Noise Reduction of Dental Drill Noise

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Abstract

Dental drills produce a characteristic noise that is uncomfortable for patients and is also known to be harmful to dentists under prolonged exposure. It is therefore desirable to protect the patient and dentist whilst allowing two-way communication, which will require a headphone - type system. Re-establishing good communication between the dentist and patient will be achieved through a combination of three noise cancellation technologies, namely, Passive Noise Control (PNC), Adaptive Filtering (AF) and Active Noise Control (ANC). This paper describes how far a test-rig has been developed to achieve sufficient noise reduction that the uncomfortable noise can no longer be heard.

1. Drill Noise Characteristics

Dental drill noise occurs at high frequency ranges, typically 2kHz to 6kHz, and is proportional to its rotational speed. Figure 1 shows the noise peaks of electromotor driven, which has a narrow band characteristic.

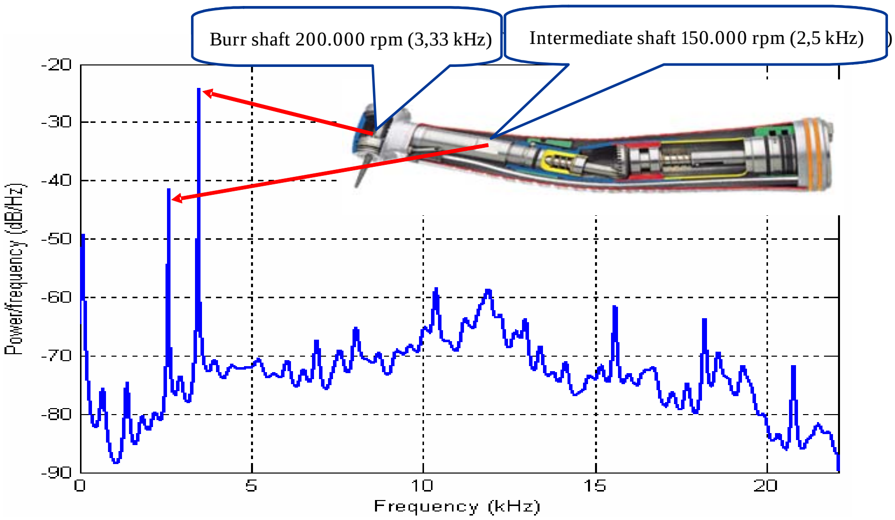

Figure 1 Electromotor driven drill, and its related peaks

These pitched noises are produced by both electromotor and pneumatically driven drills. High speed dental drills, which are used mainly for cutting purposes in a dental surgery, work at a speed of 200,000 to 350,000 revolutions per minute. Therefore the generated noise peaks begin in a frequency range from 2 - 3 kHz. This peak frequency depends on the different drill manufacturers, who use different bearing and design. The noise also has harmonics at higher frequencies but often the first frequency is the major peak. These high frequency narrow band noises cause the discomfort to patients, and probably damage to the dentist's hearing [1]. Because the noise characteristic is in narrow defined bands selective hearing loss in these frequencies is likely. Furthermore, this noise causes anxiety in patients and is one reason patients fail to get dental treatment[2].

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2. Noise Reduction Methods

Passive Noise Control (PNC) is a physical barrier used to cancel high frequency acoustic noise but often needs Active Noise Control (ANC) to address low frequency noise.

ANC cancels acoustic noise with anti -noise. It is normally limited to low frequency because of physical and computational limitations. Looking at these limitations over ten years ago this did not look practicable. However, with faster processing narrowband dental drill noise now presents an opportunity to apply ANC to this application.

Adaptive Filtering (AF) filters the noise that distorts the electrical signal from the microphone but it does not influence the acoustic path.

