An intelligent thrust reverse noise detector

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Abstract
An intelligent thrust reverse noise detector is presented in this paper (TREND).

A first detector is customized for the detection of landing sound events. When one of those events is detected, a second detector is triggered to detect thrust reverse. In the case that both events are detected, each of them have to be classified in two separate block. If the first events is classified as landing, and the second one as thrust reverse, the system identifies the activation of thrust reverse.

The detection is based on thresholds applied to the sound power level (instead of sound pressure level in the traditional approaches) time histories, which are estimated using a microphone array and an inverse sound propagation model. This approach has worked well, as the estimation of sound power level enhances the sound events and their separation, even if landing and thrust reverse are close to each other.

The classification is implemented through pattern recognition techniques, which reduces the number of false positive in the detection stages.

The results obtained in Madrid-Barajas airport through the implementation of the methodology in this TREND tool are promising with error rates lower than 10%.

Keywords: Aircraft noise, airport noise restrictions, thrust reverse, detection, classification

1. Introduction

The activation of the thrust reverser to slow down the aircraft after landing is a major source of acoustic impact (and also emissions), annoyance, and complaints in the vicinity of airports. Thrust reverse is usually activated immediately after touch down, producing a sudden change in the regular air flow in the engine, producing a huge turbulence that generates high noise emissions, especially in the low frequency range[1-4]. It can be quite disturbing, as a rapid change of engine power from idle to reverse occurs causing a sudden noise burst (in terms of L_{Amax} and L_{AE}), producing disturbance in airport surroundings, and a increase in the number of complaints. Therefore, over 80 airports in the European Union, like Paris-Orly, London-Heathrow, and many others all over the world, like O'Hare International in Chicago, DeKalb-Peachtree in Atlanta or Sydney airport, have established restrictions for the use of thrust reverse after landing, especially during the night period, as a way of reducing the noise impact of airport operations on the community in circumstances where it is critical[5].

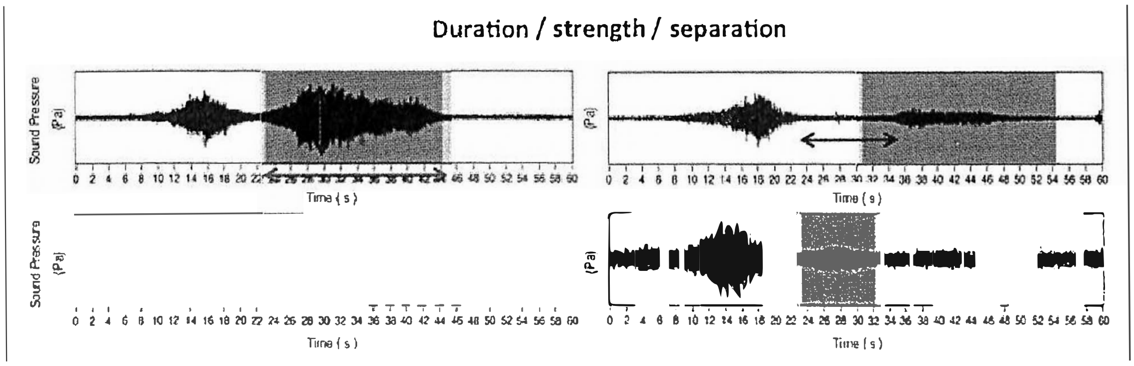

Figure 1. Examples of audio signals of a landing with thrust reverse activation (highlighted)

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A thrust reverse noise detector is a basic tool for an effective implementation of restrictions. Traditional detectors are based on the application of time and duration thresholds to the sound pressure level time history captured by a noise-monitoring unit[6]. But this approach leads to very poor effectiveness in the detection, as there are many factors affecting the strength, separation and duration of the noise events: the aircraft model and the type of thrust reverser, the weather conditions and the company procedures, the aircraft destination, pilot behaviour...

Overcoming the previous approach, the methodology proposed in this paper (TREND) includes signal processing and pattern recognition techniques for implementing a detector that solves most of the problems found in traditional tools.

