

Cross-correlation demo

Estimate distance between two microphones using cross-correlation of left and right channels of a stereo audio recording. The recorded stereo audio is a shshshsh, aaahhh, or a whistle.

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Load data

```
% First record stereo audio (use Python)

clear

% [x, fs] = audioread('stereo_aahh_in_class.wav');
% t0 = 2.3;
% xlim1 = [0.07 0.085];

[x, fs] = audioread('stereo_audio_angle2_sshh.wav');
t0 = 1.5;
xlim1 = [0.07 0.085];

% [x, fs] = audioread('stereo_whistle_in_class.wav');
% t0 = 1.7;
% xlim1 = [0.07 0.085];

fs      % Sampling rate (samples/second)
```

```
fs = 48000
```

Listen to audio

```
sound(x, fs);
```

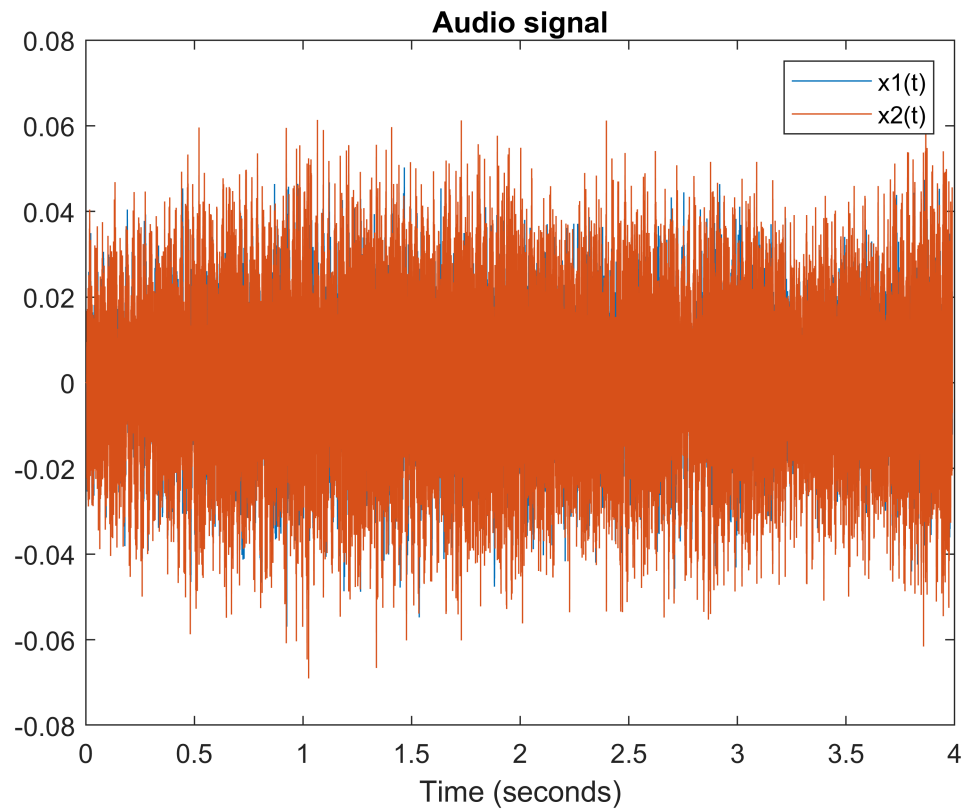
Display audio signal

```
N = length(x);
n = 1:N;
t = n/fs;

x1 = x(:, 1);      % Channel 1
x2 = x(:, 2);      % Channel 2

figure(1)
clf
plot(t, x1, t, x2)
title('Audio signal')
legend('x1(t)', 'x2(t)')
xlabel('Time (seconds)')
```

