# DSP Block

## FMCW RADAR MODULE

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# Agenda

- Overview of various DSP algorithms  and approaches in Literature for FMCW Radar Module

- Practical Problems and Reasoning

- Possible Solutions

# Time domain method

- Ratio of Beat frequency signal and its derivative
- Integrate over specific time-period and summation over few samples

**Table 1.** Computation complexity for fast Fourier transform (FFT) and proposed time-domain algorithms with $M$ samples.

| Ranging Schemes | Additions/Subtractions | Multiplications | Divisions |
|---|---|---|---|
| FFT estimation | $6M \log_2 M$ | $2M \log_2 M$ | 0 |
| Proposed algorithm | $3M$ | 0 | 1 |

# Time domain method

- Advantages
  - Range resolution is independent of Bandwidth
  - Periodic characteristics of error in increasing range
  - Lower computational complexity
  - Easily implementable and effective
  - No need of frequency domain stuff like FFT,  peak detector etc.
- Disadvantages
  - Single target scenario
  - Stationary Object

# Practical Issues in FMCW Radar Modules

- Multi-Target Detection is Critical for Automotive Applications.

- Range-Velocity-Angle Ambiguity Problems causing Ghost Targets, Missed Targets and unreliable angle information.

- Clutter and Noise

# Working Principle of FMCW Radars

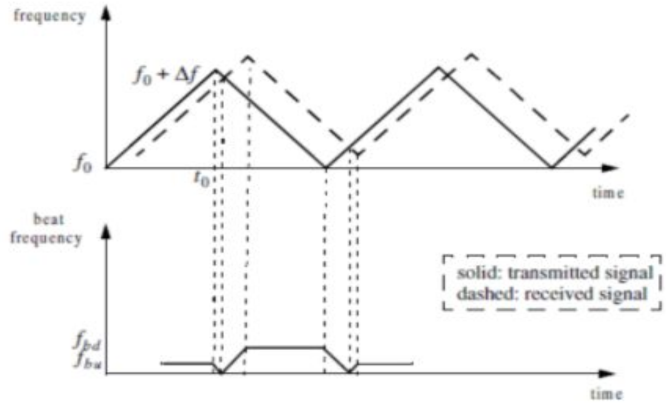



**Figure 3.6. Transmited and received LFM signals and beat frequency, for a moving target.**

$$f_{bu} = \frac{2R}{c}\dot{f} - \frac{2\dot{R}}{\lambda}$$

$$f_{bd} = \frac{2R}{c}\dot{f} + \frac{2\dot{R}}{\lambda}$$

Adding above two eqns., Range can be obtained

$$R = \frac{c}{4\dot{f}}(f_{bu} + f_{bd})$$

Subtracting above two eqns., Range rate can be obtained

$$\dot{R} = \frac{\lambda}{4}(f_{bd} - f_{bu})$$

Reference: *Mahafza, Bassem R, "Radar signal analysis and processing using MATLAB", CRC Press, 2016*

# Range Resolution (ΔR)

Frequency Resolution for DFT/FFT = $\frac{F_s}{N}$ = $\frac{F_s}{T_c * F_s} = \frac{1}{T_c}$

For two objects separated by a distance Δd, the difference in their IF frequencies is given by $\Delta f = \frac{S2\Delta d}{c}$

Since the observation interval is $T_c$, this means that

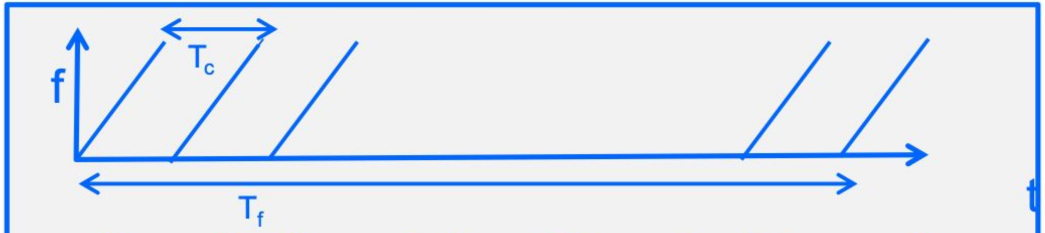
$$\Delta f > \frac{1}{T_c} \Rightarrow \frac{S2\Delta d}{c} > \frac{1}{T_c} \Rightarrow \Delta d > \frac{c}{2ST_c} \Rightarrow \frac{c}{2B} \quad \text{(since } B=ST_c\text{)}$$

