n} \frac{C_i \cdot R_i}{\sum_{i=1}^{n} C_i \cdot R_i}
\]

(5)

where \( C_i \) is the output value associated with the \( i^{th} \) receptive field.

![Fig. 1. Database sites around Tripoli airport](image1)

![Fig. 2. Architecture of GRBFNN](image2)
The \( n \) simultaneous linear equations for the \( n \) unknown weight coefficients \( (c_i) \) can be shown in a matrix form as [13]:

\[
\begin{bmatrix}
    c_1 \\
    c_2 \\
    \vdots \\
    c_{10}
\end{bmatrix} = \begin{bmatrix}
    \exp\left(\frac{-||X-u_1||^2}{2\sigma_1^2}\right) & \ldots & \exp\left(\frac{-||X-u_{10}||^2}{2\sigma_{10}^2}\right) \\
    \exp\left(\frac{-||X-u_1||^2}{2\sigma_1^2}\right) & \ldots & \exp\left(\frac{-||X-u_{10}||^2}{2\sigma_{10}^2}\right) \\
    \vdots & \ddots & \vdots \\
    \exp\left(\frac{-||X-u_1||^2}{2\sigma_1^2}\right) & \ldots & \exp\left(\frac{-||X-u_{10}||^2}{2\sigma_{10}^2}\right)
\end{bmatrix}
\]

\[ D = (G + \lambda I)C \]  

Equation (6) may be reformulated as:

\[ C = (G + \lambda I)^T (G + \lambda I)^{-1} D \]  

where \( D = [d_1, d_2, \ldots, d_{10}]^T \), \( C = [c_1, c_2, \ldots, c_{10}]^T \), \( I \) is identity matrix and \( \lambda \) is regularization parameter (positive real number) used to avoid the singularity in matrix \( G \). In order to speed up the time-consuming learning process the mean least square error MLSE is used to find \( C \) [12]:

\[ C = (G + \lambda I)^T (G + \lambda I)^{-1} D \]  

Clearly, the aim was to minimise the MLSE with respect to the weights [12].

### C. Wavelet Transform

In a similar manner to Fourier analysis, the continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function \( \psi \) [14],

\[ C(\text{scale}, \text{position}) = \int_{-\infty}^{\infty} s(t) \psi(\text{scale}, \text{position}, t) dt \]  

Generally, it can be applied as [15],

\[ C(\text{scale}, \text{position}) = \int_{-\infty}^{\infty} s(t) \frac{1}{\sqrt{a}} \psi \left( \frac{t-b}{a} \right) dt \]  

where the scale \( a \) is related to level \( j \) by \( 2^j \). The scale is inversely related to the resolution since the resolution is defined as \( 1/a \). The position \( b \) can be obtained by \( b = ka \) for \((j,k) \in R \). A small scale and a large scale are useful features of combining local and global analyses respectively, i.e., more compressed wavelets. The Gaussian version of the wavelet function \( \psi \) was used in this work. The Gaussian probability density function is shown as [15]:

\[ \psi(x) = \left( \frac{2}{\sqrt{3}} \right) x^{-1/4} \left( 1 + x^2 \right) e^{-x^2/2} \]

Fig. 4 shows Gaussian wavelet function of 8th order derivatives. Note the difference with Gaussian radial basis function given in Fig. 3. The Gaussian wavelet function is more rippling than in Fig. 3 so that better accuracies obtained to analysis various levels of noises’ signals. The pseudo-frequency \( F_n \), in Hz, corresponds to a scale by the following relationship,

\[ F_n = \frac{F_c}{a\Delta} \]  

where \( \Delta \) is the sampling period and \( F_c \) is the center frequency of a wavelet in Hz. Fig. 5 characterizes the correspondence table of scales and frequencies so that the correlations with Fourier spectra being clear. The wavelet procedure was used to compute a correspondence table between values of scales and frequencies. This table depends on the selected wavelet and the scale corresponding to the frequency or vice versa. It is expected that maximum noise power occurred about 1.58Hz frequency which corresponds to the scale of 128.
A. Maximum Noise Predictions

