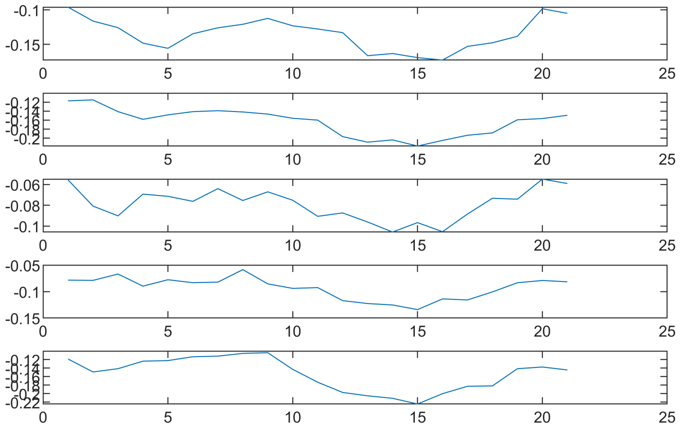
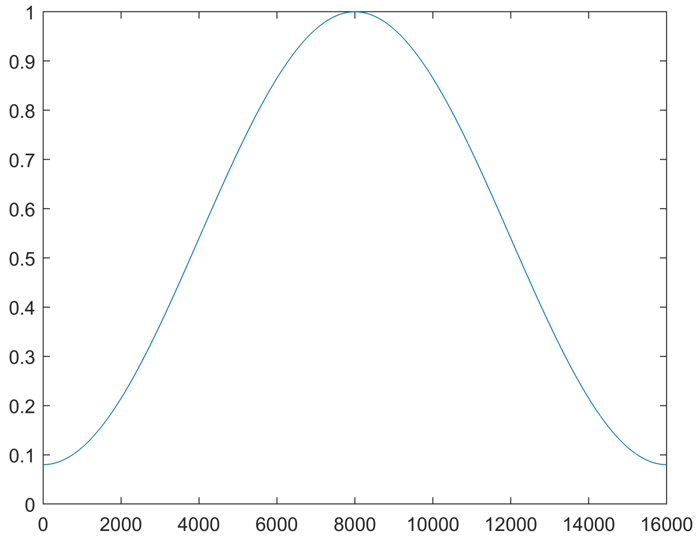
```
clear;
close all;
clc;

[x1, sr] = audioread('sample5/F01_22HC010H_BUS.CH1.wav');
[x2, sr] = audioread('sample5/F01_22HC010H_BUS.CH3.wav');
[x3, sr] = audioread('sample5/F01_22HC010H_BUS.CH4.wav');
[x4, sr] = audioread('sample5/F01_22HC010H_BUS.CH5.wav');
[x5, sr] = audioread('sample5/F01_22HC010H_BUS.CH6.wav');

x = [x1, x2, x3, x4, x5];
x = x';
nsample = size(x,2);
nmic = 5;
npair = nmic - 1;

figure;
st = 49000;
ed = st + 20;
subplot(6,1,1); plot(x(1,st:ed)); %
subplot(6,1,2); plot(x(2,st:ed)); % ref_mic assumed
subplot(6,1,3); plot(x(3,st:ed)); %
subplot(6,1,4); plot(x(4,st:ed)); %
subplot(6,1,5); plot(x(5,st:ed)); %
```



make hamming window

```
nwin = 16000; % 1 sec
%     hamm_val = 0.54 - 0.46*cos(6.283185307*i/(window-1));
win = zeros(1,nwin);
```

```
for i = 1:nwin
    win(i) = 0.54 - 0.46 * cos(6.283185307*(i-1)/(nwin-1));
end

figure; plot(win);
```



```
disp(win(1:10)');
```

```
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
    0.0800
```

testing calculating xcorr

```

% Comparing from frame 300 to 16300
% 1st xcorr calculation iteration 1: 0.239386
% 2nd xcorr calculation iteration 1: 0.152243
% avg xcorr between 1 and 2
% 0.230185

npiece = 200;
nfft = 16384*2;
nbest = 2;

scroll = floor(nsample / (npiece+2));
```

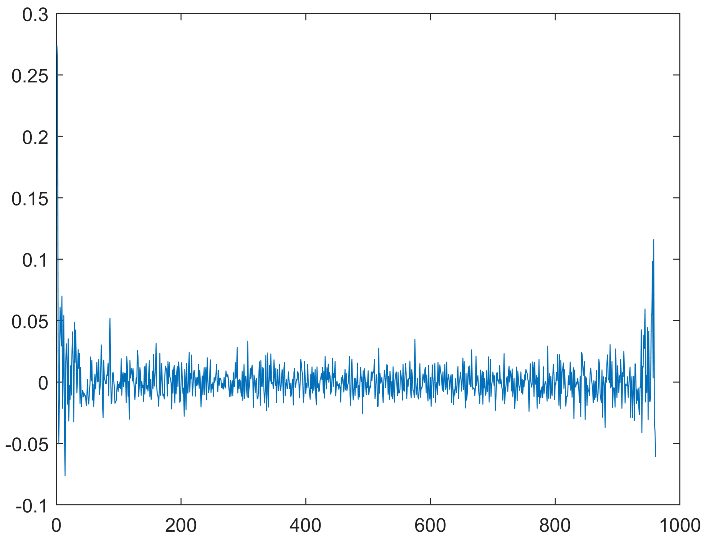
```
stft1 = fft([x(1,scroll:(scroll+nwin-1)) .* win, zeros(1,nfft-nwin)]);
stft2 = fft([x(2,scroll:(scroll+nwin-1)) .* win, zeros(1,nfft-nwin)]);

numerator = stft1 .* conj(stft2);
ccorr = real(ifft(numerator ./ (abs(numerator))));
ccorr = [ccorr(1:481), ccorr(end-479:end)];
best2_ccorr = maxk(ccorr, 2);

disp('scroll');
```

```
scroll
```

```
disp(scroll);
```

```
   300
```

```
plot(ccorr);
```



```
disp(best2_ccorr);
```

```
    0.2739    0.2559
```

