RADAR

Electromagnetic (EM) SENSOR

Uses Radio Waves

Used for Detection of Objects
Finding Position, vel
Imaging of Objects/Gnd
Tracking objects etc

Complex System Multidisciplinary knowledge

Hardware design follows COTS approach

Software development comprises extensive amount of DSP concepts

Radar concepts can be used in ROBOT Radar, SONAR, Ultrasonic ranging etc

Acts as a Motivation for Learning and Understanding DSP
INTRODUCTION TO RADAR

RADAR = Radio Detection and Ranging

• Detects targets by receipt of reflected echoes from transmitted RF pulses

• Measures metric coordinates of detected targets:
  - Range
  - Doppler/velocity of targets
  - Angle (azimuth and/or elevation)

• Special-purpose radars also measure:
  - Target size / shape (target imaging)
  - Target motion spectrum
    - Ground map images (SAR)
RADAR: Working Principle
Radar Measurements

• Metric Coordinates of Detected Targets

  – Range: \[ R = \frac{c\tau}{2}; \quad c = \text{speed of light, m/s} \]
    \[ \tau = \text{round-trip echo time, s} \]

  – Range Rate: \[ v_r = \frac{\lambda f_d}{2}; \]
    \[ v_r = \text{target radial velocity, m/s} \]
    \[ \lambda = \text{wavelength of RF Txmit pulse, m} \]
    \[ f_d = \text{Doppler freq. shift of echo, Hz} \]

  – Azimuth / Elevation \( \Theta, \Phi \)

  – Position of antenna beam at time of detection.
Radar Measurements

- **Measurement Resolution of Metric Coordinates**
  
  - Range: $\Delta R = \frac{c}{2B}$; $B =$ pulse bandwidth, Hz
  
  - Range Rate: $\Delta v_r = \frac{\lambda}{2T_c}$; $T_c =$ coherent integration time, s
  
  - Angle: $\Delta \Theta = \frac{\lambda}{D_\Theta}$; $D_\Theta =$ antenna aperture, m
    
    ($\Delta \Theta$ in radians)

- **Special-Purpose Radar Measurements**
  
  - Target Motion Spectra; Modulation of Doppler shift by target motion
  
  - Synthetic Aperture Radar; Conversion of Doppler shift to angle offset
1. How to find range of the object/Target?
   *Time Domain Processing (Band Pass Sampling)*

2. How to find the speed of the object/Target?
   *Frequency Domain Processing (DFT/FFT)*

3. How to achieve desired range resolution?
   *Frequency Domain Processing (Fast Convolution, Windowing)*

4. How to suppress Unwanted signal/Clutter?
   *Frequency Domain Processing (FIR Filters)*
Radar On a Robot
Radar Basics
## RADAR FREQUENCY BAND

<table>
<thead>
<tr>
<th>Band Designation</th>
<th>Frequency range (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>3 - 30</td>
</tr>
<tr>
<td>VHF</td>
<td>30 - 300</td>
</tr>
<tr>
<td>UHF</td>
<td>300 - 1000</td>
</tr>
<tr>
<td>L</td>
<td>1000 - 2000</td>
</tr>
<tr>
<td>S</td>
<td>2000 - 4000</td>
</tr>
<tr>
<td>C</td>
<td>4000 - 8000</td>
</tr>
<tr>
<td>X</td>
<td>8000 - 12,000</td>
</tr>
<tr>
<td>Ku</td>
<td>12,000 - 18,000</td>
</tr>
<tr>
<td>Ka</td>
<td>27,000 - 40,000</td>
</tr>
<tr>
<td>mm</td>
<td>40 - 300GHz</td>
</tr>
</tbody>
</table>

**Ultrasonic Ranging**
RADAR: Basic Types

**Continuous Wave Radars (CW)**
- Independent Transmitter and Receiver

**Pulsed Radars**
- Co-located transmitter and Receiver with a sharing antenna
- A pulse is transmitted and then the radar listens for the return
- The strength of the signal is proportional to the target distance and its electrical size
- The range is calculated from the time delay

**Bistatic Radars**

**Monostatic Radars**

- CW Radar with independent Transmitting and Receiving antenna
- Single antenna Time shared by the transmitter and receiver
RADAR WAVEFORMS

Pulsed Radar

Tx

Rx (RF)

Rx (IF)

Rx

Base band

CW Radar

Tx

Rx (RF)

Rx (IF)

Rx

Base band

Target echo train pulses

IF pulsed
1. How to find range of the object/Target?

*Time Domain Processing (Sampling)*
TARGET DETECTION: Detection Range

\[ R = \frac{c T_R}{2} \]

Where

\( c = \) velocity of light

\( T_R = \) Round Trip Time

For,

\( T_R = 1 \text{us} \)

\[ R = \frac{1}{2} \times 3 \times 10^8 \times 1 \times 10^{-6} \]

= 150 m.
RADAR WAVEFORMS

- **CW**: Continuous Wave
- **FMCW**: Freq. Modulated Continuous Wave
- **Pulsed**
- **Pulsed Coded**

![Diagram](image)

Pulse Width : \( \tau \)

Pulse Repetition Interval (PRI) : \( T \)

Pulse Repetition Frequency (PRF) : \( fr = 1/T \)