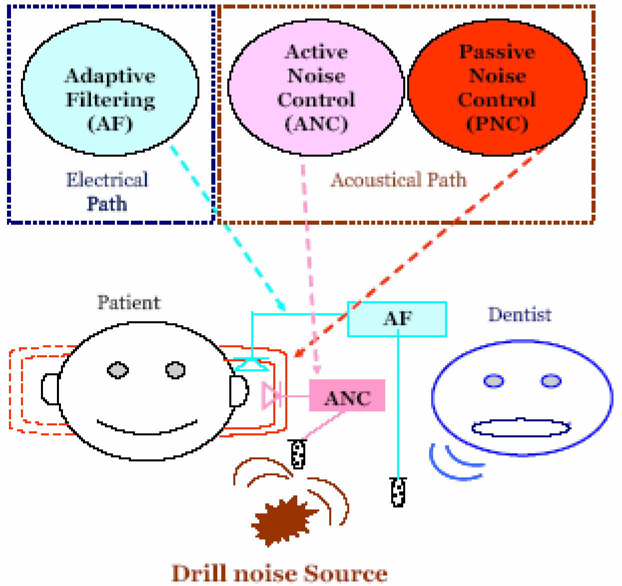

Figure 2 Combination of Noise Reduction Methods

3. Adaptive Filtering (AF) of the Electrical Path

Adaptive filtering removes the narrow band electrical noise peak. A Texas Instruments floating point Digital Signal Processor (DSP) is used to filter the electrical signal in real - time. It uses the standard LMS algorithm[3]: NC is a physical barrier used to cancel high frequency acoustic noise but needs ANC to address low frequency noise.

$$w[n+1] = w[n] + 2\mu e[n]x[n] \qquad (1)$$

Where μ is the step size factor (convergence rate factor) and $e[n]$ the error signal, which is the difference between the adaptive filter output $y[n]$ and the desired microphone signal $d[n]$. $x[n]$ is the reference noise signal picked up by a reference microphone.

$$e[n] = d[n] - y[n] \tag{2}$$

$$y[n] = \sum_{i=0}^{N-1} d[n] - y[n] \tag{3}$$

This Least Mean Squares Algorithm implementation is shown in the block diagram Figure 3.

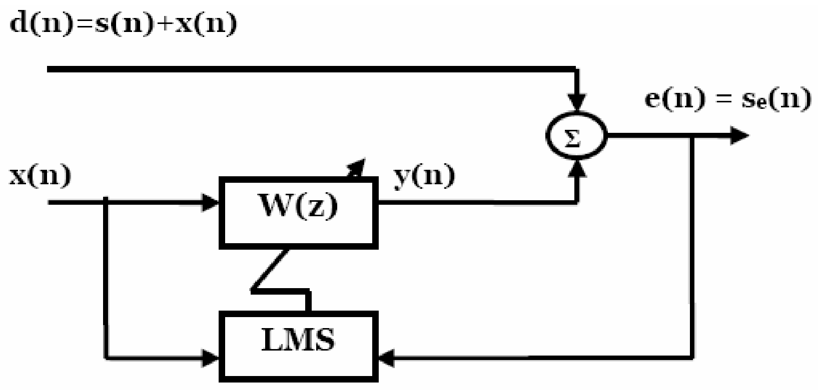

Figure 3 Least Mean Squares Algorithm Block Diagram

The results of implementing this algorithm can be seen in Figure 4.

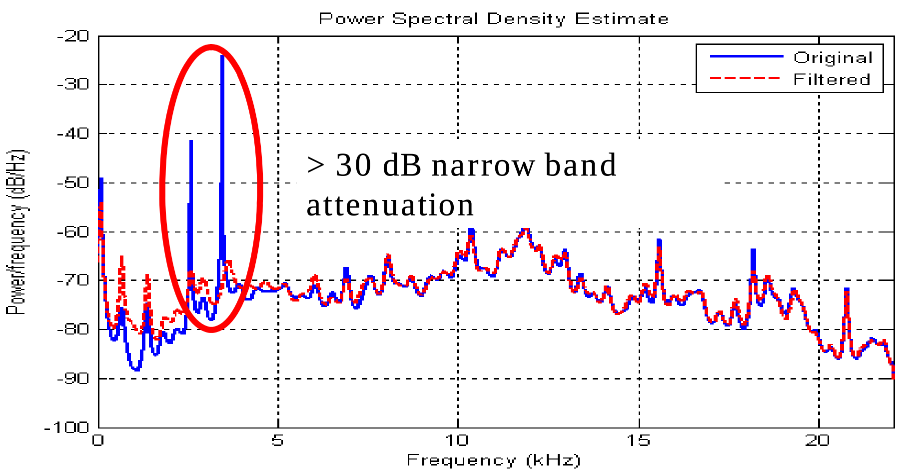

Figure 4 Real time Adaptive Filtering of Noise

This was implemented first on sound recordings through the Simulink Signal Processing Blockset on a variety of dental drills both free running, and under load.

Then it was implemented for use in real time in the dental laboratory with the setup shown in Figure 5.