calculate avg_ccorr

```
avg_ccorr = zeros(nmic, nmic);

for i = 1:npiece
    st = i * scroll;
    ed = st + 16000 - 1;
    if st + nfft >= nsample
```

```
            break;
        end

        for m1 = 1:(nmic-1)
            avg_ccorr(m1, m1) = 0;
            for m2 = (m1+1):nmic
                stft1 = fft([x(m1,st:ed) .* win, zeros(1,nfft-nwin)]);
                stft2 = fft([x(m2,st:ed) .* win, zeros(1,nfft-nwin)]);
                numerator = stft1 .* conj(stft2);
                ccorr = real(ifft(numerator ./ (abs(numerator))));
                ccorr = [ccorr(1:481), ccorr(end-480+1:end)];

                avg_ccorr(m1, m2) = avg_ccorr(m1, m2) + sum(maxk(ccorr, nbest));
                avg_ccorr(m2, m1) = avg_ccorr(m1, m2);
            end
        end
    end

    avg_ccorr = avg_ccorr / (nbest * i * (npair));
    disp(avg_ccorr);
```

```
         0    0.0964    0.0859    0.0787    0.0803
    0.0964         0    0.0802    0.0775    0.0874
    0.0859    0.0802         0    0.0998    0.0943
    0.0787    0.0775    0.0998         0    0.0995
    0.0803    0.0874    0.0943    0.0995         0
```

```
disp(sum(avg_ccorr,1)');
```

```
    0.3413
    0.3415
    0.3602
    0.3555
    0.3615
```

```
disp(max(sum(avg_ccorr,1)));
```

```
    0.3615
```

calculating scaling factor

```
% Set the total number of segments from 10 to 1 for computing scalling factor, with segment du
% Processing channel 0
% amount_frames_read: 0.000000
% segment_duration: 0.000000
% The Median maximum energy for channel 0 is 0.352051
% Set the total number of segments from 10 to 1 for computing scalling factor, with segment du
% Processing channel 1
% amount_frames_read: 0.000000
% segment_duration: 0.000000
% The Median maximum energy for channel 1 is 0.341858
% Set the total number of segments from 10 to 1 for computing scalling factor, with segment du
% Processing channel 2
% amount_frames_read: 0.000000
% segment_duration: 0.000000
% The Median maximum energy for channel 2 is 0.499451
% Weighting calculated to adjust the signal: 0.754173

nsegment = 10;

max_val = zeros(nmic, 1);

if size(x,2) <= 160000 % 10 seconds
    for m = 1:nmic
        max_val(m) = max(abs(x(m,:)));
    end
else
    if size(x,2) < 1600000 % 100 seconds
        nsegment = ceil(size(x,2) / 16000);
    end
    scroll = floor(size(x,2) / nsegment);
    max_val_candidate = zeros(nmic, nsegment);

    for s = 0:(nsegment-1)
        st = s * scroll + 1;
        ed = st + scroll - 1;
        for m = 1:nmic
            max_val_candidate(m,s+1) = abs(max(x(m,st:ed)));
        end
    end

    for m = 1:nmic

        sorted = sort(max_val_candidate(m,:), 'ascend');
        max_val(m) = sorted(end/2 + 1);
    end
end

overall_weight = (0.3 * nmic) / sum(max_val);

disp(max_val);
```

```
    0.3521
    0.3756
    0.3000
    0.3419
    0.4995
```

```
disp(overall_weight);
```

```
    0.8026
```

```
% disp((0.3 * 3) / (0.352051 + 0.341858 + 0.499451));
```

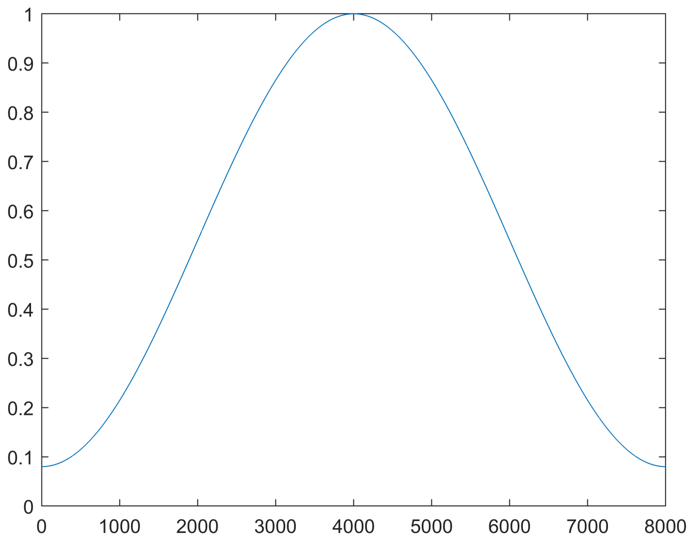
compute total number of delays

```
% int totalNumDelays
% % = (int)((m_frames - (*m_config).windowFrames - m_biggestSkew - m_UEMGap)/((*m_config).
% rate*m_sampleRateInMs));
% sr_in_ms = 16000 / 1000; % 16

% too complicated. I should do hard coding
nframe = floor(( nsample - 8000 ) / (4000));

disp(nframe);
```

```
    13
```

recreating hamming window

```
nwin = 8000; % 0.5 sec
nfft = 16384;
%     hamm_val = 0.54 - 0.46*cos(6.283185307*i/(window-1));
win = zeros(1,nwin);
for i = 1:nwin
    win(i) = 0.54 - 0.46 * cos(6.283185307*(i-1)/(nwin-1));
end

figure; plot(win);
```



```
disp(win(1:10));
```

```
    0.0800    0.0800    0.0800    0.0800    0.0800    0.0800    0.0800    0.0800    0.0800    0.0800
```

```
disp(16000 * 30 / 1000);
```

```
   480
```

