ADAPTIVE ECHO CANCELLATION USING GAMMA FILTERS

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ABSTRACT

This paper studies the performance of the Tap Delay line (TDL) and the Gamma filter in the application of echo cancellation. The TDL and Gamma filter architecture is implemented using the Least Mean Squares (LMS) algorithm. Experimental results indicate that the Gamma filter outperforms the TDL with respect to the intelligibility of the speech recovered and the number of tap weights used in the filter. The results of exchanging the inputs are also presented.

Keywords: Echo Cancellation, Least Mean Squares (LMS), Gamma filters, Tap Delay Line (TDL), IIR, FIR.

1. INTRODUCTION

The pioneering work by Principe led to the innovation of a new class of adaptive filters, the generalized feedforward filter [1]. The generalized feedforward filter is an IIR filter with restricted feedback architecture. This paper compares the performance of the TDL and the Gamma filter, a particular instance of the generalized feedforward filter, in the application of echo cancellation. The Gamma filter borrows desirable features from both FIR and IIR filters - trivial stability, easy adaptation and decoupling of memory depth from the filter order.

Most of the existing long distance communication system employs a two wire to four wire hybrid at the switching office. This particular configuration enhances the performance of the communication system. The major drawback of a practical hybrid is leakage. The received signal leaks into the transmitted signal, causing the user at the other end to hear his own voice. This ‘echo’ is particularly annoying in long distance communication since it takes perceivable amount of time for transmission. Hence, it becomes necessary to use an effective echo cancellation scheme. The entire setup is shown in figure 1. Although a tapped delay line (TDL) structure can be used, the number of tap weights required will be too large for practical implementation. The most prominent feature of Gamma filter is that the memory depth is decoupled from the filter order. Hence, the Gamma filter can be an effective alternative to the tap delay line (TDL) structure.

The remainder of the paper is organized as follows. Section 2 briefly describes the LMS algorithm and the Gamma filter. Section 3 discusses the results and Section 4 concludes the paper.

2. GAMMA FILTERS

G (z) in figure 2 is the generalized delay operator. For the Gamma filter the transfer function is given by (1)

\[ G (z) = \frac{\alpha}{z - (1 - \alpha)} \]  

(1)

\[ g(n) = \alpha (1 - \alpha)^n \]  

(2)

Where, \( g(n) \) gives the impulse response in time domain. The Gamma delay operator can be viewed as a leaky integrator, where \((1 - \alpha)\) is the gain of the feedback loop. The internal structure of \( G (z) \) is shown in figure 3.
The output of the Gamma filter is given by (3)

\[ y(n) = \sum w_k x_k(n) \]

Where, \( x_k(n) = (1-\alpha) x_k(n-1) + \alpha x_{k-1}(n-1) \)  

(3)

Although the transfer function has poles, the tap weights do not come in the feedback path. Hence, stability is attained when, \( 0 < \alpha < 2 \). Within these values, if \( \alpha < 1 \), the transfer function behaves as a low pass filter, while for \( 2 > \alpha > 1 \), it behaves as a high pass filter. TDL is a special case of Gamma when \( \alpha = 1 \). The same iterative procedure can be used in the weight update in the case of Gamma filter, the only difference being the input vector being a spatial input vector \([x_0(n), x_1(n), \ldots x_{M-1}(n)]\).

We compare the performance of the Gamma filter and the TDL, which are implemented using the LMS algorithm. The LMS algorithm is discussed in detail in [2], [3]. The outline of the procedure is,

- Compute the output :
  \[ y(n) = W^T(n) X(n) \]  
  (4)

- Determine the error :
  \[ e(n) = d(n) - y(n) \]  
  (5)

- Update Tap weight :
  \[ W(n+1) = W(n) + \mu X(n) e(n) \]  
  (6)

The drawback of the TDL structure is evident form equation (6). Since the tap weights are updated every iteration, stability would be highly impossible if an IIR structure is used. The step size \( \mu \) has to be chosen appropriately in equation (6) to maintain stability.

3. EXPERIMENTAL RESULTS

The data available are the far end signal and the near end signal, which is corrupted due to the leakage of the hybrid. The near end signal is completely incomprehensible due to leakage.