zoom xon



Extract one segment

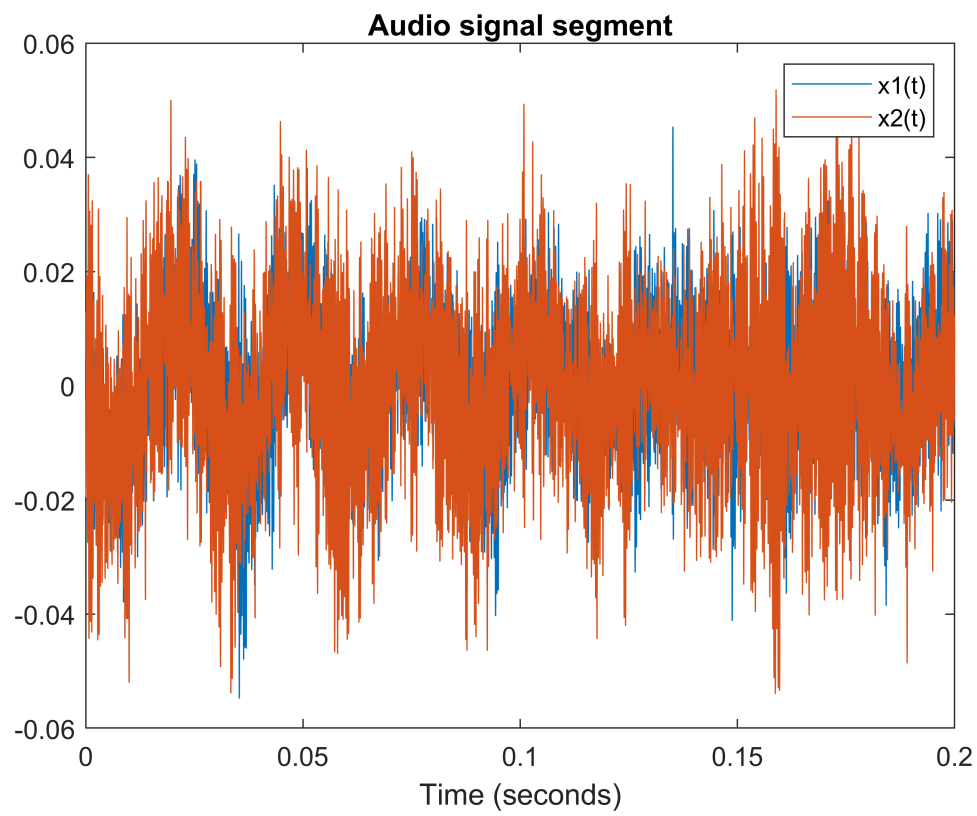
from both channels

```
T = 0.2;           % Duration of segment (seconds)

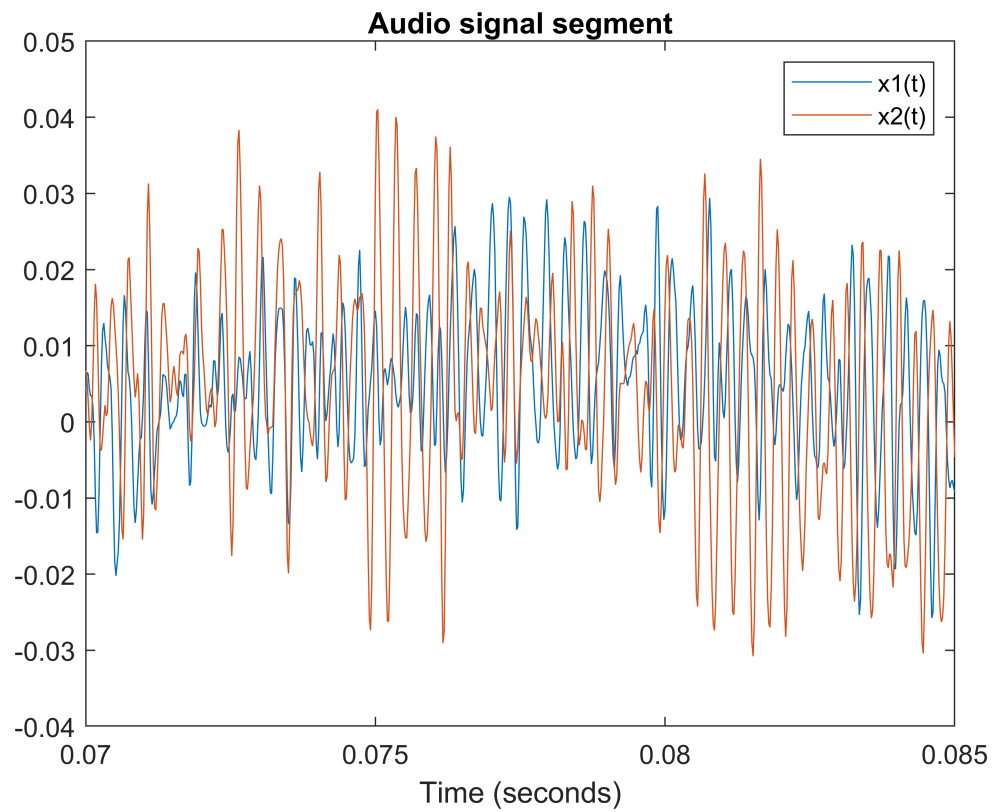
% set as appropriate...
% t0 = 1.3;        % Start-time of segment

M = round( T * fs );
m = 1:M;
v1 = x1(round(t0*fs) + m);
v2 = x2(round(t0*fs) + m);

figure(1)
clf
plot(m/fs, v1, m/fs, v2)
title('Audio signal segment')
xlabel('Time (seconds)')
legend('x1(t)', 'x2(t)')
zoom xon
```



```
% Zoom view  
xlim(xlim1)
```