compute TDOA

```
nbest = 4;
[dummy, ref_mic] = max(sum(avg_ccorr));
%ref_mic = 2;
micpair = zeros(nmic, npair);


gcc_nbest = zeros(npair, nframe, nbest);
tdoa_nbest = zeros(npair, nframe, nbest);
lrfilp_gcc = zeros(npair, nframe, nfft);

for m = 1:nmic
    p = 1; % pair idx
    for i = 1:nmic
        if i == m
            continue;
        end
        micpair(m,p) = i;
        p = p + 1;
    end
end


for t = 1:(nframe)
    st = (t-1) * 4000 + 1;
    ed = st + nwin - 1;
%     disp(st);
%     disp(ed);
        for p = 1:npair

            m = micpair(ref_mic,p);

            stft_ref = fft([x(ref_mic,st:ed) .* win, zeros(1,nfft-nwin)]);
            stft_m = fft([x(m,st:ed) .* win, zeros(1,nfft-nwin)]);
            numerator = stft_m .* conj(stft_ref);
            gcc = real(ifft(numerator ./ (eps+abs(numerator))));
            gcc = [gcc(end-479:end), gcc(1:480)];
            [gcc_nbest(p,t,:), tdoa_nbest(p,t,:)] = maxk(gcc, nbest);
            tdoa_nbest(p,t,:) = tdoa_nbest(p,t,:) - (481); % index shifting

        end
```

```
end

disp(squeeze(gcc_nbest(:,:,1)));
```

```
  1 ~ 11번 열

    0.0840    0.0958    0.3159    0.4406    0.3951    0.5243    0.3628    0.3320    0.2340    0.5149    0.3196
    0.1304    0.1247    0.4047    0.3721    0.6302    0.4966    0.4161    0.2995    0.2472    0.3946    0.4590
    0.1037    0.1352    0.3670    0.4736    0.5887    0.4686    0.5411    0.4187    0.3534    0.5520    0.5322
    0.1688    0.1912    0.4108    0.5103    0.5960    0.6375    0.5026    0.4790    0.3169    0.4470    0.4333

  12 ~ 13번 열

    0.3942    0.1622
    0.3271    0.2190
    0.4496    0.1741
    0.3144    0.2648
```

```
disp(squeeze(tdoa_nbest(:,:,1)));
```

```
     2     4     3     3     2     3     4     3     4     4     4     3     4
     2    -6     3     2     2     2     3     2     2     2     3     0     3
     0     0     0     0     0     0     1     1     1     1     1     1    -2
     2     0    -1    -1    -1    -1    -1    -1     0    -1     0    -1    -1
```

```
disp(squeeze(tdoa_nbest(:,:,2)));
```

```
    16     3     4     2     3     0     3     4     3     1     3     1     1
    -8     2     2     3     0     3     2     3     3     3     0     3    -8
     6     1     1     1     1     1     0     0     2     2     3    -2     0
     0    -1     0     2     2     0     0     0    -1     0    -1     0     0
```

find noise threshold

```
% Threshold is 0.140125 (min: 0.132648 max 0.563892)
% Thresholding noisy frames lower than 0.140125
th_idx = floor((0.1 * nframe)) + 1;

sorted = sort(sum(gcc_nbest(:,:,1),1), 'ascend');

threshold = sorted(th_idx)/npair;
%disp(sorted);
% disp(th_idx);
disp(threshold);
```

```
    0.1367
```

noise filtering

```
noise_filter = zeros(npair, nframe);

for p = 1:npair
    for t = 1:nframe
        if gcc_nbest(p,t,1) < threshold
            noise_filter(p,t) = 1;

            if t == 1  % it's silence
                gcc_nbest(p,t,:) = 0; % masking with discouraging values
                gcc_nbest(p,t,1) = 1; % only one path
                tdoa_nbest(p,t,:) = 480; % masking with discouraging values
                tdoa_nbest(p,t,1) = 0;
            else
                tdoa_nbest(p,t,:) = tdoa_nbest(p,t-1,:);
            end
        end
    end
end

disp(gcc_nbest(:,:,1));
```

```
  1 ~ 11번 열

    1.0000    0.0958    0.3159    0.4406    0.3951    0.5243    0.3628    0.3320    0.2340    0.5149    0.3196
    1.0000    0.1247    0.4047    0.3721    0.6302    0.4966    0.4161    0.2995    0.2472    0.3946    0.4590
    1.0000    0.1352    0.3670    0.4736    0.5887    0.4686    0.5411    0.4187    0.3534    0.5520    0.5322
    0.1688    0.1912    0.4108    0.5103    0.5960    0.6375    0.5026    0.4790    0.3169    0.4470    0.4333

  12 ~ 13번 열

    0.3942    0.1622
    0.3271    0.2190
    0.4496    0.1741
    0.3144    0.2648
```

```
disp(tdoa_nbest(:,:,1));
```

```
     0     0     3     3     2     3     4     3     4     4     4     3     4
     0     0     3     2     2     2     3     2     2     2     3     0     3
     0     0     0     0     0     0     1     1     1     1     1     1    -2
     2     0    -1    -1    -1    -1    -1    -1     0    -1     0    -1    -1
```

```
disp(gcc_nbest(:,:,2));
```

```
  1 ~ 11번 열

         0    0.0795    0.3060    0.1930    0.3828    0.2033    0.3329    0.1361    0.2310    0.2623    0.2912
         0    0.1145    0.1922    0.3268    0.1864    0.2997    0.2820    0.2615    0.2344    0.3583    0.2814
         0    0.0832    0.3235    0.3037    0.2260    0.4202    0.1666    0.1280    0.1855    0.2332    0.1263
    0.1297    0.1192    0.3198    0.2337    0.2307    0.2624    0.3778    0.2058    0.2509    0.4398    0.4308

  12 ~ 13번 열

    0.2259    0.1385
    0.3167    0.1628
    0.2238    0.1681
    0.2250    0.1937
```

```
disp(tdoa_nbest(:,:,2));
```

```
   480   480     4     2     3     0     3     4     3     1     3     1     1
   480   480     2     3     0     3     2     3     3     3     0     3    -8
   480   480     1     1     1     1     0     0     2     2     3    -2     0
     0    -1     0     2     2     0     0     0    -1     0    -1     0     0
```