The sound pressure levels in dB of four A/C customer of Tripoli airport are summarized in Table I. The noises of A300-600, A320, B737-800 and C-130 during takeoff and landing measured at various sites were used to predict the noises’ time scales. Fig. 6 shows raw signals of A/Cs’ noises around Tripoli Airport. GRBFNN was used to predict various noises’ signals in terms of amplitude A and frequency f based on normalized time-scale and averaged power in dB as inputs. The noises emitted by A/Cs around Tripoli Airport were used to validate the GRBFNN’s predictions. Eq. (8) was minimised using MLSE with λ=0.24 and the optimal coefficients C required were found to train and apply RBFNN for A/C noises’ predictions. The predictions at the highest noise power of A300-600, A320, B737-800 and C-130 were used in further wavelet analyses. The maximum noise power of A300-600, A320, B737-800 and C-130 were at 86dB, 88dB, 90dB and 98dB respectively. Normalized time (time scale/full time scales) was used due to the differences in time scales for the four types of aircraft noises. The range of time scales was from 0.005msec to 0.05msec. Clearly, noise signal from A320 had a small amplitudes and fluctuations whereas C-130 showed a large oscillatory noise features. A300-600 and A320 displayed comparable averaged noises although A300-600 had obvious larger variations of noise pattern. B737-800 showed the second high averaged noises after C-130. However, B737-800 and A300-600 had comparable variation patterns of noise.

B. Power Noise Spectra

Fig. 7 shows the one-sided Welch power spectral density (PSD) estimate of A/Cs’ noises around Tripoli Airport. The distribution of power per unit frequency (dB/Hz) was plotted versus pseudo frequency (Hz). The number of samples was 25000 where the sampling rate was 500-5000 samples/sec. A300-600 at 86dB, A320 at 88dB, B737-800 at 90dB and C-130 at 98dB were compared. Clearly, C-130 emitted the highest level of reverberations whereas A320 emitted the lowest level. A300-600 and B737-800 released comparable trends of noises’ spectra. However, the peaks of aircraft noises’ power were at approximately comparable frequency of 1.56Hz. However, the peaks in the spectra are not the total power at a given frequency. The noises’ spectra of A300-600 and B737-800 are very comparable although 4dB is difference in maximum noise level. The averaged levels of -22dB/Hz, -31dB/Hz, -33.4dB/Hz and -37.3dB/Hz were seen at frequency higher than 100Hz for A300-600, A320, B737-800 and C-130 respectively. B52 and Concorde planes could emit noises on the order higher than C-130 by 20-30dB. Such aircrafts may not be able to use the older airport of Tripoli due to an unmodern infrastructure and could cause unforeseen harms. The averaged powers were found by the integral of the PSD over a given frequency band. The average powers of -4.14dB, 2.717dB, 6.534dB and 12.13dB were assessed for A320, B737-800, A300-600 and C-130 respectively.

III. ANALYSES AND DISCUSSIONS

A. Maximum Noise Predictions

The sound pressure levels in dB of four A/C customer of Tripoli airport are summarized in Table I. The noises of A300-600, A320, B737-800 and C-130 during takeoff and landing measured at various sites were used to predict the noises’ time scales. Fig. 6 shows raw signals of A/Cs’ noises around Tripoli Airport. GRBFNN was used to predict various noises’ signals in terms of amplitude A and frequency f based on normalized time-scale and averaged power in dB as inputs. The noises emitted by A/Cs around Tripoli Airport were used to validate the GRBFNN’s predictions. Eq. (8) was minimised using MLSE with λ=0.24 and the optimal coefficients C required were found to train and apply RBFNN for A/C noises’ predictions. The predictions at the highest noise power of A300-600, A320, B737-800 and C-130 were used in further wavelet analyses. The maximum noise power of A300-600, A320, B737-800 and C-130 were at 86dB, 88dB, 90dB and 98dB respectively. Normalized time (time scale/full time scales) was used due to the differences in time scales for the four types of aircraft noises. The range of time scales was from 0.005msec to 0.05msec. Clearly, noise signal from A320 had a small amplitudes and fluctuations whereas C-130 showed a large oscillatory noise features. A300-600 and A320 displayed comparable averaged noises although A300-600 had obvious larger variations of noise pattern. B737-800 showed the second high averaged noises after C-130. However, B737-800 and A300-600 had comparable variation patterns of noise.

