An Approach to Data Level Target Simulation

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Abstract:

The Radar Data Processor comprises of a large number of complex algorithms that need to be validated. This paper explains the design of a data-level target simulator which is used to test the Data Processor in presence or absence of a Signal Processor in the radar. It can generate detection reports by using accurate radar detection model for any given target scenario. The target scenario can be defined for single or multiple targets.

The Target Simulator takes target database loaded by the operator and the waveform parameters from the Data Processor as inputs. It performs a correlation between the beam position and the target position. The correlated target's parameters are processed through a series of algorithms to determine whether a real target with similar parameters will be detected by the radar or not. In case the simulated target gets detected, detection reports are simulated in a realistic manner.

Key Words: Radar cross-section (RCS), Pulse Repetition Interval (PRI),Burst, Dwell

I. INTRODUCTION

The data level target simulator generates detection reports for simulated target scenarios containing single or multiple targets. This acts like a simulated signal processor of the radar for the simulated target. Therefore, even in the absence of signal processor in the radar, the target simulator can generate detection reports for simulated targets in a realistic manner which can be used to test the radar data processor.

II. DATAFLOW OF TARGET SIMULATOR

The target simulator is interfaced with a number of radar sub-systems like Data Processor, Signal Processor as indicated in Fig 1.

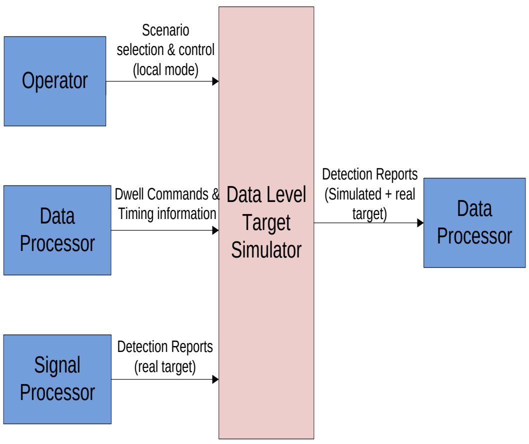

Figure 1. Interfaces of Data Level Target Simulator

The target trajectory is sampled at regular intervals and stored in the database. The target scenario is started as per the operator's instructions. The target parameters included in the database are its position, velocity, acceleration, and RCS. The target simulator indexes into the database according to the elapsed time from the scenario start. The target simulator takes waveform parameters like PRI, pulse width, transmit frequency, and beam position in azimuth and elevation, from the Data Processor as inputs. It performs a correlation between the beam position and the target position. The correlated target's parameters are processed through a series of algorithms as indicated in the Fig 2.

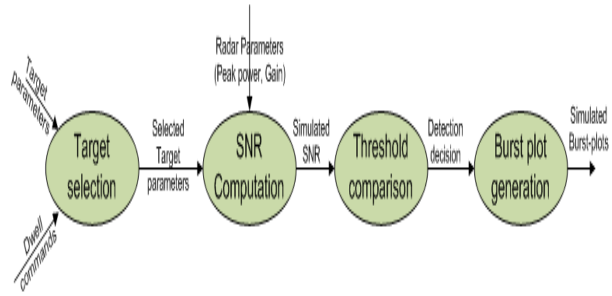

Figure 2. Dataflow of Data Level Target Simulator

The entire processing is divided into the following steps:

1. ***Target Selection***

   The difference between the target position and beam position is computed and compared against the beam width of the dwell. All those targets that fall within the beam are selected for burst plot generation.

2. ***SNR Computation***

   The target simulator computes Signal to Noise ratio taking into account the target parameters, antenna parameters and simulated system losses as inputs to the range equation. The computation of SNR is done using equation (1) and (2):

$$P_{rec} = \frac{P_t\, G_t\ \rho_t(\theta_0)\ G_r\ \rho_r(\theta_0) G_p\ \lambda^2 \sigma}{L_a\, L_b\ L_p\ L_t (4\pi)^3 R^4} \qquad (1)$$

where P_{rec} : received target power

P_t : transmit power

G_t : transmit gain of the antenna

$\rho_t(\theta_0)$: attenuation in the transmit gain as a function of beam steering deflection