**The Range Resolution ($d_{res}$) depends only on the Bandwidth swept by the chirp**

$$d_{res} = \frac{c}{2B}$$

# Velocity Resolution (ΔV)

Frequency Resolution for DFT/FFT = $\frac{F_s}{N} = \frac{F_s}{T_c * F_s} = \frac{1}{T_c}$




The velocity resolution of the radar is inversely proportional to the frame time ($T_f$)and is given by

$$v_{res} = \frac{\lambda}{2T_f}$$

$$\Delta\omega = \frac{4\pi\Delta v T_c}{\lambda}$$

$$\Delta\omega > \frac{2\pi}{N}$$

$$\Rightarrow \quad \Delta v > \frac{\lambda}{2NT_c}$$

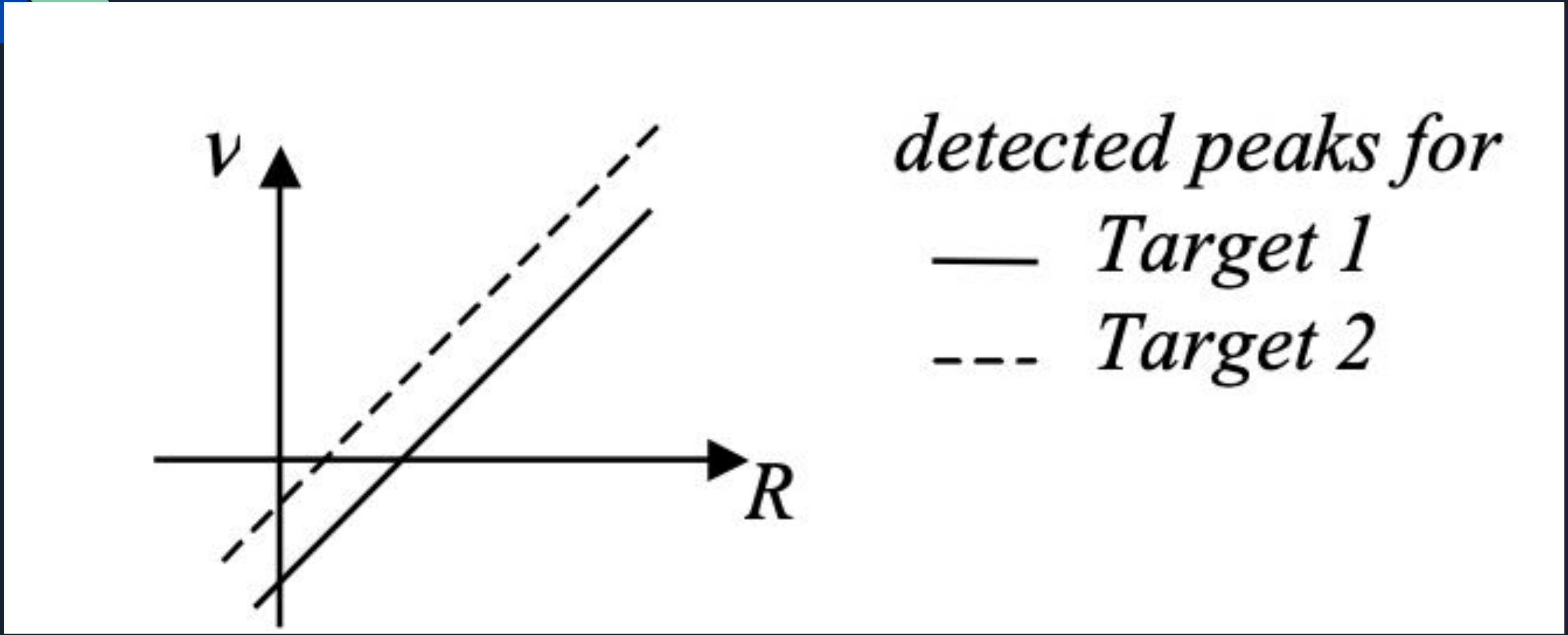
# Range-Velocity (R-V) Plot

- Useful for understanding the concept of Ghost Targets.

- Consider a multi-target setting and assume that we transmit an up chirp.

$$f_{bu} = \frac{2B}{cT_c}R - \frac{2}{\lambda}v \quad \Rightarrow \quad T_c f_{bu} = \frac{2B}{c}R - \frac{2T_c}{\lambda}v$$

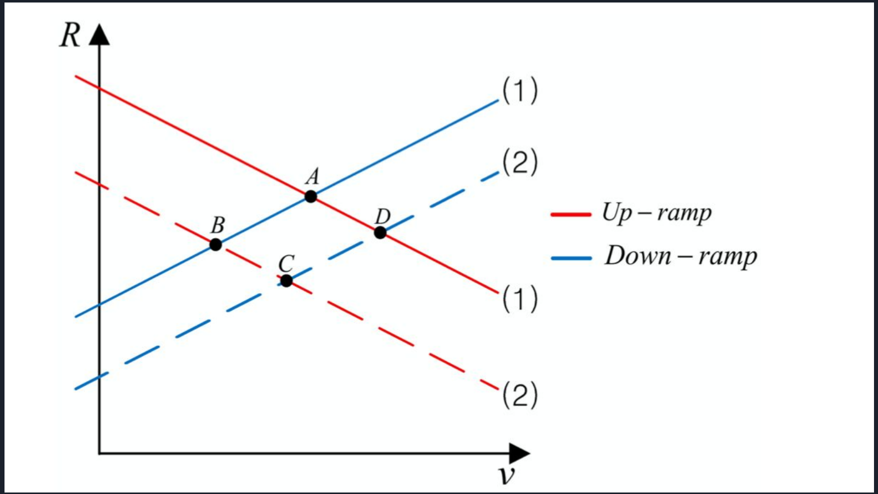
$$\kappa = \frac{R}{\Delta R} - \frac{v}{\Delta v}$$



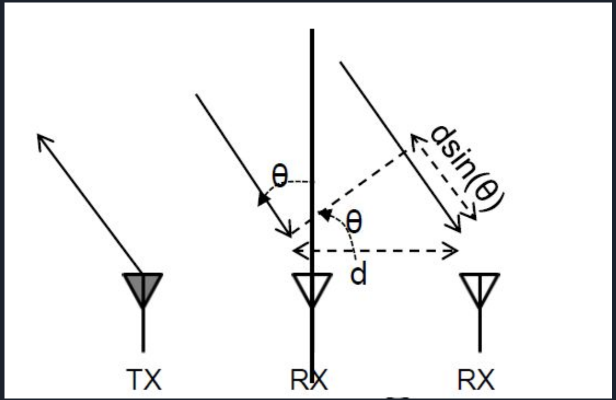
ν
R
detected peaks for
Target 1
Target 2

