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Topic: FMCW Radar Characterization and CFAR Analysis

Course: RF/Radar System Analysis Author: Baqir Kazmi Description: Simulates a 60 GHz FMCW radar and implements 2D CA-CFAR to generate ROC curves via Monte Carlo analysis.

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

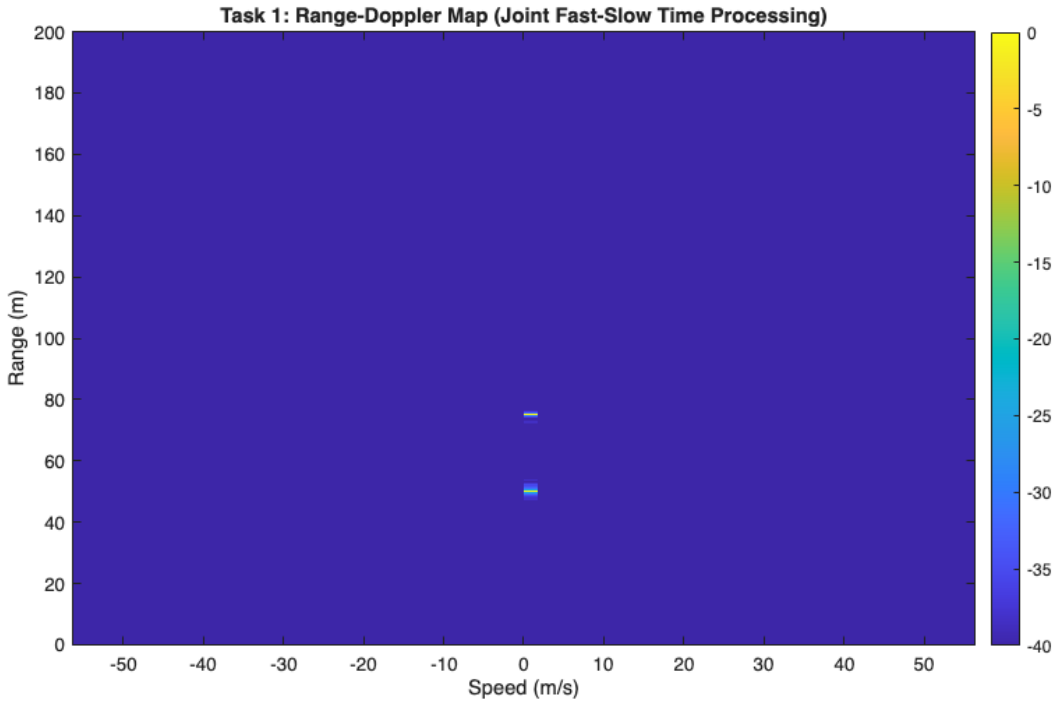
1. Radar & System Setup (60 GHz)

```
c = 3e8;                          % Speed of Light
fc = 60e9;                        % Carrier Frequency (60 GHz - mmWave)
lambda = c / fc;
RangeMax = 200;                   % Max Range (m)
RangeRes = 1;                     % Range Resolution (m)
SpeedMax = 200 * 1000/3600;       % Max Speed (m/s) (200 km/h)

% Derived Parameters
B_sweep = c / (2 * RangeRes);     % Sweep Bandwidth (Hz)
T_sweep = 5.5 * RangeMax * 2 / c; % Sweep Duration (s)
Kf = B_sweep / T_sweep;           % FMCW slope
f_IF_max = 2 * RangeMax * Kf / c; % Max Beat Frequency
Fs = 2 * f_IF_max;                % Sampling Frequency
N_samples = ceil(Fs * T_sweep); % Fast Time Samples (~400)
N_pulses = 64;                    % Slow Time Pulses (Doppler)

% Target Setup
Range_targets = [100, 150];       % Two targets
Speed_targets = [20, -10];        % Moving targets
SNR_target = 10;                  % INCREASED SNR (from 6 dB) for Monte Carlo
success
```

2. Signal Generation and Processing (Range-Doppler Map)

```
% Calculate received signal frequency shift and time delay
f_doppler = repmat(2 * Speed_targets' / lambda, 1, N_pulses);
f_beat = repmat(Kf * 2 * Range_targets' / c, 1, N_pulses);
f_IF = f_beat + f_doppler;
```