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**C. Wavelet Noise Analysis**

Two-level one-dimensional wavelet decompositions of the noisy data vector (s) representing A/Cs’ noises with respect to Gaussian wavelet were made. The wavelet transform computes the approximation coefficients vector and detail coefficients vector [16]. These vectors are obtained by convolving (s) with the low-pass filter for approximation and with the high-pass filter for detail, followed by downsampling [17]. These extra coefficients were only used to ensure exact global reconstruction [16]. The wavelet analysis may differ with the Signal Processing Blockset which is designed for real-time implementation [17]. Wavelet analysis produces handle boundary conditions and filter states differently [17]. Continuous Wavelet Transform (CWT) was used since its redundancy tended to reinforce the traits and made all information more visible [18]. Thus, it was easier to interpret and was especially true of very subtle information. The wavelet would have been able to detect the instant when the signal’s frequency changed [19]. This procedure produced approximate values. It was generally good enough when applied to not too complex signals. This procedure was also very efficient at detecting time or space events.

Two-dimensional scalograms of percentages of noise energy were used to analyse four client aircrafts at Tripoli airport. The same space b of 400 was used with the same scale a of 150. As earlier clarified, time scale ranges from 0.005 to 0.05ms and some cases had fewer variations than others. The dashed line of scale a = 128 corresponding with the frequency of 1.58Hz as shown in Fig. 5 was indicated for all the figures below. Fig. 8 displays 2D scalogram of percentage energy of A300-600 at 86dB. Clearly, space b = 60 which corresponds to 0.00075ms showed the highest noise energy percentage of 1.3% of 86dB. Fig. 9 displays 2D scalogram percentage of energy of A320 at 88dB. Clearly, spaces b = 40 and 320 corresponding to 0.005 and 0.04ms showed the lowest noise energy percentage of 0.18% of 88dB. However, the highest noise energy percentage of 0.9% of 88dB was seen at a = 63 (f = 8.4Hz) and b = 325 (0.0406ms) and b = 390 (0.0488ms). Fig. 10 displays 2D scalogram percentage of energy of B737-800 at 90dB. Once again, the highest noise energy percentage of 1.2% of 90dB was seen at a = 63 (f = 8.4Hz) and b = 285 (0.0356ms). However, toes-like peaks of various noise energy percentages were observed at diverse scales and spaces. Unlike the previous cases the scale of 128 did not indicate clear extremes. Fig. 11 displays 2D scalogram percentage of energy of C-130 at 98dB. Here, the scale of 128 was very close to energy extrema at space 154 (0.00195ms). Diverse moderate energies were also distributed at various scales and spaces. Overall, no obvious trends of noise energy percentages were observed in a correlation between maximum noise levels emitted by A300-600 at 86dB, A320 at 88dB, B737-800 at 90dB and C-130 at 98dB with scales and spaces. One of the agreements with Fig. 5 was observed that the maximum noise energy of A300-600 occurred at approximately a = 128 (f = 1.58Hz). The maximum energies of A300-600 and C-130 occurred at large scales and small spaces whereas on contrary for A320 and B737-800.
IV. CONCLUDING REMARKS

In this paper the wavelet technique is used to analyze different aircrafts noise levels during the phases of takeoff and landing at Tripoli international airport. The most important conclusions and recommendations are summarized below:

A significant advantage of wavelet transform over Fourier has been observed. Scalograms of percentages of noise energy have agreed with power density spectrum when the time scale is too small.

Airplanes A320 and B737-800 show diverse moderate energies distributed at various frequencies and times. Overall, no obvious trends of noise energy percentages have been observed in a correlation between maximum noise levels emitted by A300-600 at 86dB, A320 at 88dB, B737-800 at 90dB and C-130 at 98dB with scales and spaces. The maximum noise energy of A300-600 is occurred approximately at $f = 1.58\text{Hz}$ in a reasonable agreement with power density spectrum. The maximum energies of A300-600 and C-130 have occurred at large scales and small spaces whereas for A320 and B737-800 occurred at small scales and large spaces.

The study confirms that the noises along the flight path could be more harmful than elsewhere. The results have been correlated with the social survey conducted on the citizens around the airport about their attitudes on the aircraft noises.

As the extension of exist airport take place, a large area will be effected around the airport. Well-designed facilities have to be considered for the new airport of Tripoli to reduce those noises. Of those steps should be regarded by the decision makers using noise absorbing materials, ground suppressors and allowable distances between working area and runway thresholds.

The analysis could be extended to include other aircrafts being flown at the Libyan airports. Also, 3D wavelet analyses of noises’ spectra have to be considered to obtain more useful and visible results for full scale trends of noises.

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