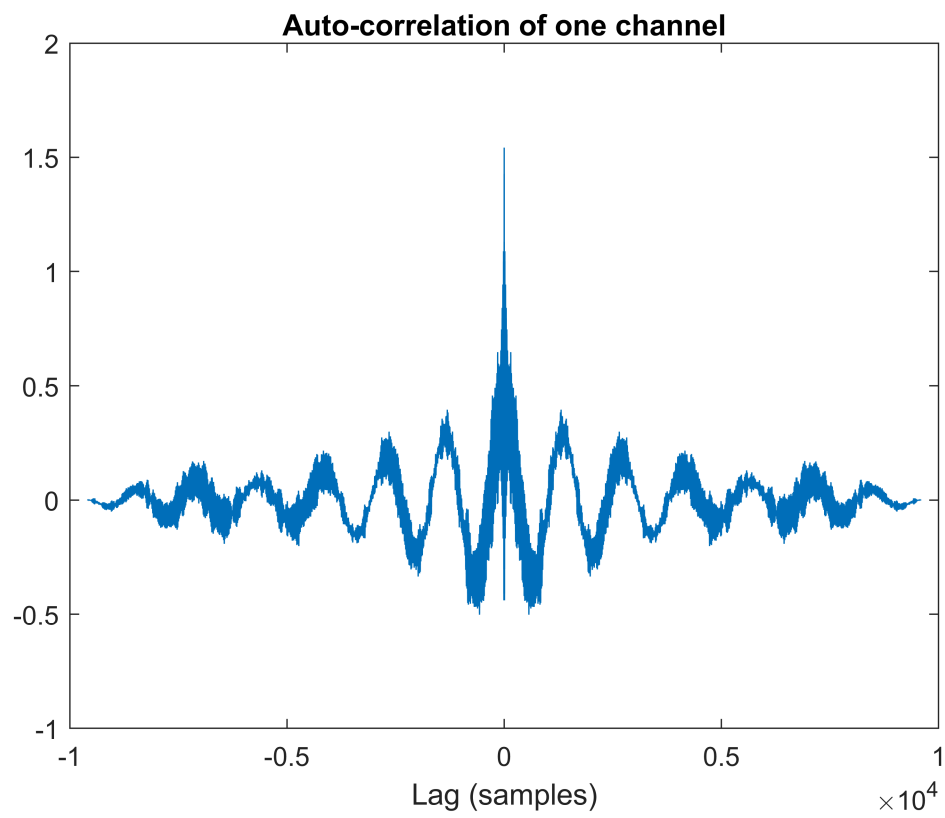


Auto-correlation

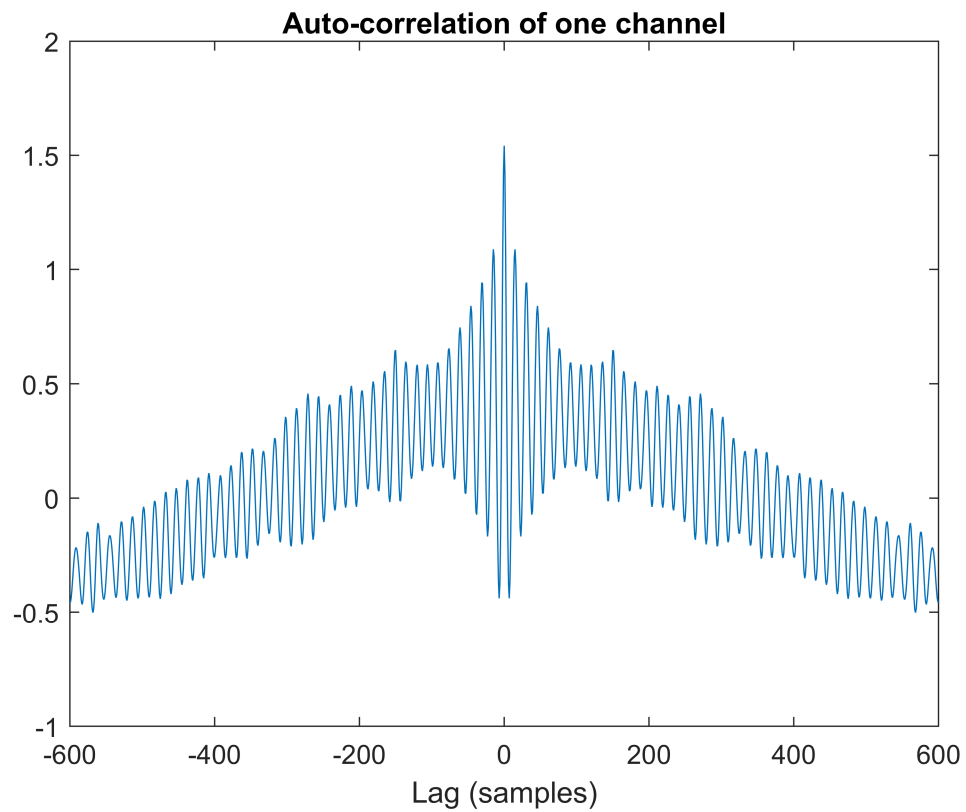
```
flip = @(x) x(end:-1:1);

r11 = conv(v1, flip(v1));

figure(1)
clf
plot(1-M:M-1, r11)
title('Auto-correlation of one channel')
xlabel('Lag (samples)')
zoom xon
```



```
% Zoom view  
xlim([-600 600])
```



