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```
% Team 20 - Signal Detection
% Nov 14th, Simulation demo
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```

Initialization

```
close all;
clear all;
```

Sensor placement

```
% Hardcoding sensor locations at (x,y) coordinates
s0 = [0 0];
s1 = [100 0];
s2 = [0 100];
s3 = [100 100];
```

Grid design

```
% data structure of all x,y locations for possible signal origins
grid = cell(100,100);

for i = 1:100
    for j = 1:100
    grid{i,j} = [ (10*i-5) (10*j+995)];


    end
end
```

Signal condition generation

```
% Two random intergers from 1-100 for origin out of possible grid
 indexes
randx = randi(100,1,1);
randy = randi(100,1,1);

% Generate random signal to noise ratio (1 to 30, with 1 being the
 most noise)
signal_to_noise_ratio = randi(30,1,1)

origin_point = {randx,randy};
origin = grid{randx, randy};

% Generate random temp in celsius, -40 C to 10 C
tempc = randi([-40 10],1,1)

% Calculate speed of sound in m/s
speed_of_sound = 331.3 * sqrt(1 + (tempc / 273.15))
```

```
signal_to_noise_ratio =

    18


tempc =

   -16


speed_of_sound =

  321.4505
```

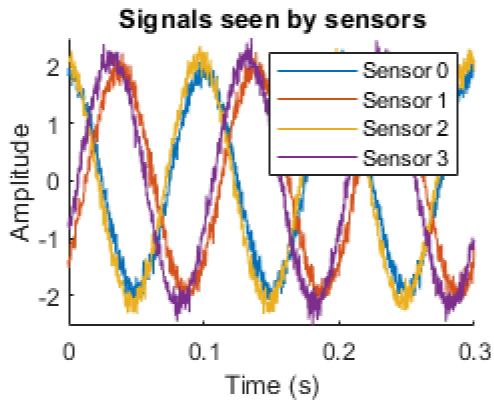
Calculate distance to sensors

```
d0 = distance(s0,origin);
d1 = distance(s1,origin);
d2 = distance(s2,origin);
d3 = distance(s3,origin);

% Calculate difference in distance from sensors 1-3 to reference
 sensor 0
delta1 = d1 - d0;
delta2 = d2 - d0;
delta3 = d3 - d0;

% Calculate amplitude decay over each distance based on energy
 distributed
% over surface area of a sphere
```

```
decay0 = 100000000/(4*pi*d0^2);
decay1 = 100000000/(4*pi*d1^2);
decay2 = 100000000/(4*pi*d2^2);
decay3 = 100000000/(4*pi*d3^2);
```

Signal Generation

```
% Time vector
t = 0:1/3413:0.3;

% Generate signal hitting the reference sensor
signal0 = decay0 .* cos(10*2*pi.*t);

% Shift each signal to match distance travelled to each sensor
wavelength = speed_of_sound/10;
shift1 = delta1/wavelength;
shift2 = delta2/wavelength;
shift3 = delta3/wavelength;

% Generate signals received by each sensor
signal1 = decay1 .* cos(10*2*pi.*(t-shift1/10));
signal2 = decay2 .* cos(10*2*pi.*(t-shift2/10));
signal3 = decay3 .* cos(10*2*pi.*(t-shift3/10));

% Add gaussian noise to each signal
signal0 = awgn(signal0,signal_to_noise_ratio);
signal1 = awgn(signal1,signal_to_noise_ratio);
signal2 = awgn(signal2,signal_to_noise_ratio);
signal3 = awgn(signal3,signal_to_noise_ratio);

% Plot signals received by sensors
figure()
subplot(2,4,[1 2]), hold on
plot(t,signal0);
plot(t,signal1);
plot(t,signal2);
plot(t,signal3);
legend('Sensor 0', 'Sensor 1', 'Sensor 2', 'Sensor 3');
title("Signals seen by sensors");
xlabel("Time (s)");
ylabel("Amplitude");
```