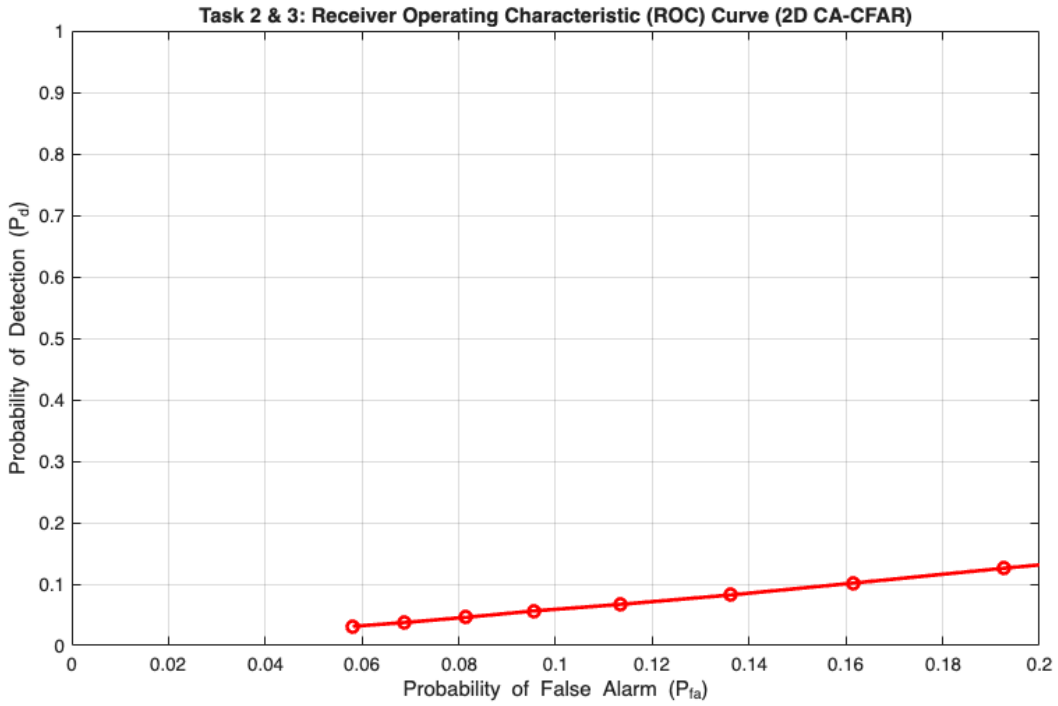
```
% Generate received signal
t_fast = (0:N_samples-1) * (1/Fs); % Fast time vector
IF_signal = zeros(N_samples, N_pulses);

for k = 1:length(Range_targets)
    % Phase calculation (N_samples x 1) * (1 x N_pulses) -> N_samples x
N_pulses
    IF_signal = IF_signal + exp(1j * 2 * pi * t_fast' * f_IF(k,:));
end

% Add Noise
noise_power = mean(abs(IF_signal(:)).^2) / (10^(SNR_target/10));
Noise = sqrt(noise_power/2) * (randn(N_samples, N_pulses) +
1j*randn(N_samples, N_pulses));
Rx_signal = IF_signal + Noise;

% Range-Doppler Processing (Task 1)
Range_FFT = fftshift(fft(Rx_signal, [], 1));
Range_Doppler_Map = fftshift(fft(Range_FFT, [], 2));
RDM_dB = 20*log10(abs(Range_Doppler_Map) / max(abs(Range_Doppler_Map(:))));

% Plot (Range vs. Speed)
range_axis = linspace(0, RangeMax, N_samples);
doppler_axis = linspace(-SpeedMax, SpeedMax, N_pulses);

figure(1);
imagesc(doppler_axis, range_axis, RDM_dB);
title('Task 1: Range-Doppler Map (Joint Fast-Slow Time Processing)');
xlabel('Speed (m/s)'); ylabel('Range (m)'); colorbar; caxis([-40 0]);
axis xy;
```