2. Methodology

The methodology proposed in this paper is based on the detection of two consecutive and separate sound events that afterwards will be classified as landing (EV1) and thrust reverse (EV2). Figure 2 summarizes the basis of TREND.

Landing sound events (EV1) can be easily detected if the sound monitor is located at the beginning of the runway, near the point where aircraft touch down. Noise level at the monitor will reduce continuously, but, if the thrust reverser is activated, the aircraft will increase its sound power emissions for a while, producing a second sound event (EV2) after EV1.

The EV1 detector

The first stage in TREND is the detection of a landing sound event (EV1). The monitor calculates the running sound pressure level (Lp). Then, like in the traditional approach, the detection is performed using time and level thresholds. The detection is improved through the use of a high frequency band pass filter (5.0 to 5.2 KHz). Figure 3 shows an example of the performance of the EV1 detector.

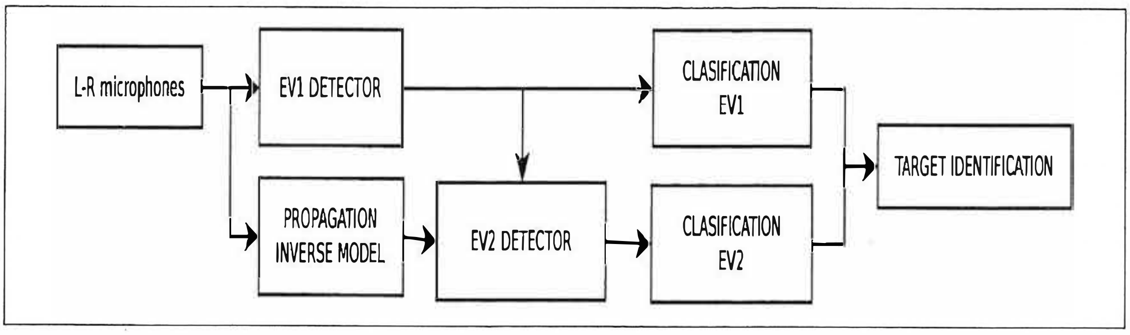


Figure 2. TREND block diagram

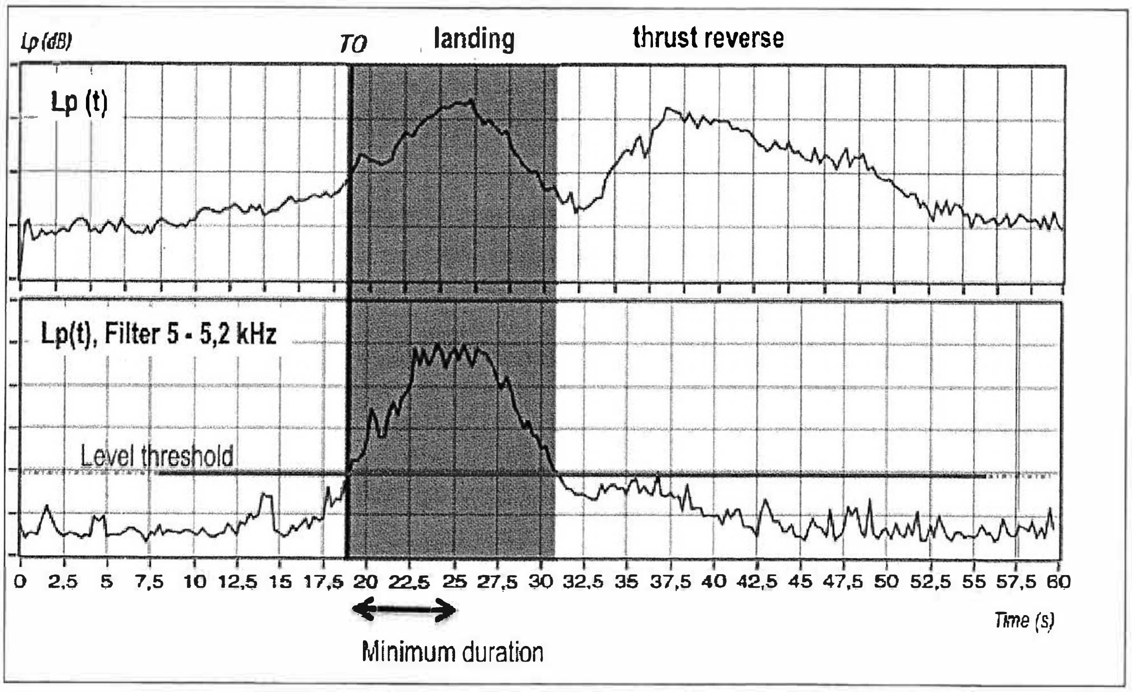
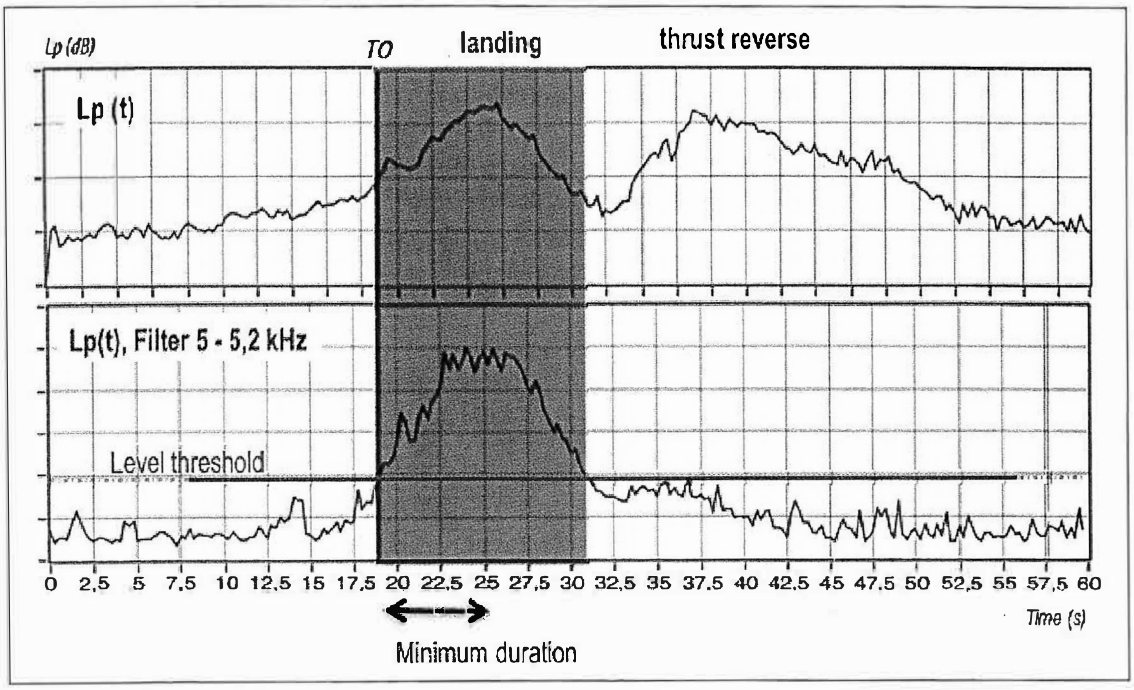


Figure 3. Example of EV1 detection

The EV2 detector

When a landing (EV1) is detected, the EV2s detector activates (Figure 4). The EV2 detector consists of two microphones (mic1 and mic2) forming an array that is used for tracking the aircraft's position along the runway, as follows.

The delay between the signals in the two microphones depends on the postion of the aircraft along the runway. This delay is calculated using a cross-correlation method in the frequency domain [7]. This time delay of arrival allows estimating the direction of arrival of the sound [8], which is used to estimate the distance (r) between the aircraft and the sensors (see Equation 1, where d is the distance from the array to the runway, c is the speed of sound, x_{12} the distance between the two microphones in the array, and ΔT_{LR} is the delay obtained in the measurement). Figure 5



Fgure 4.