Noise analysis

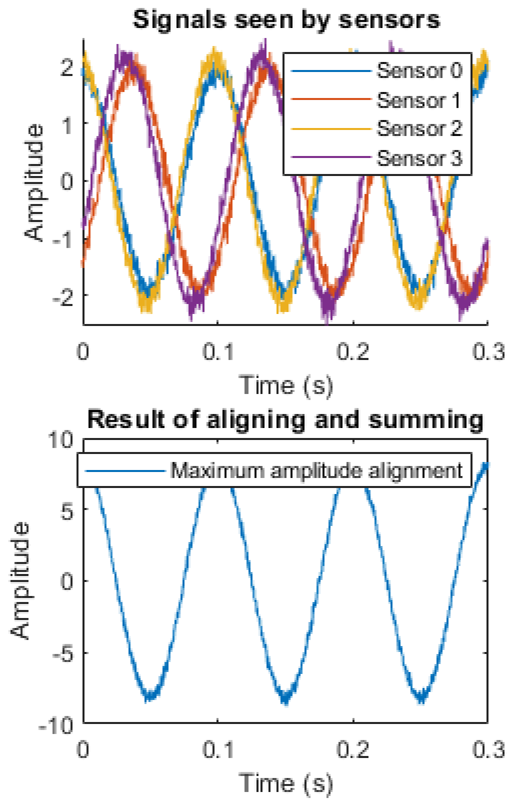
```
% Analyze noise in order to make comparison to detected signal
zero = zeros(1,1024);
noise_avg = [ ];

% Generate 100 unique sets of white noise
for k = 1:100
    % One noise signal for each sensor
    noise0 = awgn(zero,signal_to_noise_ratio);
    noise1 = awgn(zero,signal_to_noise_ratio);
    noise2 = awgn(zero,signal_to_noise_ratio);
    noise3 = awgn(zero,signal_to_noise_ratio);

    % Sum noise signals
    noise = noise0 + noise1 + noise2 + noise3;

    % Detect magnitude of 10hz frequency from fft
    noise_fft = fft(noise);
    P2 = abs(noise_fft/1024);
    P1 = P2(1:1024/2+1);
    P1(2:end-1) = 2*P1(2:end-1);
    val = P1(4);
    noise_avg = [noise_avg val];
end
```

```
% Calculate average magnitude and standard deviation of 10hz component
deviation = std(noise_avg);
average = mean(noise_avg);
```

Confidence engine and geolocation algorithim

```
% Pass sensor locations, sensor data, all possible origin points,
 speed of
% sound, and noise sampling into the confidence engine

[guess, height, mean1, std1] =
 algorithm(s0,s1,s2,s3,signal0,signal1,signal2,signal3,grid,speed_of_sound,deviati
```

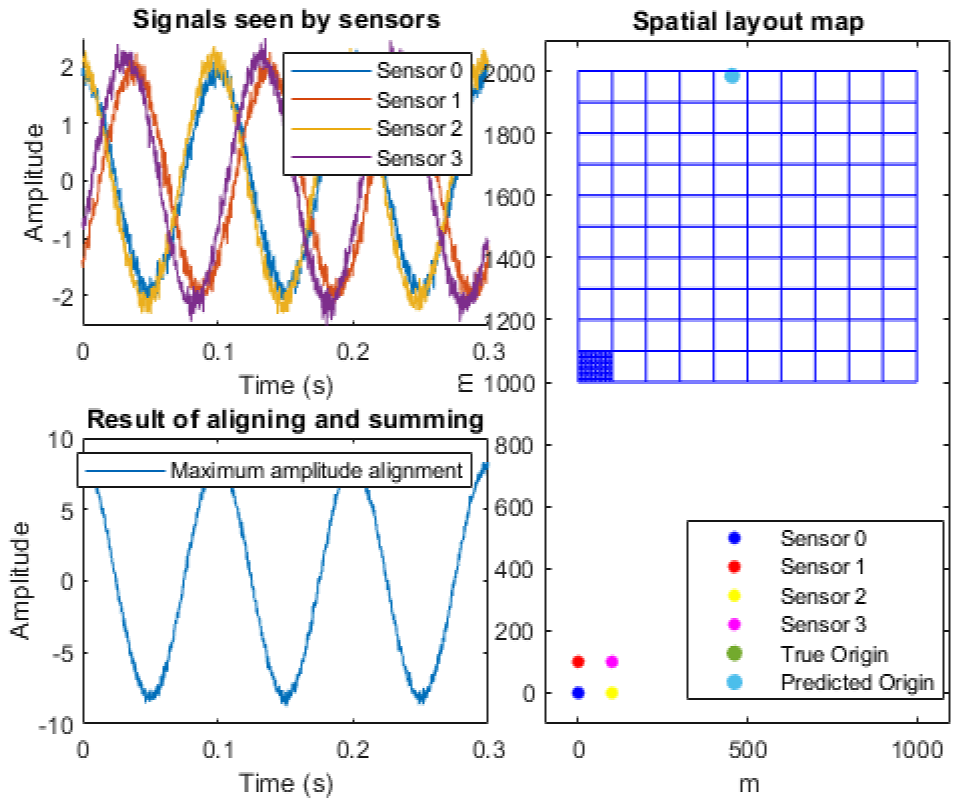
```
Z_score_of_detection =

  533.0781

The system is    100

percent confident a 10hz infrasound signal is present

Z_score_of_geolocation =

    1.7979

The system is    96.3902

percent confident it has correctly predicted the origin location
```



