CANCELLATION OF SIREN NOISE FROM TWO WAY VOICE COMMUNICATIONS INSIDE EMERGENCY VEHICLES

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ABSTRACT

Sirens' used by police, fire and paramedic vehicles have been designed so that they can be heard over large distances, but unfortunately the siren noise enters the vehicle and corrupts intelligibility of voice communications from the emergency vehicle to the control room. Often the siren needs to be turned off to enable the control room to hear what is being said. This paper discusses a siren noise filter system that is capable of removing the siren noise picked up by the two-way radio microphone inside the vehicle.

The removal of the siren noise improves the response time for emergency vehicles and thus save lives. To date, the system has been trialed within a fire tender in a non-emergency situation, with good results. A demonstration of the siren filter to various sirens can be heard by accessing http://www.elec.reading.ac.uk/rss.html and following the link to 'siren cancellation'.

1. INTRODUCTION

Emergency vehicles (including police, fire and paramedic) often use high amplitude screeching sirens to warn road users and pedestrians that the emergency vehicle is approaching. Such sirens include the traditional Hi-Lo or two-tone generated from a set of air horns or one of the electronically generated sirens' Hi-Lo, Wail, Yelp and Pulsar [1]. The electronic sirens are often created by a small generator system inside the vehicle compartment (termed cab) that drives either a 60 or 100 Watt speaker system. Recent developments also include the 'Localiser' siren designed for directivity [2]. Unfortunately, the siren noise is also present inside the cab and when the two-way radio is used, the siren noise present inside the cab is picked up by the radio microphone and subsequently corrupts voice communication intelligibility. It is also common for the siren to be turned off when the vehicle needs to communicate with the control room even though the vehicle may be in traffic or traveling at speed [3] since the control room cannot hear the voice signal due to the loud siren. Considering people's lives are often at stake, improvements to aid voice communication is an important action to undertake.

This paper discusses the development of a small, inexpensive DSP based siren noise filter system that is capable of removing siren noise embedded within a speech signal so that voice communication from an emergency vehicle is not impaired by siren noise. The original impetus for this project was generated from the British Home Office for primary use within fire and police vehicles.

2. CANCELLING SIREN NOISE

2.1 Siren characteristics

To generate the Hi-Low air horn, an air compressor is used to drive two horns of differing lengths. This type of siren has the broadest spectrum of all the sirens, being on average 40Hz to 4KHz with the low and a high tone being 450Hz and 480Hz respectively. The spectral purity of the air horn is very poor and the frequencies generated depend upon barometric pressure, vehicle speed, siren age and temperature.

The common electronic generated sirens are the Hi-Lo, Wail and Yelp. For the Hi-Lo, the low and high frequencies are 700Hz and 1000Hz respectively, the spectrum extends to 8Hz with the Hi-Lo repetition period in the order of 760ms. The Wail is a chirp type siren sweeping up and down linearly in frequency between 600Hz to 1600Hz with a repetition period of approximately 5.5s. The Yelp siren has similar characteristics to the Wail but the Yelp has a faster repetition period of approximately 470ms. Other less common sirens exist such as the Pulsar, Localiser and repetitive combinations of the above.

2.2 Siren filtering techniques

Due to its mechanical nature, the air horn siren has many harmonics so a pair of simple notch filters centered on the Hi and Low frequencies would not remove all the siren power; also the spectrum of the speech signal mixed with the siren noise would be damaged. Likewise, the electronically generated sirens are supplied from a siren generator whose output is a square wave from a saturating push-pull type output stage. The fundamental of the square wave is the required siren frequency, but many harmonics also exist. Due to the nature of the problem, there is only the need to cancel the siren noise at the vehicle. There are two main philosophies of cancelling this short-term periodic type of noise being:

- *Generation of 'dead zone'* [4]. Here, anti-noise is transmitted in the cab to form a quiet zone around the area of the microphone, thus the microphone only detects speech and the siren noise is not transmitted.
- *Filtering the microphone signal*. Apply a digital filter to the microphone signal which is capable of extracting the aperiodic (speech) from the periodic (siren) signals.