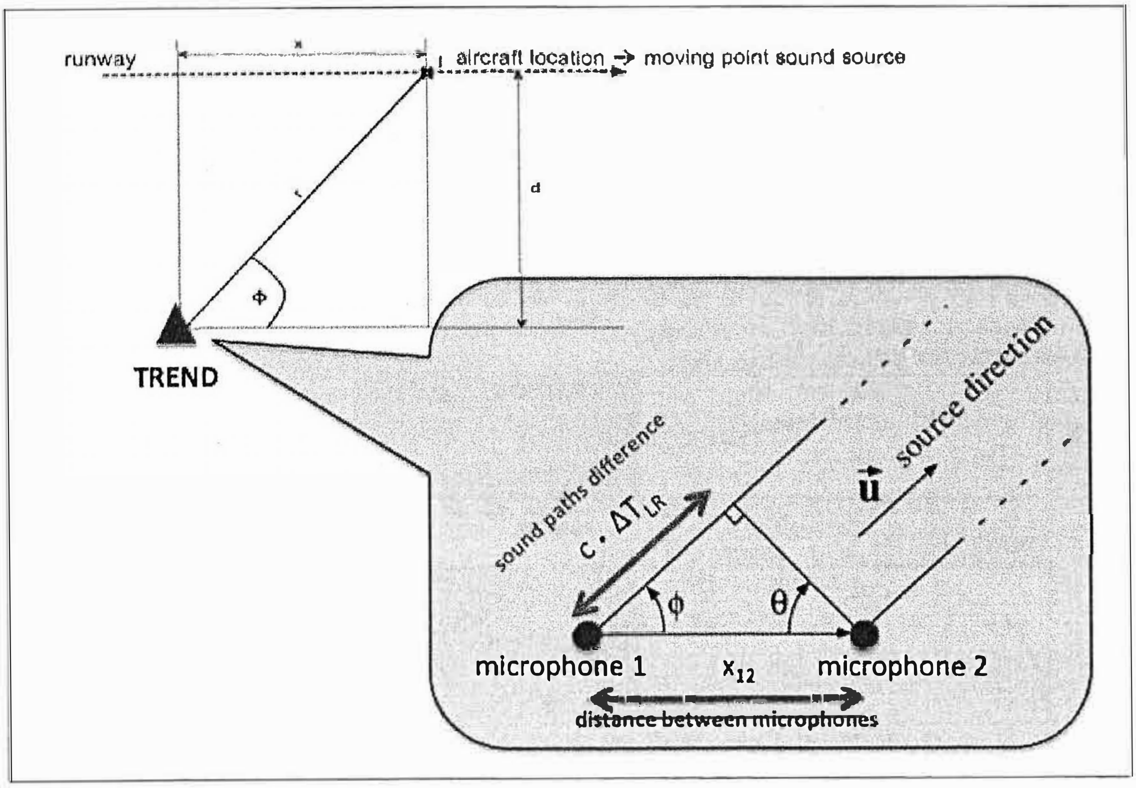


Figure 5. Aircraft location tracking

shows a simplified scheme of parameters involved in the source location tracking process.

$$r = \frac{d}{sen\left(\cos^{-1}\left(\frac{c \cdot \Delta T_{LR}}{x_{12}}\right)\right)} \quad (1)$$

Unlike sound pressure level (SPL), the distance from the source to the receiver does not affect sound power level; therefore, when the thrust reverser is activated, the sound power emitted increases suddenly, making it easier to detect. Taking advantage of this phenomenon, and using an approach similar to the one presented by the authors in [9], the estimation of the sound power level has been carried out using a simplified inverse sound propagation model based on ISO 9613[10], and shown in Equation 2.

$$Lw(t) = Lp(t) + 20\log r(t) + \frac{r(t)}{1000}\alpha + A \quad (2)$$

where $Lw(t)$ is the sound power level (dB), $Lp(t)$ the sound pressure level (dB), $r(t)$ the distance from the source to the receiver (m), and α is a coefficient describing the atmospheric attenuation of sound with the distance (dB/Km), and A is a constant that counts for all other factors.