single channel viterbi - emission, trans prob

```
emission1 = zeros(npair, nframe, nbest);
diff1 = zeros(npair, nframe, nbest, nbest); % do not using 1st idx
transition1 = zeros(npair, nframe, nbest, nbest); % do not using 1st idx

for p = 1:npair
    for t = 1:nframe
        for n = 1:nbest
            if gcc_nbest(p,t,n) == 0
                emission1(p,t,n) = -1000;
            else
                emission1(p,t,n) = log10(gcc_nbest(p,t,n));
            end
        end
    end
end



for p = 1:npair
    for t = 2:nframe
        for n = 1:nbest
            for nprev = 1:nbest
                diff1(p,t,n,nprev) = abs(tdoa_nbest(p,t,n) - tdoa_nbest(p,t-1,nprev));
            end
        end
    end
end

maxdiff1 = max(diff1(:));

% for p = 1:npair
%     for t = 2:nframe
%         for n = 1:nbest
%             if maxdiff1 < max(diff1(p,t,n,:));
%             maxdiff1(p,t,n) = max(diff1(p,t,n,:));
%         end
%     end
% end

for p = 1:npair
    for t = 2:nframe
        for n = 1:nbest
            for nprev = 1:nbest
                % there is a computational bug.
%                 disp((2+maxdiff1(p,t,n)));
%                 disp(diff1(p,t,n,nprev));
%                 disp(maxdiff1(p,t,n));
%                 disp(log10(481/482));
%                 disp(1 + maxdiff1(p,t,n) - diff1(p,t,n,nprev));
%                 disp((2+maxdiff1(p,t,n)));
                nume = 1 + maxdiff1 - diff1(p,t,n,nprev);
                deno = (2+maxdiff1);
                transition1(p,t,n,nprev) = log10(nume / deno);
%                 disp(transition1(p,t,n,nprev));
            end
        end
    end
end
```

single channel viterbi - searching

```
nbest2 = 2;
score1 = zeros(npair, nframe, nbest, nbest); % tmp variable
score1_table = zeros(npair, nframe, nbest);
back1_table = zeros(npair, nframe, nbest);
bestpath1 = zeros(npair, nframe, nbest2); % state idx stored.

for p = 1:npair

    for n = 1:nbest
        score1(p,1,n,:) = emission1(p,1,n); % broadcasting
        score1_table(p,1,n) = emission1(p,1,n);
    end
end

for p = 1:npair
    for t = 2:nframe
        for n = 1:nbest
            for nprev = 1:nbest
                score1(p,t,n,nprev) = ...
                    score1_table(p,t-1,nprev,1) + ...
                    25*transition1(p,t,n,nprev) + ...
                    emission1(p,t,n);
            end
            %score1_table(p,t,n) = max(score1(p,t,n,:));
            [score1_table(p,t,n),back1_table(p,t,n)] = max(score1(p,t,n,:));
        end
    end
end

for p = 1:npair
    [dummy, bestpath1(p,end,1)] = max(score1_table(p,end,:));
end

for p = 1:npair
    for back_t = 0:(nframe-2)
        t = nframe - back_t;
        bestpath1(p,t-1,1) = back1_table(p,t,bestpath1(p,t,1));
    end
end

% If you put more weight on transition, the back table changes.
% If I had put weight 10 on transition, the back table became intuitive.
disp(back1_table(1,:,:)); % compare first mic pair trellis plot
```

```
(:,:,1) =

     0     1     1     1     1     2     1     2     1     1     1     1     1


(:,:,2) =

     0     1     1     1     1     1     1     1     1     2     1     1     1


(:,:,3) =

     0     1     1     1     1     1     1     1     1     2     1     1     1


(:,:,4) =

     0     1     1     1     1     2     1     2     1     1     1     1     1
```

```
disp(score1_table(1,:,:));
```

```
(:,:,1) =

  1 ~ 11번 열

         0   -1.0412   -1.6314   -2.0097   -2.4578   -2.7519   -3.2370   -3.7532   -4.4287   -4.7393   -5.2570

  12 ~ 13번 열

   -5.7061   -6.5408


(:,:,2) =

   1.0e+03 *

  1 ~ 11번 열

   -1.0000   -0.0508   -0.0017   -0.0024   -0.0024   -0.0032   -0.0033   -0.0041   -0.0044   -0.0051   -0.0053

  12 ~ 13번 열
```

```
   -0.0060   -0.0066


(:,:,3) =

   1.0e+03 *

  1 ~ 11번 열

   -1.0000   -0.0508   -0.0021   -0.0025   -0.0027   -0.0034   -0.0039   -0.0043   -0.0045   -0.0051   -0.0054

  12 ~ 13번 열

   -0.0061   -0.0066


(:,:,4) =

   1.0e+03 *

  1 ~ 11번 열

   -1.0000   -0.0509   -0.0023   -0.0030   -0.0031   -0.0035   -0.0038   -0.0042   -0.0052   -0.0055   -0.0057

  12 ~ 13번 열

   -0.0064   -0.0069
```

```
disp(bestpath1(1,:,1));
```

```
     1     1     1     1     2     1     2     1     1     1     1     1     1
```