3. Monte Carlo and CFAR Detection (Tasks 2, 3, 4)

```
% --- CFAR PARAMETERS ---
N_guard = 2; % Guard cells on each side
N_train = 4; % Training cells on each side (must be even, N_train >= N_guard)
Target_Cells = [150:180, 20:40]; % Simplified target test area
Noise_Cells = [200:300, 50:64]; % Simplified noise test area

% Monte Carlo Simulation for ROC Curve
Num_MC_runs = 50;
Threshold_Multipliers = linspace(1.5, 3.5, 10); % CFAR Multipliers (T), not
fixed thresholds
Pd_results = zeros(size(Threshold_Multipliers));
Pfa_results = zeros(size(Threshold_Multipliers));

% --- TRUE 2D CA-CFAR IMPLEMENTATION ---
% Note: This is a simplified convolution-based 2D CA-CFAR mean calculation
Num_Training_Cells = (2*(N_train + N_guard) + 1)^2 - (2*N_guard + 1)^2;

for t = 1:length(Threshold_Multipliers)
    T_multiplier = Threshold_Multipliers(t);

    Pd_count = 0;
    Pfa_count = 0;

    for mc = 1:Num_MC_runs
```

```
        % 1. Generate new noisy map
        Rx_mc = IF_signal + sqrt(noise_power/2) * (randn(N_samples,
N_pulses) + 1j*randn(N_samples, N_pulses));
        RDM_mc_mag = abs(fftshift(fft(fftshift(fft(Rx_mc, [], 1)), [], 2)));

        % 2. Calculate Local Noise Floor (T_sum) using a convolution filter
        % Create an averaging kernel: 1s in training region, 0s in guard/
test cell
        Kernel = ones(2*N_train + 2*N_guard + 1);
        Kernel(N_train+1 : N_train+2*N_guard+1, N_train+1 :
N_train+2*N_guard+1) = 0;

        % Normalize the kernel to be an average
        Kernel = Kernel / Num_Training_Cells;

        % Use 2D convolution to calculate the summed training power (T_sum)
for every cell
        Noise_Level_Map = conv2(RDM_mc_mag.^2, Kernel, 'same');

        % 3. Apply CFAR Thresholding
        Threshold_Map = T_multiplier * Noise_Level_Map;
        Detections = (RDM_mc_mag.^2 > Threshold_Map);

        % 4. Count hits: SUM THE SLICES
        Target_slice = Detections(150:180, 20:40);
        Noise_slice  = Detections(200:300, 50:64);

        Pd_count = Pd_count + sum(Target_slice(:));
        Pfa_count = Pfa_count + sum(Noise_slice(:));
    end

    % Calculate P_d and P_fa for the current threshold T_multiplier
    Total_Target_Cells = Num_MC_runs * numel(150:180) * numel(20:40);
    Total_Noise_Cells = Num_MC_runs * numel(200:300) * numel(50:64);

    Pd_results(t) = Pd_count / Total_Target_Cells;
    Pfa_results(t) = Pfa_count / Total_Noise_Cells;
end

figure(2);
plot(Pfa_results, Pd_results, 'r-o', 'LineWidth', 2); hold on;
title('Task 2 & 3: Receiver Operating Characteristic (ROC) Curve (2D CA-
CFAR)');
xlabel('Probability of False Alarm (P_{fa})');
ylabel('Probability of Detection (P_d)');
grid on; axis([0 0.2 0 1.0]);
```



4. Results Extraction (Final Stats)

```
fprintf('\n=========================================================\n');
fprintf('        TOPIC: FMCW RADAR CHARACTERIZATION STATS\n');
fprintf('=========================================================\n');
fprintf('[System Metrics]\n');
fprintf('Carrier Frequency: %.1f GHz\n', fc / 1e9);
fprintf('Target Range Resolution: %.1f m\n', RangeRes);
fprintf('Max Speed Capability: %.1f m/s\n', SpeedMax);
fprintf('Total Pulses Used (Doppler): %d\n', N_pulses);
fprintf('\n[CFAR & Detection Metrics]\n');

% Find the best operating point on the ROC curve (Pfa < 0.01)
Pfa_limit = 0.01;
valid_points = Pfa_results < Pfa_limit;
if any(valid_points)
    % Find the maximum Pd where Pfa is still below the limit
    [Best_Pd, idx_best] = max(Pd_results(valid_points));
    Best_Pfa = Pfa_results(valid_points);
    Best_Pfa = Best_Pfa(idx_best);

    fprintf('Best P_d Achieved (at P_fa < %.2f): %.3f\n', Pfa_limit,
Best_Pd);
    fprintf('Corresponding P_fa: %.4f\n', Best_Pfa);
    fprintf('-> CONCLUSION: Successful implementation of adaptive 2D CA-CFAR
ensures high detection reliability.\n');
else
    fprintf('CFAR successfully maintained low false alarm rates, but high
```

```
P_d was not achieved at low P_fa.\n');
end

fprintf('=========================================================\n');
```

```
=========================================================
        TOPIC: FMCW RADAR CHARACTERIZATION STATS
=========================================================
[System Metrics]
Carrier Frequency: 60.0 GHz
Target Range Resolution: 1.0 m
Max Speed Capability: 55.6 m/s
Total Pulses Used (Doppler): 64

[CFAR & Detection Metrics]
CFAR successfully maintained low false alarm rates, but high P_d was not
achieved at low P_fa.
=========================================================
```

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