Using this transformation every thrust reverse sound event is enhanced, making its dynamic range higher (see Figure 6), thereby improving the performance of a threshold detector.

The classification

If thrust reverse was activated, two sound events will have been detected. Then, each of them must be classified using static pattern recognition techniques, where two independent classifiers are trained to recognize landing (EV1 classifier) and thrust reverse (EV2 classifier).

Each of the sound events is described through 22 features, which are extracted in a 3 seconds time frame. Twenty MFCC (mel-frequency cepstral coefficients) were selected, as theyhave shown very good results in previous aircraft classification studies (Asensio, Ruiz & Recuero 2010, Rabaoui, Lachiri & Ellouze 2004). Two new features were added to form a 22 dimension space. These are the coefficients of a linear regression analysis of the delay between the microphones within the 3 second interval. This will give simple information regarding the position of the sound source on the runway, whether it is moving or not, and the direction of the movement (L-R or R-L).

The recognition process starts with a principal components analysis (PCA). Afterwards, different algorithms were tested for each of the classifiers independently, so that those two showing the best performance were selected:

- A k-nearest neighbour [11] was used for thrust reverse events (K=5).
- A Parzen classifier [12] was used for landing events.

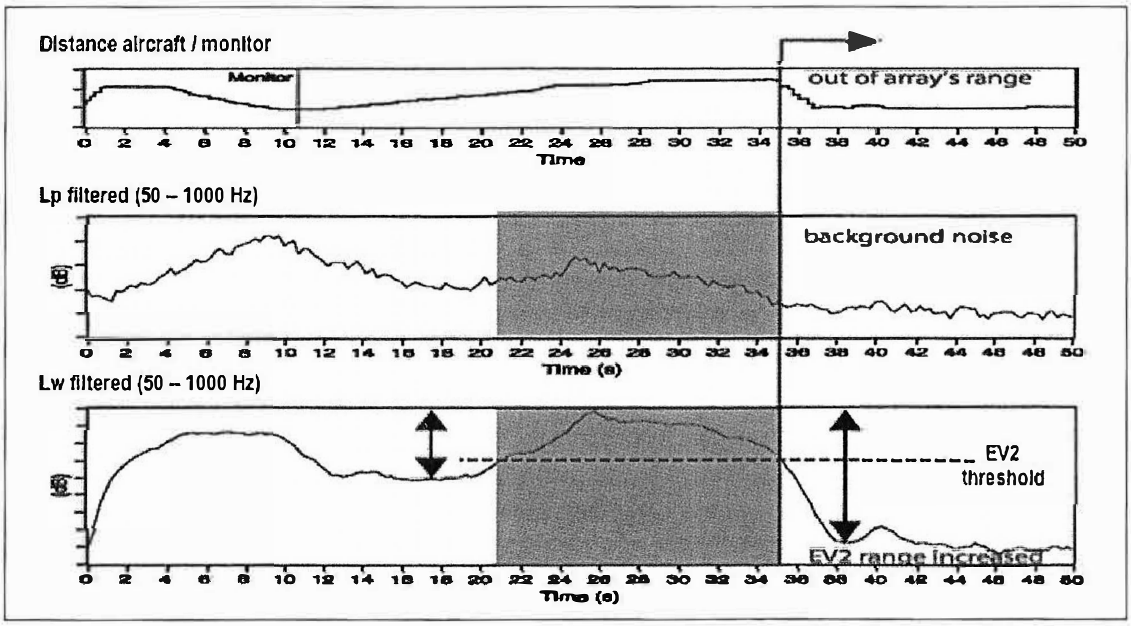


Figure 6. EV2 enhancement for detection

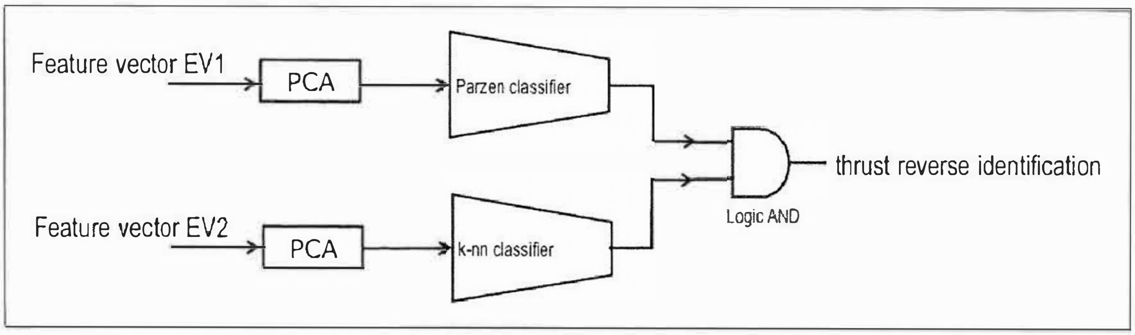


Figure 7. Thrust reverse noise identification

Table 1. Overall identification results

Event type	Detection error rates (%)	Classification error rates (%)	Overall error rates (%)
Landing with thrust reverse	4.0	4.9	8.5
Landing without thrust reverse	24.0	40.0	9.6

The identification of thrust reverse activation is positive if the first event is classified as landing and the second one is classified as thrust reverse noise (see Figure 7).

3. Results

The tests were carried out at Madrid-Barajas airport. The recordings were manually edited and labelled, creating a sound events database, consisting of 315 landings with thrust reverse activation and 83 without it.

The EV1 detector has shown a great performance, almos every landing is detected without any false positive. On the other hand, EV2 detector performance is lower, as sources other than thrust reverse are incorrectly detected as EV2 (taxi, run-ups...), making false positive appear. After the classification stage, the operation point of the detectors can be optimized, and the overall identification rates have been improved.