# Ghost Targets

- Caused due to Range-Velocity Ambiguity



# Azimuthal Angle (θ) for Single Object



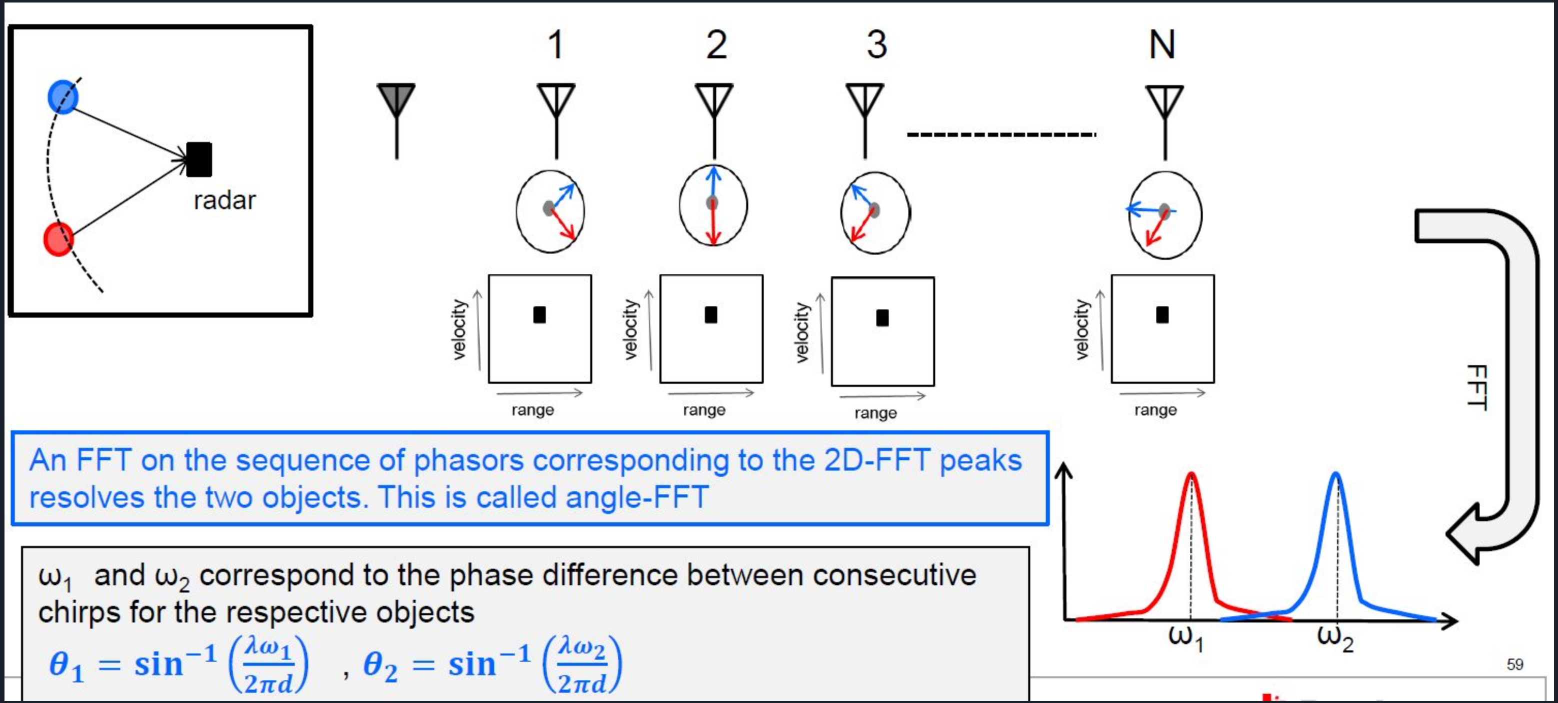

- Angle measurement from phase difference

$$\theta = sin^{-1}(\frac{l\omega}{2\pi d})$$

- Where,
  - W - phase difference
  - L - wavelength

$$\theta_{max} = sin^{-1}(\frac{l}{2d})$$

# Azimuthal Angle (θ) for Multiple Object



# Angle Resolution

- Minimum angle between two object to detect in radar

$$\theta_{res} = \frac{l}{Ndcos(\theta)}$$

  - Resolution often calculates at $d = \frac{l}{2}$ and θ = 0
  - Resolution = $\frac{2}{N}$