The feedback parameter \( \alpha \) is fixed and the filter order is determined for which the MSE is minimum. From figure 4, the filter order is determined to be \( M=31 \). Now keeping the filter order fixed, feedback parameter \( \alpha \) is varied between 0 and 1 to get minimum MSE. It is determined to be around 0.15 as shown in figure 5.

Thus, Filter order \( M=31 \) and \( \alpha=0.15 \) is used in the adaptation of the tap weights in the Gamma filter. The MSE is calculated by finding the MSE for the last 100000
samples of e(n). A step size of 0.05 was used in the update equation. The learning curve for the Gamma filter is shown in figure 6. \( J(\infty) \) is determined to be \( 5.42 \times 10^{-5} \). Tap weight tracks are shown in figure 7.

We compare the performance of the Gamma filter with TDL. Similar to the Gamma filter, the step size is fixed to be 0.05, which is approximately equal to \( \frac{1}{50* \lambda_{\text{max}}} \). Figure 8 shows the optimal filter order for the TDL to be around 250. It can be observed that the MSE decreases continuously with filter order \( M \). \( M=250 \) is chosen as the optimum filter order, as the MSE decreases negligibly after that.

The learning curve for the TDL is shown in figure 9. \( J(\infty) \) is obtained as \( 5.91 \times 10^{-5} \) for the TDL. Hence, the minimum MSE obtained, is more or less same for both the type of filters. The bottom line is that the Gamma filter can obtain comparable \( J(\infty) \) for lesser number of tap weights. The Learning curve for the LMS algorithm is shown in figure 9. The tap weight tracks are shown in figure 10. These plots suggest that the environment is stationary, as there is no change in path for the tap weight tracks.

Careful observation of the learning curve and the tap weight tracks for LMS and the Gamma filter suggests that, LMS algorithm converges faster when the structure is TDL. On the other hand, the Gamma filter outperforms the TDL in terms of the number of tap weights used. This might prove to be a valuable advantage when it comes to practical application.

### 3.1 Speech Recovery

The original corrupted signal on the near end, signal recovered by passing the corrupted speech through the adapted TDL filter, signal recovered by passing the corrupted signal through the adapted Gamma filter, are shown in figure 11. Though, both the filters were unable to remove the background echo completely, the signal recovered by the Gamma filter was much more intelligible than that by TDL.

Using TDL, only some words like ‘darkness’ is audible, while in Gamma filter, most of the sentence is discernable.
3.2 EFFECT OF EXCHANGING THE INPUT AND DESIRED SIGNALS

Interchanging the input and desired signals prove to be a poor idea due to the following reason. Since, the near end and far end signals are uncorrelated; the minimum mean square error is attained when, $W(z) = 1/H(z)$ (figure 1). The leakage might be reduced, but the desired signal is transformed by $W(z)$. On the contrary, in the original setup, the input was transformed by $W(z)$, unaffecting the desired signal. At optimal performance, $W(z)$ will approximately equal $H(z)$. The minimum mean square degrades to $2.17 \times 10^{-2}$, compared to $5.91 \times 10^{-5}$ in the original setup, for the TDL. Similarly, the minimum mean square degrades to $4.5 \times 10^{-2}$, in the case of Gamma filter.

### Table 1

<table>
<thead>
<tr>
<th>S.No</th>
<th>Parameter</th>
<th>TDL</th>
<th>Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$M$</td>
<td>250</td>
<td>31</td>
</tr>
<tr>
<td>2.</td>
<td>$\alpha$</td>
<td>----</td>
<td>0.15</td>
</tr>
<tr>
<td>3.</td>
<td>$J_{\text{min}}$</td>
<td>Original $\times 10^{-5}$</td>
<td>Swap</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.91</td>
<td>0.022</td>
</tr>
</tbody>
</table>

4. CONCLUSION

In this paper, the performance of TDL and Gamma filters in adaptive echo cancellation is compared. The LMS algorithm is implemented in both the structures. The results show that, to achieve the same performance, the Gamma filter requires much lesser number of taps. Since the feedback in Gamma filter is restricted and appears before the tap weights, the stability is trivial. The intelligibility of the recovered speech is higher for the Gamma filter. The results of this study, confirm that Gamma filter outperforms the TDL of same order [4]. Exchanging the input and desired signals degrade the performance of both the filters.

5. REFERENCES