The tests showed an error rate lower than 10% (Table 1), which can still be optimized with a proper customization of the sensors and the measurement setup, or adding knowledge in the form of probability of thrust reverse occurrence, during the training stage of the classifier.

An extended version of the paper and results can be found in [13,14].

4. Acknowledgements

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Miami Springs council bans anonymous noise complaints

With much attention lately focused on "late-night noise" from loud music and subsequent complaints, many of them of the anonymous variety, the Miami Springs council made the subject one of its primary focal points at its May 27 meeting. A unanimous vote was taken by council to make a slight alteration in the current ordinance that previously allowed all phone calls to remain completely anonymous. Effective immediately, anyone who calls to complain about loud music or noise will be required to at least give their "general location." "There was an objection to the fact that anonymous complaints were being accepted for noise complaints because noise complaints have a component in it that deals with distance, so how can you possibly verify or dispute whether a complaint is justified or not unless you know at least where it's coming from," said City Attorney Jan Seiden. "In a memo I stated we don't really care if the person gives their name but we need to know an address so then the police can go to that address to see if there is noise at that address. Without an address to go to there's no way to verify."

Britons are babies about airport noise

Britons make an "excessive" fuss about noise levels from aircraft flying over their homes, a board member of Heathrow Airport has claimed. Qatar Airways chief executive Akbar Al Baker, who is also on the board of Heathrow, said European airports should open 24 hours a day if they want to compete with the emerging Gulf hubs in Dubai and Doha, which are claiming a growing slice of international passenger traffic. Home owners living under flight paths "wouldn't even hear the aircraft" after a while, Al Baker suggested. Al Baker, who joined Heathrow's board after Qatar Holding bought a 20pc stake in the west London airport in 2012, was speaking ahead of his airline's move on May 27 to Doha's new $17bn airport, Hamad International, which will be able to handle 50m passengers a year when it is completed in full in two-and-a-half years' time. Al Baker said European airlines are unable to grow as quickly as Gulf carriers due to the restrictions placed on them around night flights. Residents in the Gulf "are not making so much fuss" about aircraft noise as they do in Europe, he said, allowing carriers such as Qatar to make better use of their aircraft.