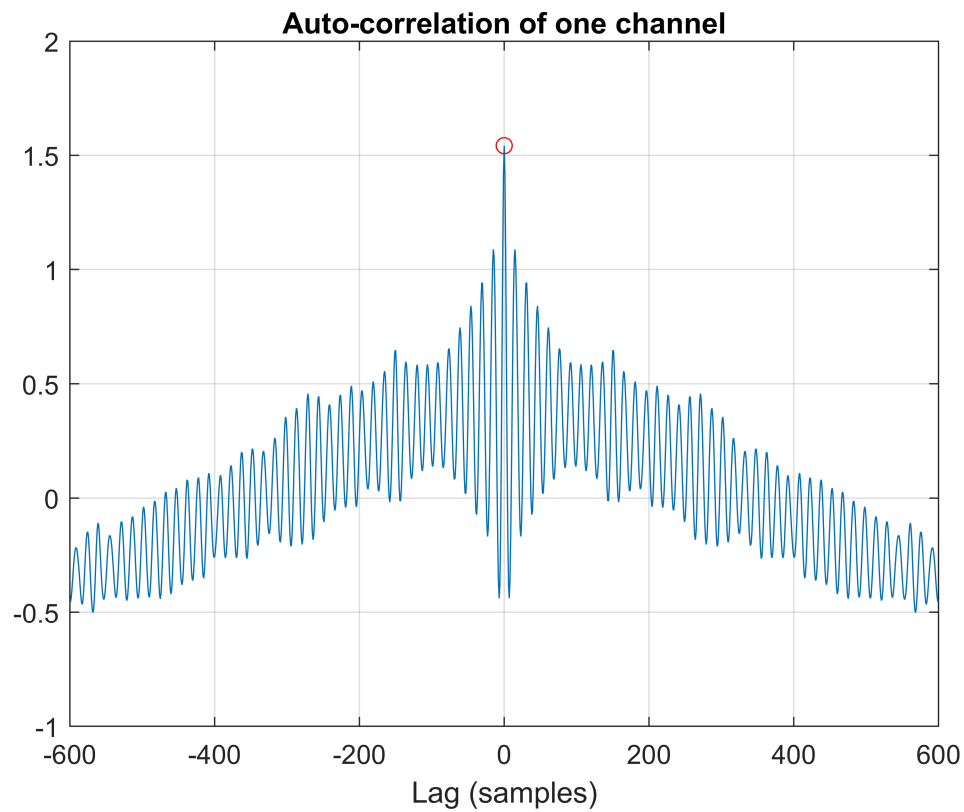
```
% xlim([-200 200])
```

```
[r11_max, k] = max(r11);
```

```
lag_max = k - M
```

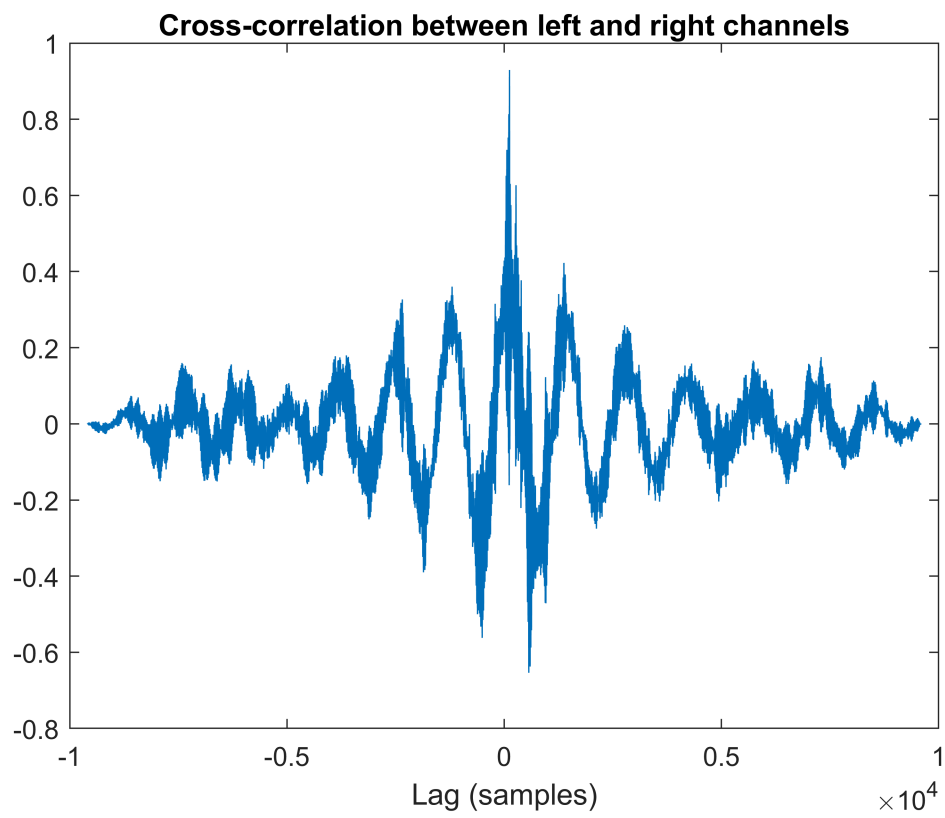
```
lag_max = 0
```

```
hold on  
plot(lag_max, r11_max, 'ro')  
grid on
```