Although the generation of a dead zone around the microphone would be pleasing to the user of the two-way radio, the generation of an acoustical dead zone is impractical for this application due to the non-stationary nature of the microphone, personnel moving around the vehicle, noise from the apparatus, etc. Thus the project centered on removing the siren noise mixed with the speech signal detected by the cab microphone.

Horvei et al [5] developed a siren noise canceller for use with an electronic siren generator and was designed to remove the siren noise picked up by the two-way radio microphone. The instantaneous siren frequency was simply found by sampling the output from the siren generator and timing the zero crossing points. The siren noise was removed from the microphone signal by a set of 3 cascaded notch filters implemented using a single Texas Instruments C40 Digital Signal Processor. To aid speed, the filter parameters were found by the use of a look-up table. The siren filter system was reported to give an attenuation of 28dB for the Wail siren and 22dB for the Yelp on the fundamental components, not the harmonics. By using the output of the siren generator to develop a reference, the presence of speech does not interfere with the measurement of the siren frequency.

However, this system has 3 major drawbacks:

- *Time lag in estimation of instantaneous siren frequency*. For the faster changing sirens, once the instantaneous frequency has been calculated, and filter characteristics implemented, the siren has changed frequency due to the continuously changing chirp nature. Thus the implemented notch filter is not centered on the actual current siren frequency.
- *Harmonics not removed*. Since the output of the siren generator is a square wave, zero crossing detection will yield the fundamental siren frequency, but the system does not allow for removal of harmonics of the siren frequency. Also, tests were not reported on the systems ability to cancel the Hi-Lo siren signal that has the largest power spectrum over its harmonics compared to the other sirens.
- *A finite look-up table*. The calculated instantaneous siren frequency must be rounded to an entry in the look up table.

The above system suffers from the lack of adaption, 3 classical notch filters will not necessarily give the same level of attenuation as an adaptive filter. The adaptive filter may also be trained on all signal components of the siren.

2.3 Siren filtering by adaption

In order to train the filter to various acoustical environments and also remove siren harmonics, various adaptive filters were verified using the different types of sirens.

There is an obvious advantage to system implementation if no reference signal is required, as was required in Horvei et al [5]. The Linear Predictor [6] trained by Least Mean Square [7] is a filter system which does not require a separate training input sequence, it uses a delayed version of the input sequence as its own reference. In the case of a siren filter, the cab microphone signal is the only input required, as depicted in figure 1.

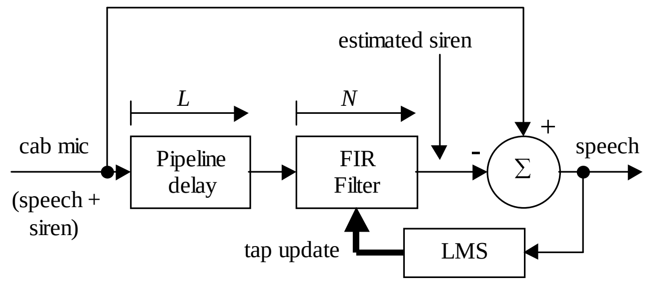

Figure 1. Block diagram of the adaptive Linear Predictor siren filter.

The filter is a standard FIR type of length *N* elements. If the pipeline delay is of length, *L*, then the FIR filter output, *y*, is an estimate of the siren signal detected at the microphone described as:

$$y(n) = \sum_{k=0}^{N-1} W(k).x(n-k); \quad \text{and} \qquad (1)$$

$$x(n-N-1-L) = microphone(n) \qquad (2)$$

Where *x* is the signal detected by the microphone, *n* is the current sample and *W* is the filter tap vector controlled by the standard LMS algorithm given by:

$$W(n+1) = \sum_{k=0}^{N-1} W(k) + 2.\mu.e(n).x(n-k); \quad \text{where} \qquad (3)$$

$$e(n) = speech(n) = microphone(n) - y(n) \qquad (4)$$

Also, μ is a constant that controls the LMS adaption rate. One of the advantages of this filter arrangement is that the output of the FIR filter is a siren estimate and therefore the speech itself is not being filtered or altered. The actual results of using the Linear Predictor siren filter may be seen in the results section below.

