Acoustic Echo Cancellation

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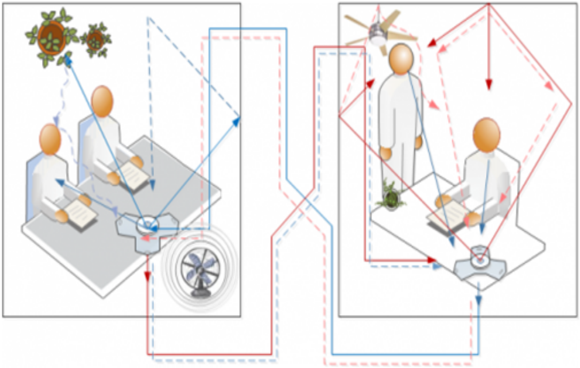
Contents

Contents

Acoustic Echo

- **Echo**: Echo is a reflection of sound that arrives at the listener with a delay after the direct sound.
- **Reverberation**: When sound is reflected multiple times from multiple surfaces, the echo is characterized as a reverberation.
- **Acoustic Echo**: Sound from a loudspeaker is picked up by the microphone in the same room.
- **Example**:
  - Hands-free car phone systems.
  - Audio-conferencing.

Acoustic Echo



- It can be solved by the acoustic echo cancellation to stop the feedback[1].

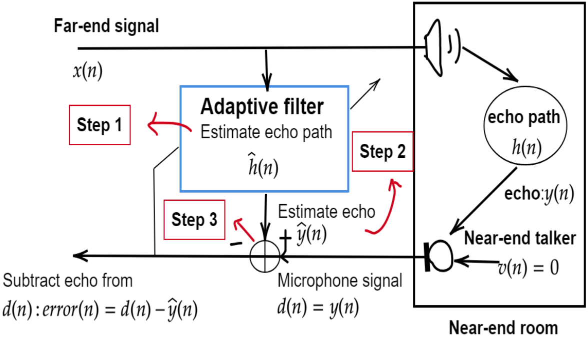
[1] Acoustic Echo Cancellation Using Modified Normalized Least Mean Square Adaptive Filters(Akingbade, Kayode Francis and Alimi, Isiaka Ajewale)

Contents

Acoustic Echo Cancellation (AEC)

- **Basic idea**:
- Acoustic echo cancellation (AEC) catch the originally transmitted signal that reappears, with some delay.
- Once the echo is recognized, it can be removed by subtracting it from the transmitted signal.
- Echo cancellers must be adaptive (FIR filter).

AEC With Adaptive Filter



- Estimate the characteristics of echo path h(n) of the room: $\hat{\mathrm{h}}(\mathrm{n})$.
- Create a estimate echo signal: $\hat{\mathrm{y}}(\mathrm{n})$.
- Echo is then subtracted from microphone signal to obtain the desired signal: Desired Signal $= \mathrm{d(n)} - \hat{\mathrm{y}}(\mathrm{n})$[1].

Least Mean Squares Algorithm (LMS)

- Each iteration of the LMS algorithm requires 3 distinct steps in this order:
- The output of the FIR filter,$y(n)$ is calculated using equation 1.

$$\hat{y}(n) \ = \sum_{i\,=\,0}^{N-1} w(n)x(n-i) = w^T(n)x(n) \tag{1}$$

- The value of the error estimation is calculated using equation 2.

$$e(n) = d(n) - \hat{y}(n) \tag{2}$$

- The tap weights of FIR vector are updated in preparation for the next iteration,by using equation^2.

$$\mathrm{w}(n+1) = \mathrm{w}(n) + 2\mu e(n)\mathrm{x}(n) \tag{3}$$

Least Mean Squares Algorithm (LMS)

- **How to update the tap weight of FIR vector:**
- The cost function use mean squared error (MSE)[3]:

- $$\boxed{J(\mathrm{w}) = E\left\{|e(n)|^2\right\}}$$
- $$\boxed{\begin{aligned} \nabla_{\mathrm{w}} J = 2e(n)\frac{\partial e(n)}{\partial \mathrm{w}} &= 2e(n)\frac{\partial\left(d(n) - \mathrm{w}(n)^T x(n)\right)}{\partial \mathrm{w}} \\ &= -2e(n)x(n) \end{aligned}}$$
- $$\boxed{\mathrm{w}(n+1) = \mathrm{w}(n) - \mu\nabla_{\mathrm{w}} J}$$
- $$\boxed{\mathrm{w}(n+1) = \mathrm{w}(n) + 2\mu e(n)\mathrm{x}(n)}$$

[3] Echo Cancellation in Audio Signal using LMS Algorithm(Nagendra, Sanjay K and SB, Vinay Kumar)

LMS Algorithm

- Each iteration of the LMS algorithm requires 2N additions and 2N+1 multiplications
- N for calculating the output $y(n)$, one for $2\mu e(n)$ and an additional N for the scalar by vector multiplication[2].
- The μ is the step size parameter,and is a small positive constant.
  - If μ is too small, the time the adaptive filter takes to converge on the optimal solution will be too long;
  - If μ is too large,the adaptive filter becomes unstable and its output diverges.

[2] Adaptive algorithms for acoustic echo cancellation in speech processing(Chinaboina, Radhika and Ramkiran, DS and Khan, Habibulla and Usha, M and Madhav, B and Srinivas, K and Ganesh, G)

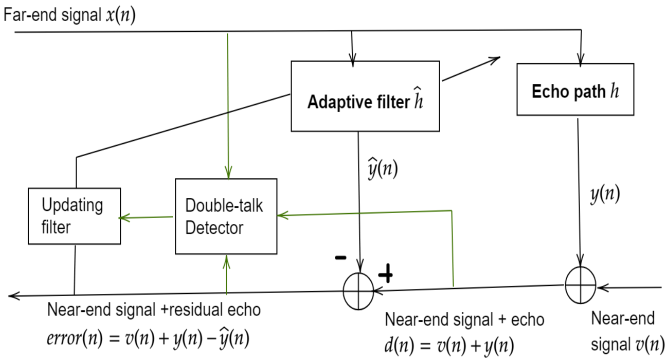
LMS Algorithm

- LMS Algorithm tends to the minimum absolute value of the error for each sample[6].
- **Advantage:**
  - Low computational complexity
  - Easy of implementation
- **Disadvantage:**
  - Weak convergence
  - Have a fixed step size parameter for every iteration.

[6] A system approach to multi-channel acoustic echo cancellation and residual echo suppression for robust hands-free teleconferencing

Contents

Robust Acoustic Echo Cancellation (RAEC)



- **Double-Talk Detector (DTD):** It will estimate the statistic decision, compare to the threshold to make the DTD decision to control the updating filter (freeze the adaptation or not).
- **Updating filter block:** It permits the update of weight vector or not[1].

The Geigel algorithm

- **A simple approach:** Measure the power of the received signal $d(n)$,compare it to the power of the far-end signal $x(n)$;
- **The decision variable:**

$$d_G(n) = \frac{|d(n)|}{max\{|x(n), ...|x(n-N+1)||\}}$$

- If $d_G(n)$ is larger than some preset threshold, T_G, it is treated that Double Talk is occurring, otherwise not[5].

[5] Adaptive echo cancellation analysis(Sun, Yongdong)

Normalized Least Mean Square Algorithm (NLMS)

- **The difference between NLMS algorithm and LMS algorithm:**
- When μ is optimized as described by

$$\mu = \frac{\alpha}{\beta + x^T(n)x(n)}\ , \alpha \in (0, 2), 0 \leq \beta$$

- β guarantees that the denominator never becomes zero,
- α is a relaxation factor, the normalized LMS algorithm results.
- The weight vector update now is[1]:

$$\mathrm{w}(n+1) = \mathrm{w}(n) + \frac{\alpha}{\beta + x^T(n)x(n)} e(n)\mathrm{x}(n)$$