single channel viterbi - 2-best path

```
emission1_bak = emission1;
for p = 1:npair
    for t = 1:nframe
        best1 = bestpath1(p,t,1);
        emission1(p,t,best1) = -1000;
    end
end

for p = 1:npair
    for n = 1:nbest
        score1(p,1,n,:) = emission1(p,1,n); % broadcasting
        score1_table(p,1,n) = emission1(p,1,n);
    end
end

for p = 1:npair
    for t = 2:nframe
        for n = 1:nbest
            for nprev = 1:nbest
                score1(p,t,n,nprev) = ...
```

```
                    score1_table(p,t-1,nprev,1) + ...
                    25*transition1(p,t,n,nprev) + ...
                    emission1(p,t,n);
            end
            [score1_table(p,t,n),back1_table(p,t,n)] = max(score1(p,t,n,:));
        end
    end
end

for p = 1:npair
    [dummy, bestpath1(p,end,2)] = max(score1_table(p,end,:));
end

for p = 1:npair
    for back_t = 0:(nframe-2)
        t = nframe - back_t;
        bestpath1(p,t-1,2) = back1_table(p,t,bestpath1(p,t,2));
    end
end


disp(squeeze(bestpath1(1,:,:))');
```

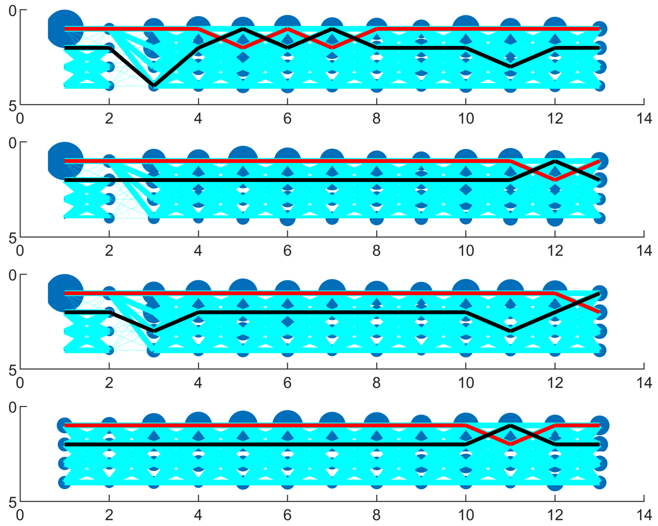
```
     1     1     1     1     2     1     2     1     1     1     1     1     1
     2     2     4     2     1     2     1     2     2     2     3     2     2
```

```
disp(squeeze(bestpath1(2,:,:))');
```

```
     1     1     1     1     1     1     1     1     1     1     1     2     1
     2     2     2     2     2     2     2     2     2     2     2     1     2
```

plot path

```
% https://kr.mathworks.com/help/matlab/ref/scatter.html
figure;

emission_plot = zeros(npair, 3, nbest * nframe);
for p = 1:npair
    for ibest = 1:nbest
        for iframe = 1:nframe
            emission_plot(p,1,(ibest-1) * nframe + iframe) = iframe;
            emission_plot(p,2,(ibest-1) * nframe + iframe) = ibest;
            emission_plot(p,3,(ibest-1) * nframe + iframe) = 1 + 400 * 10^(emission1_bak(p, if
        end
    end
end

hold on;
for p=1:npair
    subplot(npair,1,p);
    scatter(...
        squeeze(emission_plot(p, 1,:)), ... % x range (x data for scatter)
        squeeze(emission_plot(p, 2,:)), ... % y range (y data for scatter)
        squeeze(emission_plot(p, 3,:)), ... % radius
        'filled');
    axis ij;
    ylim([0 nbest+1]); % for readability
end

hold on;
max_linewidth = 1+max(max(max(max(transition1))));
for p=1:npair
    subplot(npair, 1, p);
    for t = 2:nframe
        for n = 1:nbest
            for nprev = 1:nbest
                line([t-1 t], ... % x data
                    [nprev n], ... % y data
                    'LineWidth', 10^(transition1(p,t,n,nprev))*3,... % tuning
                    'Color','cyan');
            end
        end
    end
end

hold on;
for p = 1:npair
    subplot(npair,1,p);
    for t = 2:nframe
        line([t-1 t], [bestpath1(p,t-1,1) bestpath1(p,t,1)], ...
            'LineWidth', 2, ...
            'Color', 'red');
        line([t-1 t], [bestpath1(p,t-1,2) bestpath1(p,t,2)], ...
            'LineWidth', 2, ...
            'Color', 'black');
    end
end
```



multi channel viterbi - state define

```
nbest2 = 2;
nstate = nbest2 ^ npair;
g = zeros(nstate, npair);
tmp_row = zeros(3,1);
l = 1;
for ibest = 1:nbest2
    [g, l] = fill_all_comb(1, npair, ibest, nbest2, tmp_row, g, l);
end

disp(g);
```

```
     1     1     1     1
     1     1     1     2
     1     1     2     1
     1     1     2     2
     1     2     1     1
     1     2     1     2
     1     2     2     1
     1     2     2     2
     2     1     1     1
     2     1     1     2
     2     1     2     1
     2     1     2     2
     2     2     1     1
     2     2     1     2
     2     2     2     1
     2     2     2     2
```

multi channel viterbi - emission, trans prob

```
emission2 = zeros(nframe, nstate);

diff2 = zeros(nframe, nstate, nstate); % do not using 1st idx
transition2 = zeros(nframe, nstate, nstate); % do not using 1st idx

for t = 1:nframe
    for l = 1:nstate
        for m = 1:npair
            ibest = bestpath1(m, t, g(l,m));
            if gcc_nbest(m,t,ibest) > 0
                emission2(t, l) = emission2(t, l) + log10(gcc_nbest(m,t,ibest));
            else
                emission2(t, l) = emission2(t, l) + -1000;
            end

        end
    end
end

for t = 2:nframe
    for l = 1:nstate
        for lprev = 1:nstate
            for m = 1:npair
                ibest = bestpath1(m, t, g(l,m));
                jbest = bestpath1(m, t, g(lprev,m));
                transition2(t,l,lprev)...
                    = transition2(t,l,lprev)...
                    + transition1(m,t,ibest,jbest);
            end
        end
    end
end
```