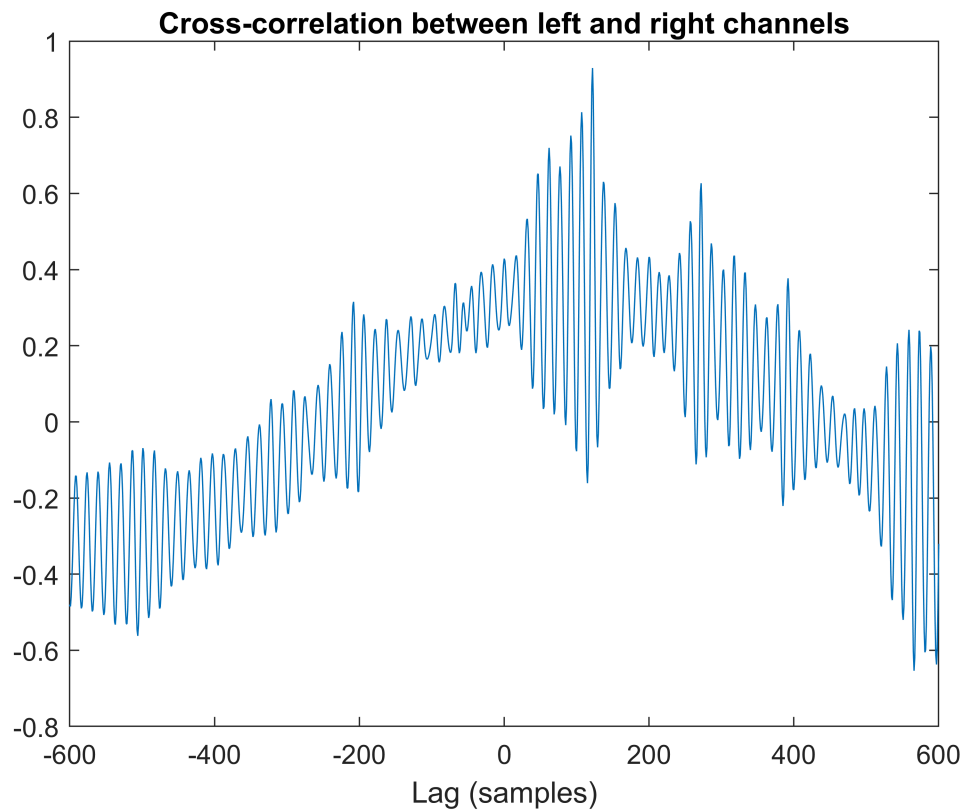


Cross-correlation

```
r12 = conv(v1, flip(v2));  
  
% The Matlab function xcorr can also be used here.  
% r12 = xcorr(v1, v2);  
  
figure(1)  
clf  
plot(1-M:M-1, r12)  
title('Cross-correlation between left and right channels')  
xlabel('Lag (samples)')  
zoom xon
```



```
% Zoom view  
xlim([-600 600])
```

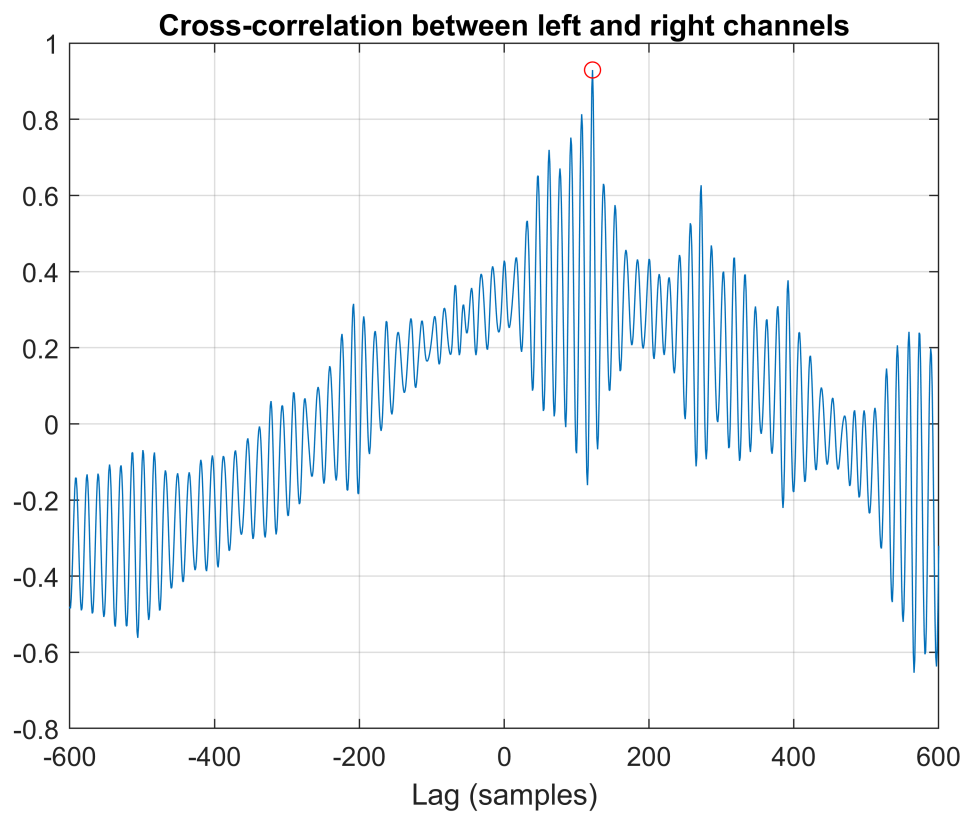



Estimate delay (in samples)