Plot

```
% Sensors
subplot(2,4,[3 4 7 8]);
gscatter(0,0,'Sensor 0', 'b'),hold on
gscatter(0,100,'Sensor 1', 'r');
gscatter(100,0,'Sensor 2', 'y');
gscatter(100,100,'Sensor 3', 'm');
xlim([-100 1100]),ylim([-100 2100]);


% True and predicted origin
scatter([origin(1)],[origin(2)],'filled');
scatter([guess(1)],[guess(2)],'filled');
legend('Sensor 0', 'Sensor 1', 'Sensor 2', 'Sensor 3', 'True
 Origin','Predicted Origin');
title("Spatial layout map");

% Plot grid
x1 = [];
y1 = [];

% One square filled to 100x100 resolution
for x = 1:10
    for y = 1:10
```

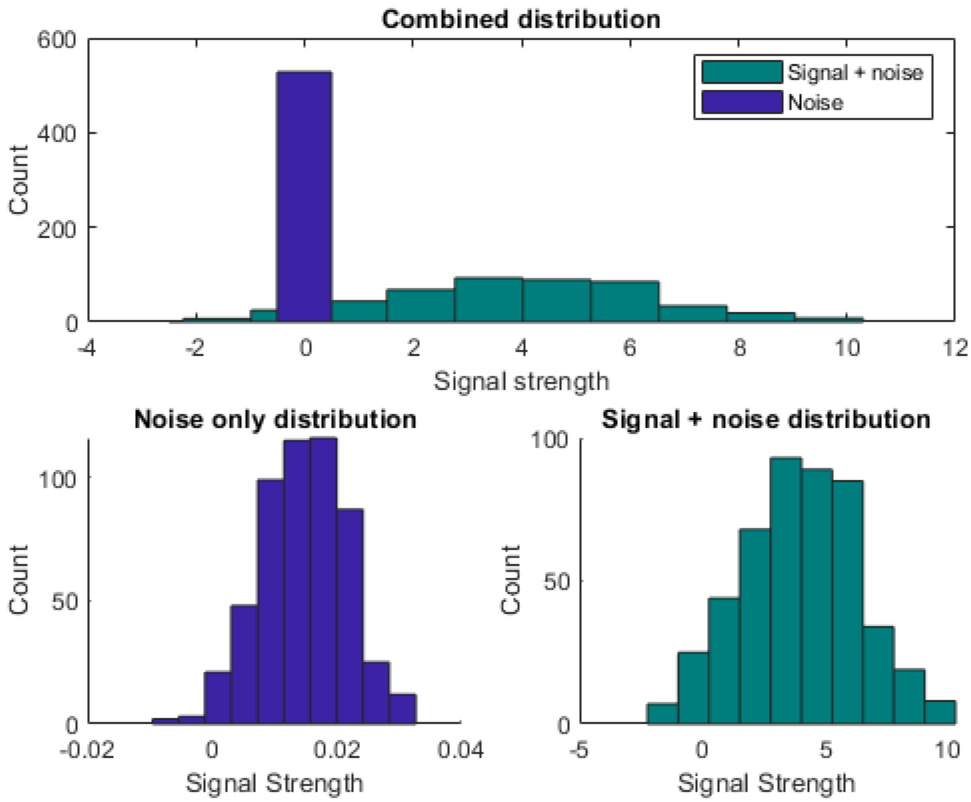
```
        z = grid{x,y};
        k1 = [(z(1) - 5) (z(1) +5) (z(1) +5) (z(1) -5) (z(1) -5)];
        k2 = [(z(2) + 5) (z(2) +5) (z(2) -5) (z(2) -5) (z(2) +5)];
        x1 = [x1 k1];
        y1 = [y1 k2];
    end
    plot(x1,y1,'b','HandleVisibility', 'off'), hold on;
    x1 = [];
    y1 = [];
end

% 10x10 resolution
for x = 1:10
    for y = 1:10
        z = grid{x*10,y*10};
        k1 = [(z(1) - 50) (z(1) +50) (z(1) +50) (z(1) -50) (z(1) -50)]
 - 45;
        k2 = [(z(2) + 50) (z(2) +50) (z(2) -50) (z(2) -50) (z(2) +50)]
 - 45;
        x1 = [x1 k1];
        y1 = [y1 k2];
    end
    plot(x1,y1,'b','HandleVisibility','off'),xlabel("m"),ylabel("m")
    x1 = [];
    y1 = [];
end
hold off;
```