There are cases where a siren reference input may be found to help train the adaptive process as used by Horvei et al [5]. Such systems will have a faster training time than the Linear Predictor as required by the Yelp siren. However such filter systems will require a more complicated installation process due to the extra input. A separate reference input may be used in cases, but not exclusively, for:

- *Reference microphone for use with Hi-Lo air horns.* Either a contact or throat microphone attached near to the horn or a separate microphone in the cab may be used to capture a reference of siren with little of the speech component detected by the two-way radio cab microphone.
- *Sampling the siren generator output.* If the electrical output of the siren generator is used, then external influences such as road noise, vibration and noise from the personnel will not be present.

A block diagram of the separate reference input siren filter is presented in figure 2.

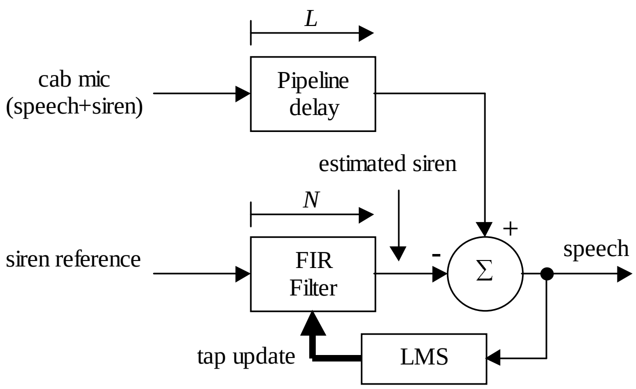

Figure 2. Block diagram of the reference input adaptive siren filter.

The FIR filter is used to alter the siren reference signal toward the siren signal detected by the cab microphone. Hence, the system requires a particular point of the siren reference to arrive before the same point in the cab microphone, and in this endeavor the pipeline delay is added to insure the early arrival of the altered reference.

The actual results of using the reference input siren filter may be seen in the results section below.

3. IMPLEMENTATION

To compare the relative performance of the Linear Predictor type siren filter with the two input (reference and cab microphone) siren filter, both systems were designed and implemented using a dedicated signal processing board utilizing an Analog Devices Sharc processor (ADSP-21061 running at a speed of 120MFLOP). A standard siren generator manufactured by Premier-Hazard® was used and all tests were performed using a Volvo FG/14 fire tender.

4. RESULTS

The system goal is to minimize the siren noise transmitted by a two-way voice communication radio system and consequently, the sampling rate for the digital filter need not be high. However a high sample rate of 44.1KHz was used which is over-sampling compared to the bandwidth of the communication channel. This is to minimize aliasing problems and to allow easy communication of the CODEC with the host DSP processor.

4.1 Linear Predictor results

Using the processor available, the size of N was limited to 310 to allow all the required processing for the Linear Predictor algorithm to be performed within one sample time and each sample time. However in practice there was minimal improvement in results for N over 100 and as a consequence N was set to 100. The Linear Predictor delay, L, was set to $N/2$ and the LMS adaption parameter μ was set to 0.01.

Siren type	Attenuation (dB)
Air horn Hi-Lo	**6**
Electronic generated Hi-Lo	**6**
Electronic generated Wail	**3**
Electronic generated Yelp	**0**

Table 1. Adaptive Linear Predictor siren filter attenuation results.

Trial	Siren type	Attenuation (dB)
1	Air horn Hi-Lo	**24 → 34**
2	Electronic generated Hi-Lo	**30 → 38**
3	Electronic generated Wail	**24 → 34**
4	Electronic generated Yelp	**18 → 24**
5	Electronic generated Pulsar	**7 → 12**

Table 2. Reference siren adaptive filter attenuation results.

Trial 1 using a contact microphone reference.
Trial 2-5 using electrical output from siren generator.