as peak cross-correlation

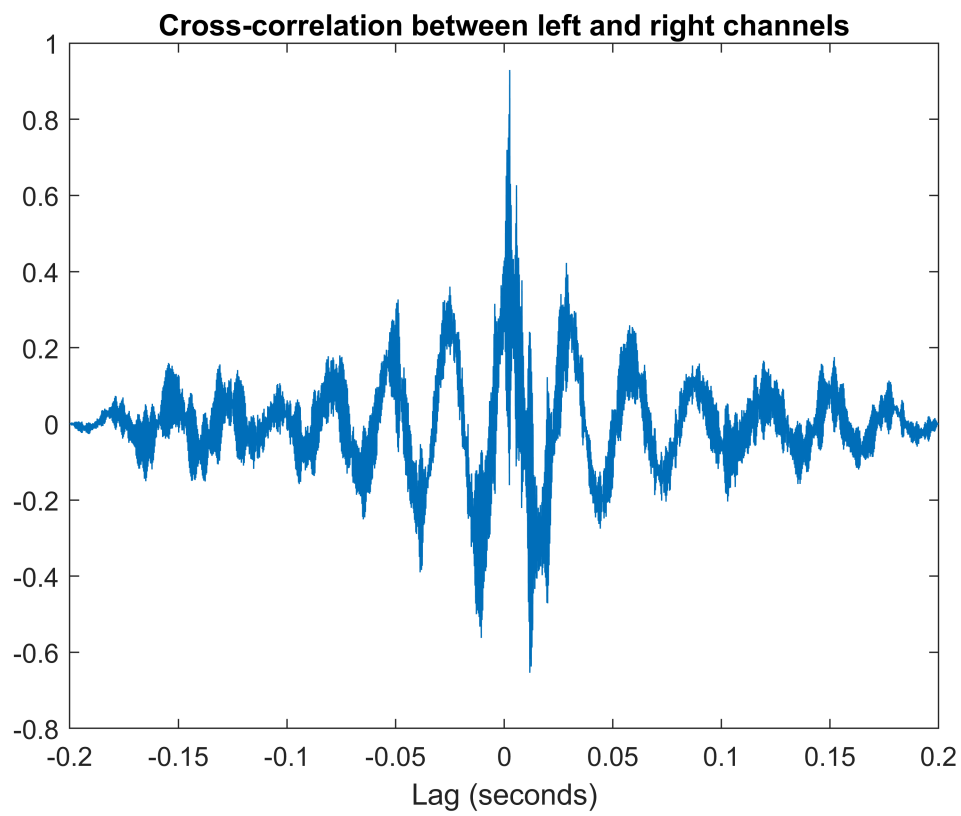
```
[r12_max, k] = max(r12);    % r12_max : Peak cross-correlation  
lag_max = k - M    % lag_max : Lag at which cross-correlation peaks  
  
lag_max = 122
```

```
hold on  
plot(lag_max, r12_max, 'ro')  
grid on
```

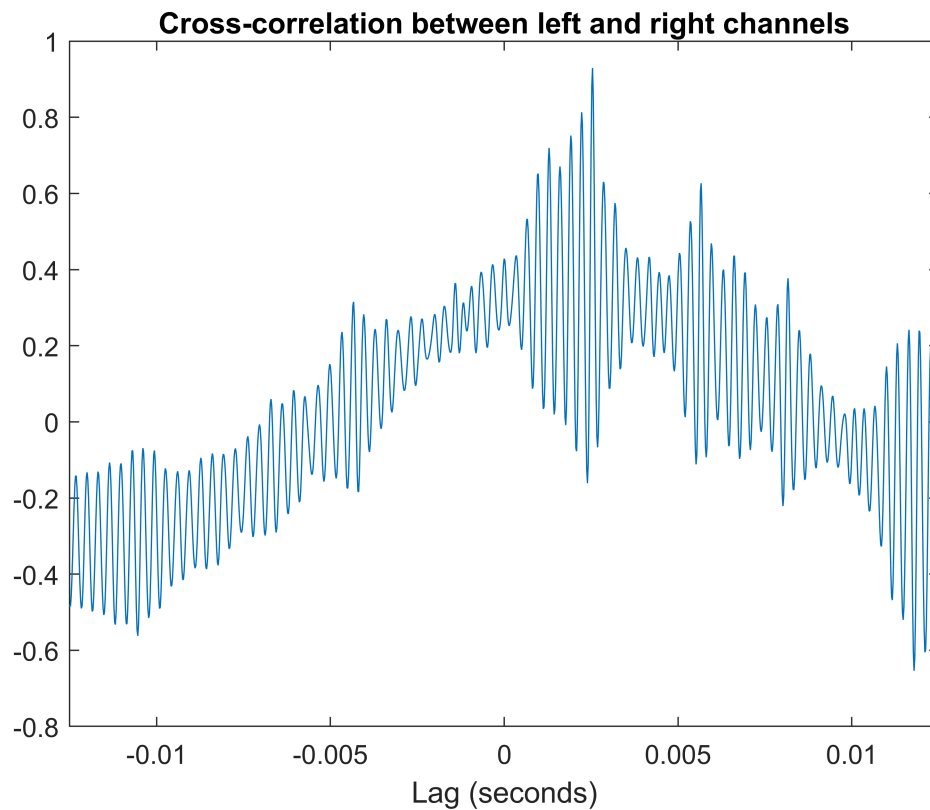


Show lag in units of seconds, not samples

```
figure(1)
clf
plot((1-M:M-1)/fs, r12)
title('Cross-correlation between left and right channels')
xlabel('Lag (seconds)')
```



```
% Zoom view  
xlim([-600 600]/fs)
```