Histogram Generation

```
% Generate histograms to show the different distributions between
 noise
% analysis and detected signal
n = 1000; signalPresentAbsent = rand(1,n);
signalPresentAbsent = round(signalPresentAbsent);

for i = 1:length(signalPresentAbsent)
  % if signal present trial
  if signalPresentAbsent(i) == 1
    % then pull a random draw from the signal distribution with mean =
 1 and std = 1
    signal(i) = random('norm',mean1,std1);
  else
    % otherwise it is a noise trial so pull a random draw from the
 noise distribution with mean = 0 and std = 1
    signal(i) = random('norm',average,deviation);
  end
end

% Plot both distributions on one plot
figure()
subplot(2,1,1)
```

```
hist(signal(signalPresentAbsent==1)),title("Combined
 distribution"),hold on,xlabel("Signal strength"),ylabel("Count");
h = findobj(gca,'Type','patch');
h.FaceColor = [0 0.5 0.5];


k = -2:1:2;
hist(signal(signalPresentAbsent==0),k),legend('Signal +
 noise','Noise')

% Plot signal+noise distribution
subplot(2,2,4), hold on
hist(signal(signalPresentAbsent==1)),title("Signal + noise
 distribution"),xlabel("Signal Strength"),ylabel("Count");
% show signal absent distribution
h = findobj(gca,'Type','patch');
h.FaceColor = [0 0.5 0.5];

% Plot noise only distribution
subplot(2,2,3), hold on
hist(signal(signalPresentAbsent==0)),title("Noise only
 distribution"),xlabel("Signal Strength"),ylabel("Count");



% Additional statistical analysis
response = signal>0.5;

% get total number of present trials
nPresent = sum(signalPresentAbsent==1);
% compute hits as all the responses to trials in which signal was
 present (signalPresentAbsent==1) in which the response was present
 (i.e. == 1). Divide by number of present trials.
hits = sum(response(signalPresentAbsent==1)==1)/nPresent;
% misses are the same except when the responses are 0 (absent even
 though signal was present)
misses = sum(response(signalPresentAbsent==1)==0)/nPresent;
% same idea for correctRejects and falseAlarms
nAbsent = sum(signalPresentAbsent==1);
correctRejects = sum(response(signalPresentAbsent==0)==0)/nAbsent;
falseAlarms = sum(response(signalPresentAbsent==0)==1)/nAbsent;

zHits = icdf('norm',hits,0,1);
zFalseAlarms = icdf('norm',falseAlarms,0,1);
dPrime = zHits-zFalseAlarms;
```