The PRF is chosen to meet the max. unambiguous Range desired:

\[
\text{Dist} = \text{Speed} \times \text{Time}
\]

\[
2 \times R_{\text{unamb max}} = C \times T = C \times 1/fr
\]

\[
\therefore \quad fr \leq C/2R_{\text{unamb max}}
\]
The radar range equation is:

\[ R_{\text{max}} \propto [P_T G^2 \lambda^2 \sigma / (4\pi)^3 S_{\text{min}}] \]

- \( P_T \): Transmitted power
- \( G \): Gain of the antenna
- \( \lambda \): Wave length
- \( \sigma \): Target cross section
- \( S_{\text{min}} \): Minimum Detection signal
- \( R_{\text{max}} \): Maximum range
- \( Ae \): Antenna aperture
Range measurement

- Radar measures distance by measuring time delay between the transmit and received pulse.
  - 1 us = 150 m
  - 1 ns = 15 cm

\[ R = \frac{c \tau}{2} \]

\( \tau \) = time delay between transmission and reception

\( c \) = velocity of propagation

\( R \) = Range to the jet.
Radio Detection and Ranging (RADAR)

Uses Electromagnetic wave

Distance: $2R$

Speed: $3 \times 10^8$ m/s

$R = T_D \cdot 3 \times 10^8$

For 1 Km $T_D = 6.666 \mu$sec

1 $\mu$sec delay = 150 m range
How to Find Range?

Power: Radar range Equation
Pulse Width: Range Resolution
Pulse Length: Unambiguous Range & Doppler
Number of Pulses: Doppler and Energy
Modulation inside Pulse: Range Resolution
Range (A/D) Sampling Process

- Pulse repetition interval (PRI)
- Xmit pulse
- Target echoes
- Xmit pulse
- Target echoes
- Xmit pulse

Range / time

N_r A/D Sampling Strobes

N_r / f_s

f_s = A/D Sampling rate

(1/ f_s)
TARGET DETECTION: Maximum Range

Maximum unambiguous Range, $R_{un} = \frac{cT}{2}$
1. How to find the speed of the object/Target?

*Frequency Domain Processing (DFT/FFT)*
TARGET DETECTION: Detect Velocity (Doppler Shift)

- Total Velocity
- Radial Velocity
- Tangential Velocity

Produces Maximum Doppler Shift
Zero Doppler Shift
Part of the target’s velocity produces doppler shift
Any echo signal coming from a moving target suffers a change in phase with respect to time.

Frequency being rate of change of phase:

\[ f = \frac{1}{2\pi} \frac{d\Phi}{dt} \]

The echo signal suffers a change or shift in frequency called the

DOPPLER FREQUENCY shift, given by:

\[ f_d = \frac{2v_r}{\lambda} = \frac{2v \cdot \cos\theta}{\lambda} \]

Wavelength: \( \lambda \) is the distance the wave must travel to suffer a 360° phase change or complete one cycle:

Time for 1 cycle = \( \frac{1}{f} \)
SPECTRUM OF PULSED RADAR SIGNAL

TIME DOMAIN:

$$T = \frac{1}{f_r}$$

FREQUENCY DOMAIN:

Line spectrum weighted by SINC function.

For target echo: central line will be $$f_t$$, $$f_d$$

Each line has a spread:

Spread depend on several factors

but mainly dominated by inverse of antenna dwell time.
TARGET DETECTION: Doppler Ambiguity

-PRF

Unambiguous doppler

Echo spectral line

Unambiguous doppler region

Transmit spectral line

Clutter echo

0

f_d

Doppler shift

f_a

Ambiguous doppler

TARGET DETECTION:
Doppler Ambiguity
Graphical Analysis of Radar signal Spectrum
Continuous Wave (CW)
Infinite Length

Train of Noncoherent Pulses
(Random starting phases)
Train of Coherent Pulse
Infinite Length

Train of Coherent Pulses
Limited Length
How to Find Velocity?
Time & Frequency Trade Off

PRF 1 (low)

Good for Range Finding

PRF 2 (high)

Good for Velocity Finding

Line spectrum

Repetitive
SINGLE LONG PULSE

EIGHT PULSE TRAIN

1000 Pulses

2 Pulses
21. CW wave represented by a single line in the spectrum of an infinitely long pulse train. As the length of train is reduced, this wave becomes a single pulse and its spectrum broadens into a sin x/x shape.

\[ F(\omega) = \frac{A \tau N}{2} \left\{ \frac{\sin \left( \omega - \omega_c \right) NT}{\left( \omega - \omega_c \right) NT} \sum_{n=1}^{\infty} \frac{\sin \left( n\omega_o \pi \right)}{n\omega_o \pi} \right\} + \frac{A \tau N}{2} \left\{ \frac{\sin \left( \omega - \omega_c - n\omega_o \right) NT}{\left( \omega - \omega_c - n\omega_o \right) NT} + \frac{\sin \left( \omega - \omega_c + n\omega_o \right) NT}{\left( \omega - \omega_c + n\omega_o \right) NT} \right\} \]

33. Positive-frequency portion of the Fourier transform for a rectangular train of N pulses. The pulses have a width \( \tau \), a carrier frequency of \( \omega_c \), a PRF of \( \omega_o \), and an interpulse period of \( T \).
Reference

INTRODUCTION TO AIRBORNE RADAR

BY GEORGE W. STIMSON

SCITECH PUBLICATIONS