Estimate delay (in seconds)

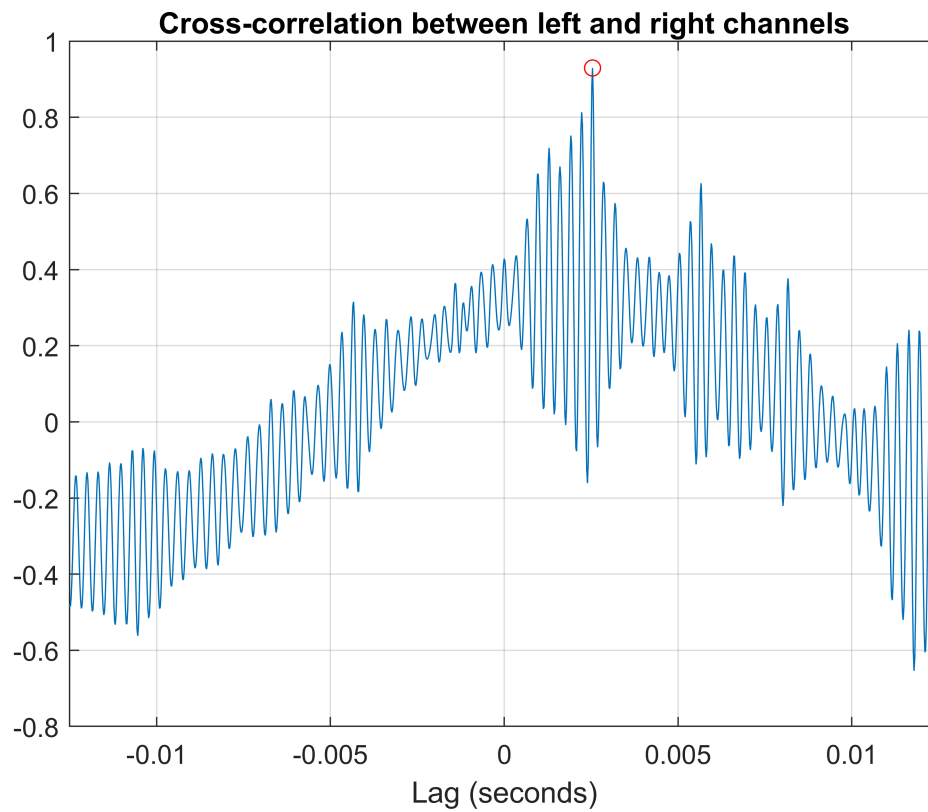
```
tau = lag_max / fs % Peak lag in seconds
```

```
tau = 0.0025
```

```
txt = sprintf('Estimated inter-microphone time delay = %.2f milliseconds', 1000*tau)
```

```
txt =  
'Estimated inter-microphone time delay = 2.54 milliseconds'
```

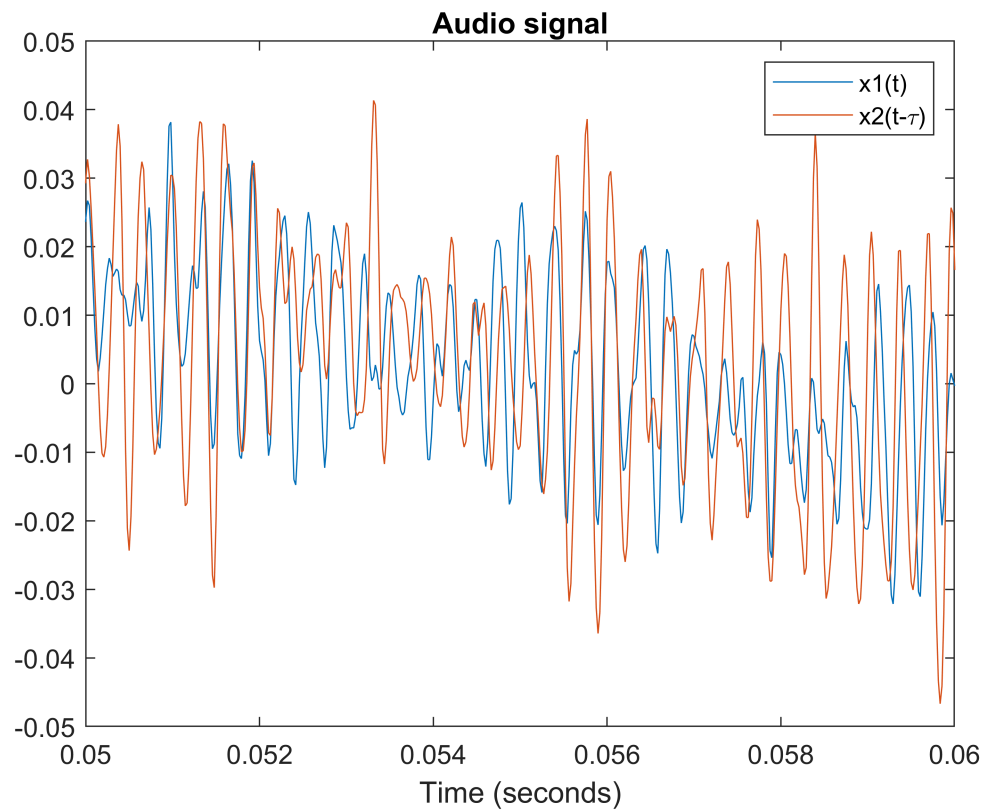
```
hold on  
plot(tau, r12_max, 'ro')  
grid on
```