multi channel viterbi - searching

```
score2 = zeros(nframe, nstate, nstate);
score2_table = zeros(nframe, nstate);
back2_table = zeros(nframe, nstate);

for l = 1:nstate
    score2_table(1,l) = emission2(1,l);
end

for t = 2:nframe
    for l = 1:nstate
        for lprev = 1:nstate
             score2(t,l,lprev) = ...
                score2_table(t-1,lprev) + ...
                25*transition2(t,l,lprev) + ...
                1*emission2(t,l);

        end
        [score2_table(t,l), back2_table(t,l)] = max(score2(t,l,:));
    end
end

bestpath2 = zeros(nframe,1); % state idx stored.

[dummy, bestpath2(end)] = max(score2_table(end,:));

for back_t = 0:(nframe-2)
    t = nframe - back_t;
    bestpath2(t-1) = back2_table(t,bestpath2(t));
end


besttdoa = zeros(npair, nframe);
bestgcc2 = zeros(npair, nframe);

for t = 1:nframe
    for p = 1:npair
        l = bestpath2(t);
        ibest = bestpath1(p, t, g(l,p));
        besttdoa(p,t) = tdoa_nbest(p,t,ibest);
        bestgcc2(p,t) = gcc_nbest(p,t,ibest);
    end
end

disp(back2_table(:,:)'); % compare first mic pair trellis plot
```

```
     0     1     1     1     1     9     1     9     1     1     2     2     5
     0     1     1     1     1     9     1     9     1     1     1     1     5
     0     1     1     1     1     9     1     9     1     1     2     2     5
     0     1     1     1     1     9     1     9     1     1     1     1     5
     0     1     1     1     1     9     1     9     1     1     2     2     5
     0     1     1     1     1     9     1     9     1     1     1     1     5
     0     1     1     1     1     9     1     9     1     1     2     2     5
     0     1     1     1     1     9     1     9     1     1     1     1     5
     0     1     1     1     1     9     1     1     1     9     2     2     5
     0     1     1     1     1     9     1     1     1     9     1     1     5
     0     1     1     1     1     9     1     1     1     9     2     2     5
     0     1     1     1     1     9     1     1     1     9     1     1     5
     0     1     1     1     1     9     1     1     1     9     2     2     5
     0     1     1     1     1     9     1     1     1     9     1     1     5
     0     1     1     1     1     9     1     1     1     9     2     2     5
     0     1     1     1     1     9     1     1     1     9     1     1     5
```

```
disp(bestpath2');
```

```
     1     1     1     1     9     1     9     1     1     1     2     5     3
```

```
disp(besttdoa);
```

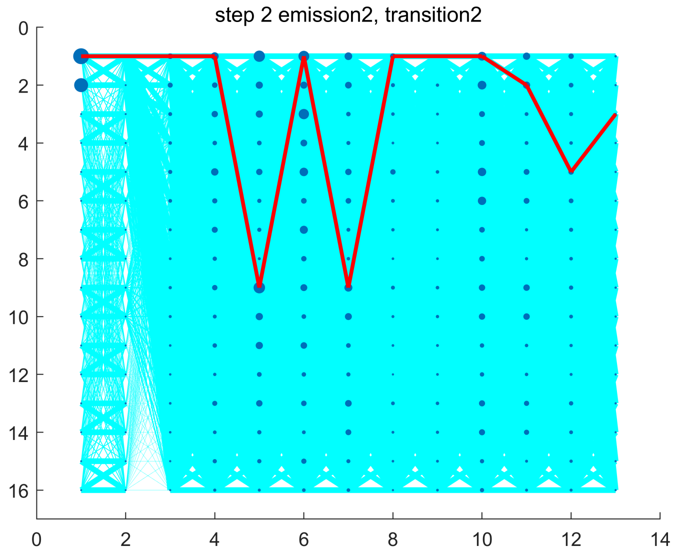
```
     0     0     3     3     2     3     4     3     4     4     4     3     4
     0     0     3     2     2     2     3     2     2     2     3     0     3
     0     0     0     0     0     0     1     1     1     1     1     1    -2
     2     0    -1    -1    -1    -1    -1    -1     0    -1     0    -1    -1
```

```
disp(bestgcc2);
```

```
  1 ~ 11번 열

    1.0000    0.0958    0.3159    0.4406    0.3951    0.5243    0.3628    0.3320    0.2340    0.5149    0.3196
    1.0000    0.1247    0.4047    0.3721    0.6302    0.4966    0.4161    0.2995    0.2472    0.3946    0.4590
    1.0000    0.1352    0.3670    0.4736    0.5887    0.4686    0.5411    0.4187    0.3534    0.5520    0.5322
    0.1688    0.1912    0.4108    0.5103    0.5960    0.6375    0.5026    0.4790    0.3169    0.4470    0.4333

  12 ~ 13번 열

    0.3942    0.1622
    0.3271    0.2190
    0.4496    0.1741
    0.3144    0.2648
```