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[1] Acoustic Echo Cancellation Using Modified Normalized Least Mean Square Adaptive Filters(Akingbade, Kayode Francis and Alimi, Isiaka Ajewale)

NLMS Algorithm

- **For the NLMS algorithm**:
- Each iteration of the NLMS algorithm requires 3N+1 multiplications, this is only N more than LMS algorithm.
- **Advantage:**
  - Far greater stability with unknown signals
  - Good convergence speed
  - Relative computational simplicity

Performance Measure

- **Performance measure:**
- Echo Return Loss Enhancement (ERLE) factor which is defined as:

$$ERLE = 10log_{10}\frac{P_d(n)}{P_e(n)} = \frac{E\left[d^2(n)\right]}{E\left[e^2(n)\right]}$$

- $ERLE$ is measured in dB, $d^2(n)$ is microphone signal's power and $e^2(n)$ is residual error signal's power.
- ERLE depends on the algorithm used for the adaptive filter. It considers the convergence time and near-end attenuation[1].

[1] Acoustic Echo Cancellation Using Modified Normalized Least Mean Square Adaptive Filters(Akingbade, Kayode Francis and Alimi, Isiaka Ajewale)

Analyze Result

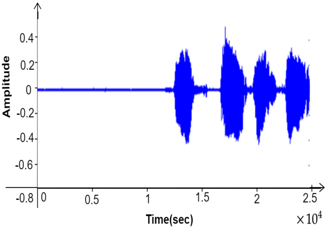

Figure-1: Near-end Speech Signal[4]

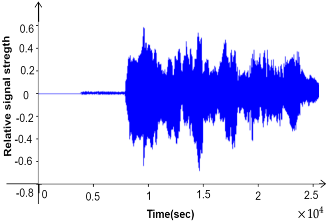

Figure-3: Echo Signal[4]

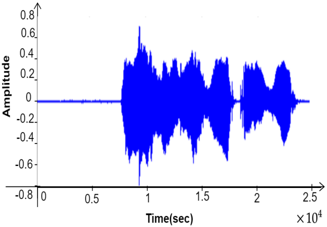

Figure-2: Far-end Speech Signal[4]

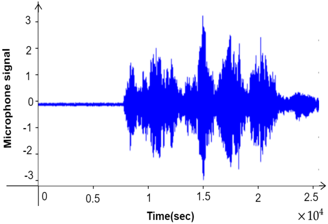

Figure-4: Microphone Signal[4]

Analyze Result

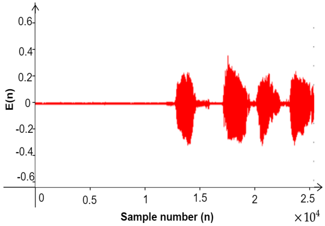

Figure-5: Desired Output Signal for NLMS[4]

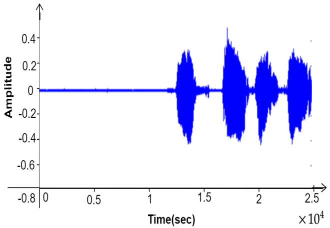

Figure-6: Compared wtih Near-end Speech Signal[4]

[4]Design And Simulation Of An Acoustic Echo Cancellation System For Hand-Free Telecommunication(Pwint, Ein Gyin and Mon, Su Su Yi and Tun, Hla Myo)

Contents

Conclusion

- **For AEC :**
- We use LMS algorithm.
  - Because of its simplicity, LMS is most popular adaptive algorithm.
  - But it suffers from slow and data dependent convergence behavior.
- **For RAEC:**
- We use DTD and NLMS algorithm.
- DTD: We use the Geigel algorithm.
- The NLMS algorithm:
  - It is more robust variant of the LMS algorithm,
  - Exhibit a better balance between simplicity and performance than the LMS algorithm.
  - The NLMS has been largely used in real-time applications.

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THANK YOU!