Do the signals roughly line up?

```
figure(1)
clf
plot(m/fs, v1, (m + lag_max)/fs, v2)
title('Audio signal')
xlabel('Time (seconds)')
legend('x1(t)', 'x2(t-\tau)')
zoom xon

% Zoom view
xlim([0.05 0.06])
```



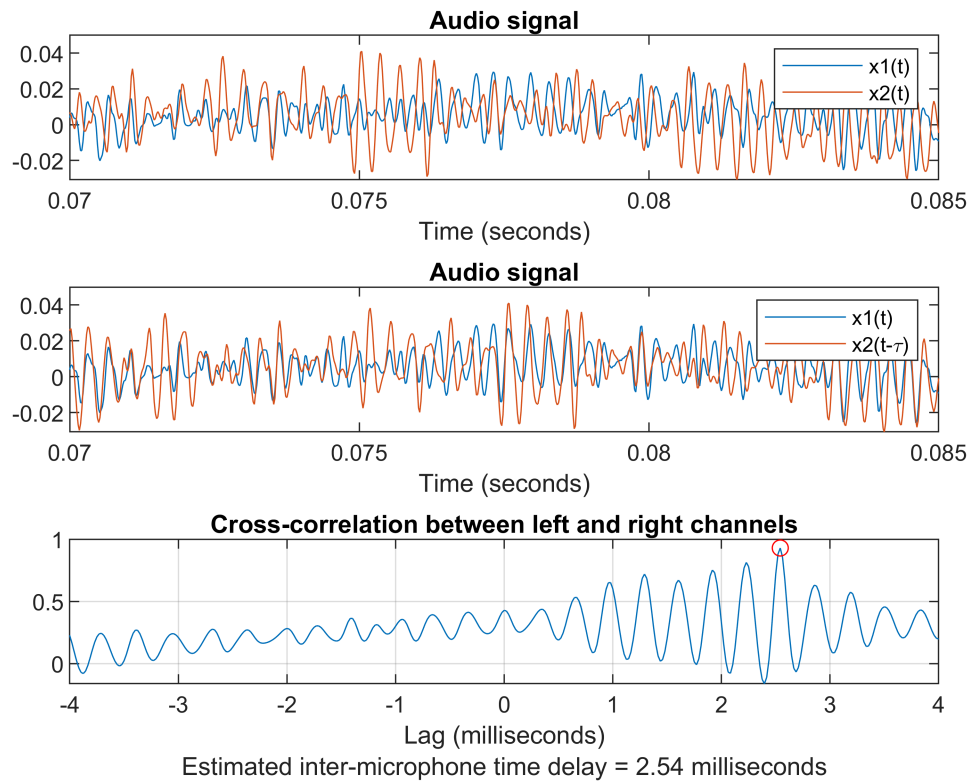
```
figure(1)
clf

subplot(3, 1, 1)
plot(m/fs, v1, m/fs, v2)
title('Audio signal')
xlabel('Time (seconds)')
legend('x1(t)', 'x2(t)')
xlim(xlim1)

subplot(3, 1, 2)

plot(m/fs, v1, (m + lag_max)/fs, v2)
xlim([0 T])
title('Audio signal')
xlabel('Time (seconds)')
legend('x1(t)', 'x2(t-\tau)')
xlim(xlim1)

subplot(3, 1, 3)
plot((1-M:M-1)/fs*1000, r12, tau*1000, r12_max, 'ro')
title('Cross-correlation between left and right channels')
xlabel({'Lag (milliseconds)', txt})
grid on
xlim([-4 4])
```



```
orient tall
% print -dpdf demo_01_SHSHSHSH
```

Estimate inter-microphone distance

```
% Speed of sound at sea level = 340.29 m/s

sos = 340.29; % speed of sound (meters/second)

dist = tau * sos;

d = abs(dist)/1.1557;

a = acos(d);

angle = rad2deg(a);

fprintf('Estimated inter-microphone angle = %.2f degrees\n', angle)
```

Estimated inter-microphone angle = 41.55 degrees

```
fprintf('Estimated inter-microphone distance = %.2f meters\n', dist)
```

Estimated inter-microphone distance = 0.86 meters