*Measurements taken across whole siren bandwidth.

The results for the Linear Predictor siren filter as applied to various sirens is depicted in table 1. As can be seen from the table, the attenuation for the Wail and Yelp is very disappointing due to the change in the siren frequency being noticeable across the Linear Predictor delay (siren is a different frequency at each ends of the delay). Smaller values of L did not give a sufficient amount of delay. There was, however, a small but noticeable click at the output of the filter due to the re-adaption of the filter when the siren tone changes from Hi to Lo and vice versa.

The attenuation to the Hi-Lo siren signals is however very encouraging. The presence of the attenuated siren is noticeably reduced and does not corrupt the speech signal to the same level as without the siren. Bearing in mind that most fire tenders are using the air horn Hi-Lo signal, and coupled with the lack of a reference signal requirement for this filter, the Linear Predictor is a useful filter for reducing the Hi-Lo type siren noise when mixed with speech.

4.2 Reference siren filter results

In order to tackle the Wail and Yelp sirens, the reference adaptive siren filter was tested and the results are depicted in table 2. Trial 1 was using a separate contact microphone at the throat of the air horns to sample the air horn Hi-Lo siren, whereas trial 2, 3, 4 and 5 sampled the electrical output from the siren generator directly (through the use of an opto-coupler).

With the use of the reference siren filter, the Hi-Lo signal is extracted from the speech + siren signal detected by the cab microphone. As a result, only traces of the Hi-Lo siren can be heard when the vehicle is stationary and the residual siren is below the noise floor when the vehicle is in motion. Also, the clicks that could be heard between the Hi-Lo transitions when using the Linear Predictor filter could not be heard when using the reference siren filter. The reference siren filter was also successful in cancelling the electronically generated Wail and Yelp sirens.

These reference siren filter results for Wail and Yelp are comparable to the attenuation results discussed in Horvei et al, although their attenuation to the Hi-Lo siren was not presented. However, with the use of an adaptive approach, attenuation to other siren components such as reflections and harmonics can be cancelled. This cannot be the case when using a set of cascaded notch filters as implemented in Horvei et al.

An electronic demonstration of the siren filter to various sirens can be downloaded in WAV file format by accessing the WWW URL http://www.elec.reading.ac.uk/rss.html and following the link to 'siren cancellation'

5. SUMMARY

This research and development work has been directed towards removing siren noise from voice communications for use with emergency service vehicles. The removal of the siren noise improves intelligibility and reduces the response time for the emergency situation. This work has developed using previous researchers' work by applying an adaptive approach to the removal of the siren noise. The adaptive filter has been implemented using two solutions; a self-referenced Linear Predictor and a separate reference input architecture filter.

It was found that the Linear Predictor siren removal filter was capable of cancelling the Hi-Lo siren to a level of attenuation that did not interfere with voice communications. However, a small click was audible (approximately 10ms) when the filter re-adapted to the change in the Hi to Lo siren pitch and vice versa. Unfortunately, the Linear Predictor was not fast enough to remove the Wail and Yelp sirens and therefore the Linear Predictor can only be used to cancel the traditional Hi-Lo type air horn. However, since no reference signal was needed, little interface hardware was required.

Using a separate reference for the siren signal was found to give the best adaption performance, attenuation level and above all this filter architecture worked as required for all sirens tested. However, the system does require extra interface hardware (although inexpensive) to obtain the reference from the siren generator or air horn.

6. FUTURE WORK

The research work within this project has yielded a siren noise filter particularly useful for emergency vehicles. To aid road and personnel safety, the filter may also be used for hands free operation of the radio system, since currently, when the siren is operated the hands free VOX detects 'voice'. With very little further work, the system can be integrated into the hands free system.

To date, work has been concentrated on the traditional two-tone siren and the electronically generated Hi-Lo, Wail and Yelp. However, other sirens exist and more complicated sirens containing white noise bursts are expected on the market. The removal of these sirens poses a very complicated task.

7. ACKNOWLEDGEMENTS

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