multi channel viterbi - plot

```
% https://kr.mathworks.com/help/matlab/ref/scatter.html
figure;

%figure;
%max_linewidth = 1+max(max(max(max(transition2))));

title(sprintf('step 2 emission2, transition2'));
for t = 2:nframe
    for l = 1:nstate
        for lprev = 1:nstate
            line([t-1 t], ... % x data
                [lprev l], ... % y data
                'LineWidth', 3*(exp(transition2(t,l,lprev))),... % tuning
                'Color','cyan');
            axis ij;
        end
    end
end
% ylim([0 nstate+1]);
% xlim([0 nframe+1]);

emission2_plot = zeros(3, nstate * nframe);

for l = 1:nstate
    for iframe = 1:nframe


        emission2_plot(1,(l-1) * nframe + iframe) = iframe;
        emission2_plot(2,(l-1) * nframe + iframe) = l;
        emission2_plot(3,(l-1) * nframe + iframe) = 1 + 400 * 10^(emission2(iframe, l));
    end
end

hold on;
scatter(...
    squeeze(emission2_plot(1,:)), ... % x range (x data for scatter)
    squeeze(emission2_plot(2,:)), ... % y range (y data for scatter)
    squeeze(emission2_plot(3,:)), ... % radius
    'filled');

hold on;
for t = 2:nframe
    line([t-1 t], [bestpath2(t-1) bestpath2(t)], ...
        'LineWidth', 2, ...
        'Color', 'red');
end


axis ij;
ylim([0 nstate+1]); % for readability
xlim([0 nframe+1]);
```



compute local xcorr

```
tmp_localxcorr = zeros(nmic, nmic, nframe);
localxcorr = zeros(nmic, nframe);

mic2refpair = zeros(nmic,1);
mic2refpair(ref_mic) = 0;

for p = 1:npair
```

```
    m = micpair(ref_mic,p);
    mic2refpair(m) = p;
end

for t = 1:nframe
    ref_st = (t-1) * 4000 + 1;
    ref_ed = min(ref_st + 8000 - 1, nsample);

    for m1 = 1:(nmic-1)
        for m2 = (m1+1):nmic

            if m1 == ref_mic
                st1 = ref_st;
                ed1 = ref_ed;
            else
                p = mic2refpair(m1);
                st1 = max(1,ref_st + besttdoa(p,t));
                ed1 = min(nsample, ref_ed + besttdoa(p,t));
            end

            if m2 == ref_mic
                st2 = ref_st;
                ed2 = ref_ed;
            else
                p = mic2refpair(m2);
                st2 = max(1,ref_st + besttdoa(p,t));
                ed2 = min(nsample, ref_ed + besttdoa(p,t));
            end

            buf1 = x(m1,st1:ed1);
            buf2 = x(m2,st2:ed2);

            ener1 = sum(buf1(:).^2);
            ener2 = sum(buf2(:).^2);

            min_ed = min(ed1-st1, ed2-st2) + 1;
            tmp_localxcorr(m1,m2,t)...
                = sum(...
                buf1(1:min_ed) .* buf2(1:min_ed)...
                / (ener1 * ener2));

            tmp_localxcorr(m2,m1,t) = tmp_localxcorr(m1,m2,t);
        end
    end
end

localxcorr = squeeze(sum(tmp_localxcorr,1));
disp(localxcorr);
```

```
  1 ~ 11번 열

    0.1241    0.0749    0.0660    0.0619    0.0644    0.0685    0.0618    0.0604    0.0704    0.0804    0.1006
    0.1103    0.0666    0.0572    0.0551    0.0586    0.0606    0.0546    0.0525    0.0610    0.0715    0.0893
    0.1528    0.0899    0.0769    0.0698    0.0722    0.0762    0.0712    0.0696    0.0833    0.1025    0.1277
    0.1483    0.0849    0.0678    0.0613    0.0635    0.0679    0.0632    0.0634    0.0765    0.0926    0.1167
    0.1046    0.0605    0.0485    0.0453    0.0488    0.0526    0.0481    0.0479    0.0570    0.0663    0.0842

  12 ~ 13번 열

    0.1483    0.1360
    0.1323    0.1254
    0.1863    0.1722
    0.1719    0.1614
    0.1273    0.1183
```

compute sum weight

```
out_weight = ones(nmic, nframe) * ( 1 / nmic);
alpha = 0.05;


for t = 1:nframe

    if sum(localxcorr(:,t)) == 0
        localxcorr(:,t) = 1 / nmic;
    end

    localxcorr(:,t) = localxcorr(:,t) / sum(localxcorr(:,t));

    for m = 1:nmic
        if m == ref_mic
             out_weight(m,t) = ...
            (1-alpha) * out_weight(m,max(1,t-1)) ...
            + alpha * localxcorr(m,t);

        else
            p = mic2refpair(m);
            if noise_filter(p,t) == 0
                out_weight(m,t) = ...
                    (1-alpha) * out_weight(m,max(1,t-1)) ...
                    + alpha * localxcorr(m,t);
            end
        end
    end

    out_weight(:,t) = out_weight(:,t) / sum(out_weight(:,t));

end

disp(mic2refpair);
```

```
     1
     2
     3
     4
     0
```

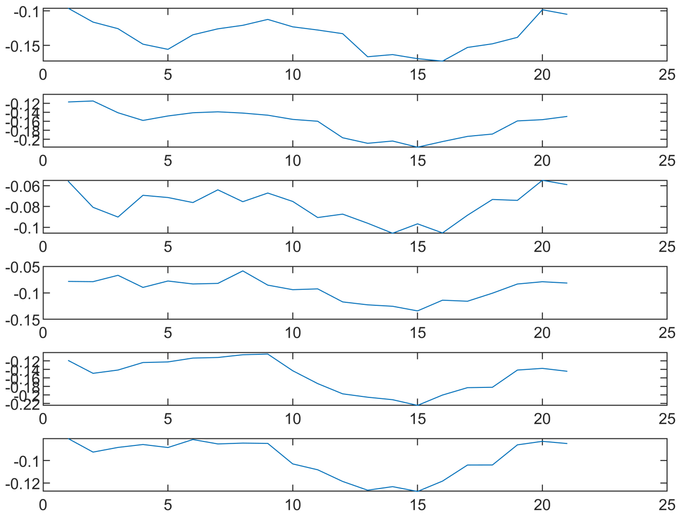
```
disp(out_weight);
```

```
  1 ~ 11번 열

    0.2000    0.2002    0.2006    0.2011    0.2015    0.2020    0.2022    0.2024    0.2024    0.2020    0.2016
    0.2000    0.2002    0.1992    0.1986    0.1982    0.1976    0.1969    0.1960    0.1949    0.1938    0.1927
    0.2000    0.2002    0.2023    0.2041    0.2056    0.2070    0.2086    0.2100    0.2115    0.2133    0.2150
    0.2016    0.2030    0.2036    0.2038    0.2039    0.2042    0.2045    0.2051    0.2058    0.2067    0.2077
    0.1982    0.1965    0.1943    0.1923    0.1907    0.1892    0.1878    0.1866    0.1854    0.1842    0.1831

  12 ~ 13번 열

    0.2012    0.2007
    0.1917    0.1909
    0.2164    0.2176
    0.2085    0.2094
    0.1822    0.1814
```