Error calculation

```
% Calculate amount of actual error in origin prediction
d_1 = distance(s0,origin);
d_2 = distance(s0,guess);

geolocation_percent_error = sqrt((d_2 - d_1)^2)/d_1 * 100;

fprintf('\n');
fprintf('\n');
fprintf("The actual error of the origin prediction is")
disp(geolocation_percent_error);
fprintf("percent")
fprintf('\n');
fprintf('\n');
```

```
The actual error of the origin prediction is     0

percent
```

Confidence engine algorithim definition

```
function [predict, amp, avg1, std1] =
 algorithm(s0,s1,s2,s3,signal_0,signal_1,signal_2,signal_3,grid,speed,deviation1,a

    amp = 0;
    amplitude = 0;
    predict = {1,1};

    data = [];
    data2 = [];
    % Iterate through all grid points
    for i = 1:100
        for k = 1:100

            % Calculate distance from current grid point to each
 sensor
            distance0 = distance(s0,grid{i,k});
            distance1 = distance(s1,grid{i,k});
            distance2 = distance(s2,grid{i,k});
            distance3 = distance(s3,grid{i,k});

            % Determine difference in distance to reach sensor 1-3
 compared
            % to reference sensor 0
            delta_1 = distance1 - distance0;
            delta_2 = distance2 - distance0;
            delta_3 = distance3 - distance0;

            % Calculate wavelength from speed of sound
            wave_length = speed/10;

            % Calculate phase shifts from wavelength
            shift_1 = delta_1/wave_length;
            shift_2 = delta_2/wave_length;
            shift_3 = delta_3/wave_length;

            % Shift signals 1-3 accordingly, in attempt to match
 signal 0
            signal0_shift = signal_0;
            signal1_shift = circshift(signal_1,round(-
shift_1*1024/3));
            signal2_shift = circshift(signal_2,round(-
shift_2*1024/3));
            signal3_shift = circshift(signal_3,round(-
shift_3*1024/3));


            % Sum all four signals
            beamformed = signal0_shift + signal1_shift + signal2_shift
 + signal3_shift;
```

```
            % Calculate root mean square ampltitude
            amplitude = mean(sqrt(beamformed.^2));
            data = [data amplitude];

            % Analyze magnitude of 10hz frequency inside signal from
fft
            x1 = fft(beamformed);
            P2 = abs(x1/1024);
            P1 = P2(1:1024/2+1);
            P1(2:end-1) = 2*P1(2:end-1);
            amp_10 = P1(4);
            data2 = [data2 amp_10];

            % Highest amplitude result survives as the prediction
until
            % another point produces one higher
            if amplitude > amp
                amp = amplitude;
                predict = grid{i,k};
                beamformed_plot_final = beamformed;
            end

        end
    end

    % Plot the beamformed signal
    t = 0:1/3413:0.3;
    subplot(2,4,[5 6]);
    plot(t,beamformed_plot_final);
    title("Result of aligning and summing");
    xlabel("Time (s)");
    ylabel("Amplitude");
    legend('Maximum amplitude alignment');


    % Output mean and std for 10hz component
    avg1 = mean(data2);
    std1 = std(data2);



    % Calculate probability of signal detection
        Z_score_of_detection = (amp_10 - average1)/(deviation1)
        prob = normcdf(Z_score_of_detection) * 100;
        fprintf('The system is ');
        disp(prob);
        disp('percent confident a 10hz infrasound signal is present');

    % Calculate geolocation accuracy probability
    data_mean = mean(data);
    data_std = std(data);
    Z_score_of_geolocation = (amp - data_mean)/data_std
    prob = normcdf(Z_score_of_geolocation) * 100;
    fprintf('The system is ');
```

```
    disp(prob);
    disp('percent confident it has correctly predicted the origin
 location');
end
```

Distance function definition

```
function dist = distance(p1,p2)
    a = p2(1);
    b = p2(2);
    dist = sqrt(abs((p2(1) - p1(1))^2 + (p2(2)-p1(2))^2));
end
```

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