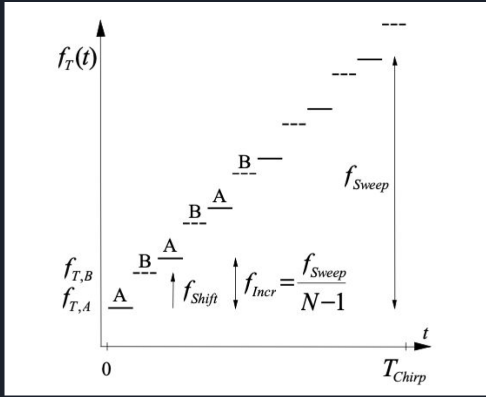
- Where,
  - N = number of receiving antenna
- Resolution degrades as angle increase

# Possible Solutions for High Performance Multi-Target Detection

- Main Idea is Ghost Target Mitigation.

- Options ?
  - Complex Chirp Waveforms -- RF Load increases
  - Trade-off :

    RF Loading - Update Time - Ghost Target Mitigation



# Overall Methodology of the Paper

- 3 Segment Method

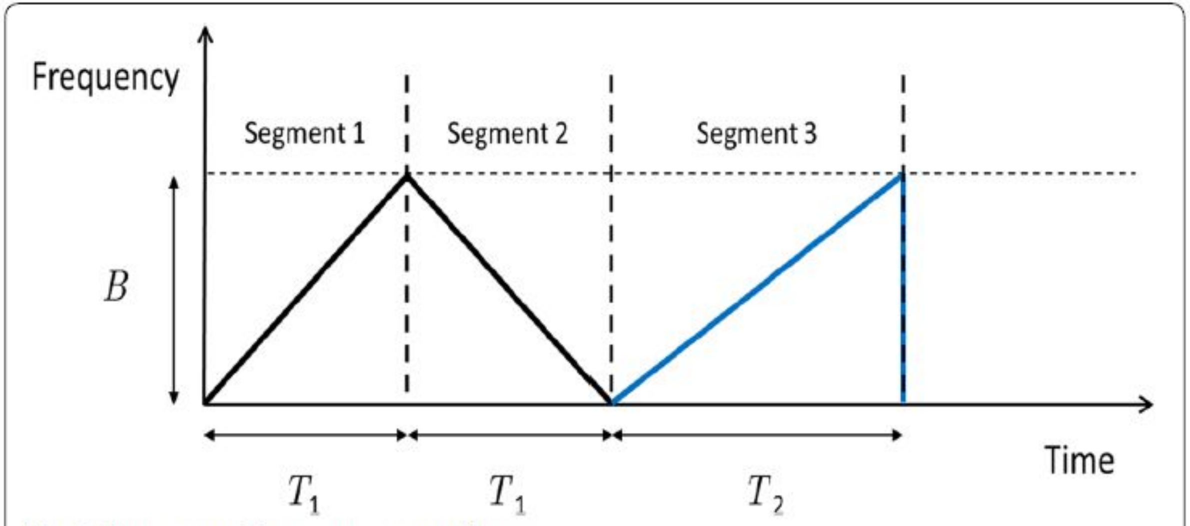



**Fig. 3** The proposed three-segment waveform

# Equations

## 3-segment equations

$$f_{bu,k} = \frac{2R_{0,k}}{c} \cdot \frac{B}{T_1} + \frac{2f_c v_k}{c},$$

$$f_{bd,k} = -\frac{2R_{0,k}}{c} \cdot \frac{B}{T_1} + \frac{2f_c v_k}{c},$$

$$f_{bc,k} = \frac{2R_{0,k}}{c} \cdot \frac{B}{T_2} + \frac{2f_c v_k}{c},$$

## R & V from 2-segments

$$R_{0,te,ij} = \frac{cT_1(f_{bu,i} - f_{bd,j})}{4B},$$

$$v_{te,ij} = \frac{c(f_{bd,i} + f_{bu,j})}{4f_c},$$

## Verification in 3rd segments

$$\hat{f}_{bc,ij} = \frac{2BR_{0,te,ij}}{cT_2} + \frac{2f_c v_{te,ij}}{c}.$$

- Compare difference of $f_{bc}$ and $\hat{f}_{bc}$ with thresould $\varepsilon$

- If diff < $\varepsilon$ => Real Target
- If diff > $\varepsilon$ => Ghost Target