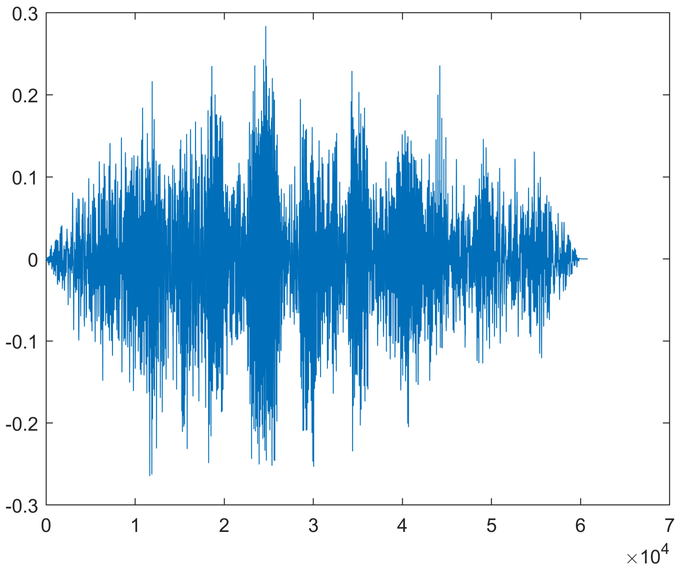
Channel sum

```
out_x = zeros(1,nsample);

% figure;
for t = 1:nframe
    ref_st = (t-1) * 4000 + 1;
    ref_ed = min(ref_st + 8000 - 1, nsample);

    for m = 1:nmic
        if m == ref_mic
            st = ref_st;
            ed = ref_ed;
        else
            p = mic2refpair(m);
            st = max(1,ref_st + besttdoa(p,t));
            ed = min(nsample, ref_ed + besttdoa(p,t));
        end

        triwin = triang(8000)';
%         if t == 1
%             triwin(1:4000) = 1;
%         end

         diff = 0;

        if (ref_ed - ref_st) ~= (ed - st) % if buf is small (always)

                diff = ref_ed - ed;

        end
        out_x(ref_st:ref_ed-diff)...
            = out_x(ref_st:ref_ed-diff)...
            + (squeeze(x(m,st:ed))...
            * out_weight(m,t)...
            .* triwin(1:min(8000,ed-st+1))...
            * overall_weight);


            %.* triwin(min(8000,min_ed-ref_st+1))...
            %* out_weight(m,t));
%          plot(out_x);
    end
end

ref_st = (t) * 4000 + 1;
ref_ed = min(ref_st + 8000 - 1, nsample);

for m = 1:nmic
    if m == ref_mic
        st = ref_st;
        ed = ref_ed;
    else
        p = mic2refpair(m);
        st = max(1,ref_st + besttdoa(p,t));
        ed = min(nsample, ref_ed + besttdoa(p,t));
    end
    buf = squeeze(x(m,st:ed));
    diff = (ref_ed - ref_st) - (ed-st);
    if diff > 0
        buf = [buf, zeros(1,diff)];
    else
        buf = buf(1:end-diff);
    end

    triwin = triang(8000)';
%     triwin(4001:end) = 1;

%     fprintf('diff: %d, ref_ed: %d, ref_st %d\n',diff, ref_ed, ref_st);
%     fprintf('ed: %d, st %d\n', ed, st);
%     fprintf('buf size: %d\n',size(buf,2));

    out_x(ref_st:ref_ed)...
            = out_x(ref_st:ref_ed)...
            + (buf...
            * out_weight(m,t)...
            .* triwin(1:min(8000,ref_ed-ref_st+1))...
            * overall_weight);

% this part helps increasing recognition accuracy.
% not in original beamformit.
%     if ref_ed < nsample
%         out_x(ref_ed+1:end) = out_x(ref_ed+1:end) + (x(ref_mic,ref_ed+1:end) * out_weight(m,
%     end
```

```
end

figure;
st = 49000;
ed = st + 20;
subplot(6,1,1); plot(x(1,st:ed)); % (+) delayed
subplot(6,1,2); plot(x(2,st:ed)); % ref_mic assumed
subplot(6,1,3); plot(x(3,st:ed)); % no idea
subplot(6,1,4); plot(x(4,st:ed)); % no idea
subplot(6,1,5); plot(x(5,st:ed)); % no idea
subplot(6,1,6); plot(out_x(st:ed)); % no idea
```



```
figure; plot(out_x);
```



```
audiowrite('enhance_1008.wav',out_x,16000);
```

```
function [table, l] = fill_all_comb(ipair, npair, ibest, nbest, tmp_row, table, l)
    tmp_row(ipair) = ibest;
    %fprintf('ipair: %d ibest: %d l: %d\n', ipair, ibest, l);

    if ipair == npair
        for j = 1:npair
            table(l, j) = tmp_row(j);
        end
        l = l + 1;
    else
        for ibest = 1:nbest
            [table, l] = fill_all_comb(ipair + 1, npair, ibest, nbest, tmp_row, table, l);
        end
    end
end
```