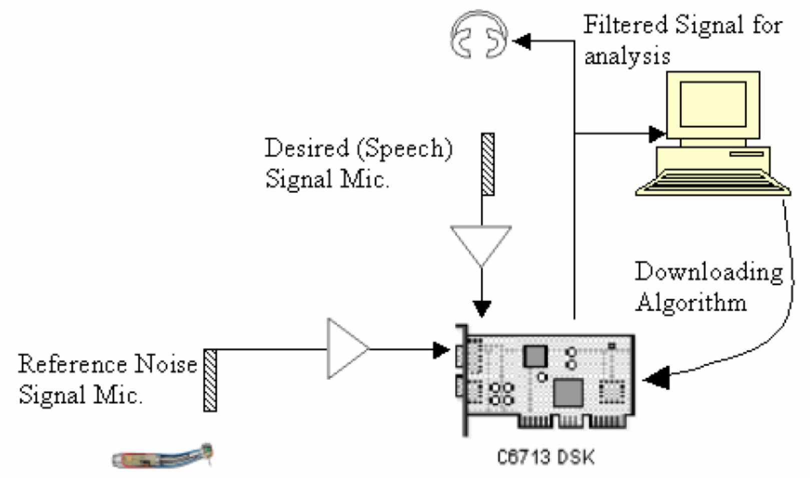

Figure 5 Experimental Arrangement for Real Time Adaptive Filtering

A Texas Instruments floating point Digital Signal Processor (DSP 6713) is used to filter the electrical signal in real - time. It uses the standard LMS algorithm. This was implemented in C.

One of the objectives was to see if the adaptive filter could track the changes of frequency in the noise as the drill is loaded. Thus recordings were made of dentists at work, and the recordings analysed to find the rates of change of frequency under load.

Experiments were conducted in order to find the optimal convergence factor for the algorithm used in the main adaptive filtering experiments. An Electromotor driven drill (W&H Synea WA-99 LT) was used as the noise source for producing the convergence plot. The same drill noise was taken as the reference as well as the desired signal so that the algorithm tries to minimise the reference signal. The algorithm minimises the noise down to zero inside the optimal convergence time, because the reference signal and the signal to be filtered are the same. The sampling frequency of the DSP was set to 44100 Hz. The convergence time from the start with this set up was found to be less than 0.07secs. Since the drill speed changes slowly this was satisfactory.

4. Passive Noise Control (PNC) of The Acoustic path

PNC is a physical barrier used to reduce acoustic noise across the frequency spectrum.

Calibrated tests on a range of acoustic damping materials have been made to inform the design of the most suitable headphones for this application. Calibration of the sound equipment and experimental setup are described in [4]. A variety of materials and their best combination was addressed in a student project by Tarek Berdi[5].

PNC attenuates the drill noise over a wide frequency band and at least 20 dB can be achieved but the attenuated sound peaks are still perceived by the patient. Thus although the sound pressure level is low, the offensive noise is still heard. The results of applying passive noise control alone are illustrated in Figure 6.

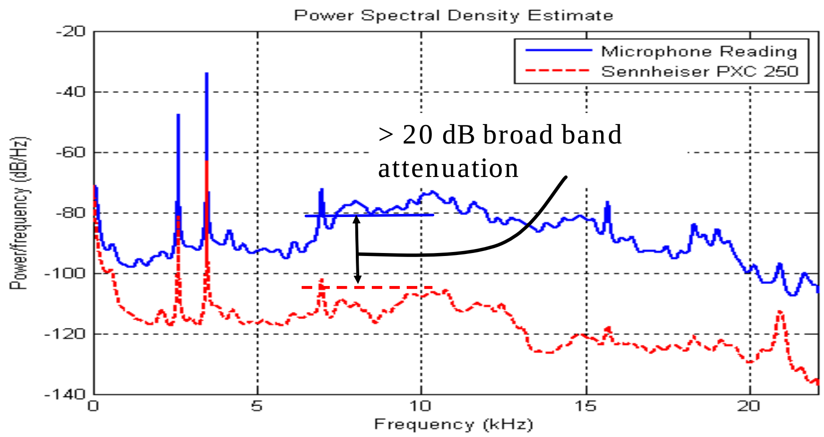

Figure 6 Passive Noise Control noise attenuation

Hence the combination of Passive Noise Control and Adaptive Filtering is generally successful.

Tests in a dental hospital surgery by dental consultants confirmed the effectiveness of this equipment.

Active Noise Control is usually applied to low frequency noise, and hence is not normally applied to the high frequencies in this application. However the application of ANC to Dental Drill noise has also been studied, and tried even though the frequencies are much higher than the range of frequencies that is usually considered possible. With the success of adaptive filtering for the dentist this appears sufficient for their comfort and health. Integrating the design of the microphones, DSP, and headphones forms a good mechatronic system on which some students have worked[5].

5. CONCLUSIONS

The combination of Passive Noise Control and Adaptive filtering implemented on a Digital Signal Processor has achieved good reductions of peak noise over 30 dB in the critical frequencies produced by a dental drill in service. The offending frequencies can no longer be heard because they are reduced below the ambient noise level.

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