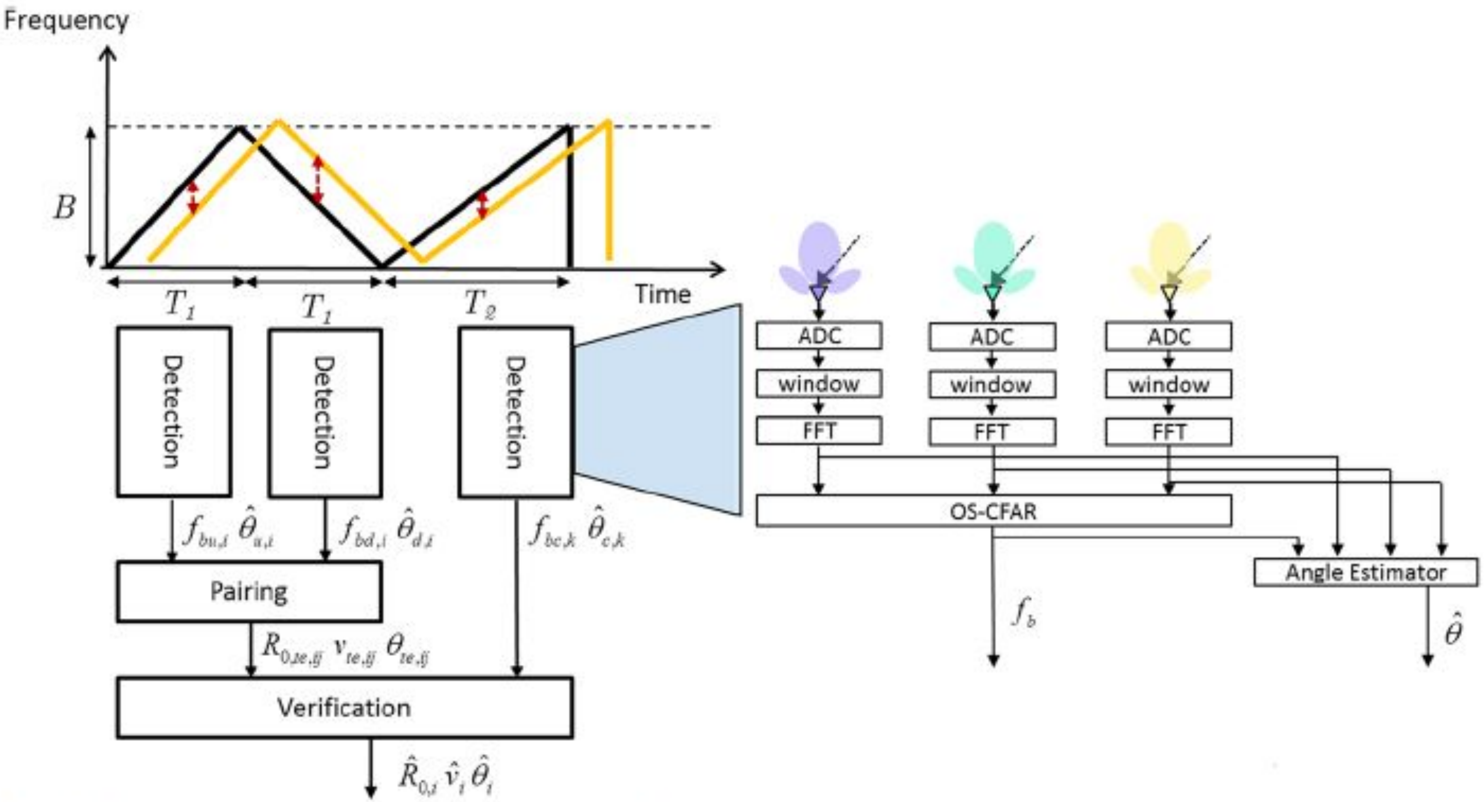



**Fig. 4** The proposed multi-target detection architecture

# Angle Estimator

- Minimum-norm method
  - Used to mitigate the unreliability of angle information due to overlapping beat frequency
- Spatial filter
  - To reduce data load in minimum norm method

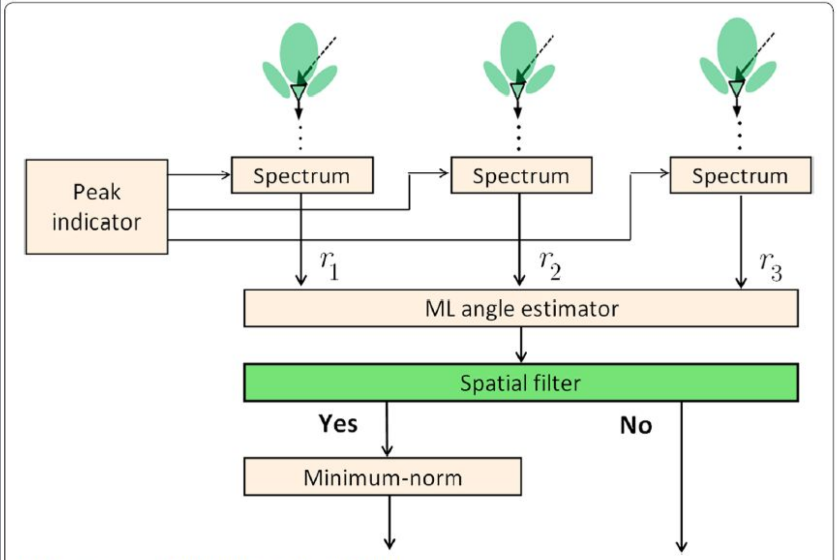


**Fig. 5** The proposed multi-target angle estimation process

# Constant false alarm rate detection(CFAR)

- Constant false alarm rate detection refers to a common form of adaptive algorithm used in radar systems to detect target returns against a background of noise, clutter and interference

- In order to obtain a constant false-alarm rate (CFAR), an adaptive threshold must be applied reflecting the local clutter situation.

- Helps in filtering out relevant beat frequencies discarding the frequencies corresponding to noise and clutter.

# Alternate Techniques

- Gradient search methods (GSM)
- Curve fitting method
- Multiple signal classification (MUSIC)
- The Chirp-Z transform (CZT)

# Gradient search methods (GSM)

Gradient Search Method is a first-order iterative optimization algorithm for finding a local minimum or local maximum of a differentiable function.

- **Gradient Descent** - To find Local MINIMA.
    - Manimizing of the function so as to achieve better optimization. It gives downwards slope or decreasing graph.
- **Gradient Ascent** - To find Local MAXIMA.
    - Maximizing of the function so as to achieve better optimization. It gives upward slope or increasing graph.

# Curve fitting method

Curve fitting  is the process of constructing a curve or mathematical function, that has the best fit to a series of data points.

- Interpolation
- Smoothing
- regression analysis

# Multiple signal classification (MUSIC)

MUltiple SIgnal Classification (MUSIC)  method is based on the eigenvectors of the sensor array correlation matrix. It is used for determining spectral density.

- Spectral MUSIC

# The Chirp-Z transform (CZT)

- The Chirp-Z transform (CZT) can refine the spectrum based on an interpolation technique with low computational complexity

- A different variant algorithm was proposed in to achieve increasing frequency resolution with an additional phase