G_r : receive gain of the antenna

$\rho_r(\theta_0)$: attenuation in the receive gain as a function of beam steering deflection

G_p : processing gain

θ_0 : deflection of the beam

λ : wavelength of the transmit beam

σ : RCS of the target

L_a : atmospheric losses

L_b : beam shape loss

L_p : processing loss

L_t : transmit loss

R : range of the target

$$SNR = \frac{P_{rec}}{N_t} \qquad (2)$$

where SNR : Signal to noise ratio

P_{rec}: received target power

N_t : thermal noise

Amongst the various inputs to the radar equation, fluctuations in the target RCS, processing gain, beam steering attenuation and system losses are simulated online. The antenna patterns are stored in the database. The thermal noise power is computed online according to the waveform bandwidth.

Computation of fluctuating RCS: The RCS of the target fluctuates based on the Swerling models. The following Swerling laws are used by the target simulator.

Swerling Case 1 (SW1):

$$p(\sigma) = \frac{1}{\sigma_{av}} e^{\frac{-\sigma}{\sigma_{av}}} \qquad (3)$$

Swerling case 3 (SW3):

$$p(\sigma) = \frac{4\sigma}{\sigma_{av}^2} e^{\frac{-2\sigma}{\sigma_{av}}} \qquad (4)$$

for $\sigma \geq 0$

Aircraft and missile fluctuating targets with no frequency diversity follow SW1 and SW3 respectively. When there is frequency diversity from pulse to pulse, fluctuations are also observed pulse to pulse. For such fast fluctuations SW2 and SW4 are followed. SW2 and SW4 have the same pdf as (3) and (4) respectively.

To simulate RCS fluctuation, uniform random number is generated using the Linear congruential Generator. This random number is transformed to a random number that follows the appropriate Swerling law probability density function. A fluctuating RCS is realized by taking the product of the random number from the Swerling pdf and the fed RCS value in the database. The seeds used to draw a new random number are target identification number, the transmit frequency of the radar antenna and the scan duration i.e whenever there is a new scan, a different RCS is computed.

Computation of thermal Noise Power: Thermal noise power is computed as:

$$N_t = kTBF \qquad (5)$$

where

N_t = thermal noise power
k = Boltzmann's constant
T = thermal temperature
B = bandwidth of the waveform played
F = Noise Figure of the radar receiver

Computation of Beam steering attenuation: As the beam is steered from the bore sight, there is an increase in the beam width and reduction in the maximum gain. The beam width varies inversely as $\cos\theta_0$ and the antenna gain decreases as $\cos\theta_0$ where θ_0 is the deflection of the beam from the bore sight.

Beam shape loss: The antenna gain used in the radar equation is assumed to be a constant equal to the maximum value gain. But the train of pulses returned from the target by a scanning antenna is modulated in amplitude by the shape of the antenna beam. Only one from the complete set of pulses has the maximum gain. Therefore Beam shape loss is calculated to consider the reduction in total signal energy received from a modulated train of pulses compared to what would have been received from a constant amplitude pulse train. Beam shape loss is calculated in the following manner:

$$L_b = \frac{n}{1 + 2\sum_{k=1}^{\frac{n-1}{2}} e^{\frac{-5.55(k*\omega*PRI)^2}{\theta_{3dB}^2}}} \qquad (6)$$

Where

L_b = beam shape loss
n = number of pulses
ω = angular speed of the antenna
PRI = Pulse Repetition Interval

Beam shape loss is calculated only in case of a rotating antenna. The antenna pattern is approximated by a Gaussian shape.

Processing loss: Due to the radar processing chain, the received SNR of the target suffers from some loss which is being considered here. These are sampling loss, encoder loss, CFAR loss etc. CFAR loss is computed as shown in (9).

$$\chi_n = \frac{({}^{P_d}/_{P_{fa}})^{1/N}}{1 - {P_d}^{1/N}} \qquad (7)$$

$$\chi_\infty = \frac{\ln\left({}^{P_{fa}}/_{P_d}\right)}{\ln(P_d)} \qquad (8)$$

$$\text{CFAR loss} = \frac{\chi_N}{\chi_\infty} \qquad (9)$$

where P_{fa} : probability of false alarm
P_d : probability of detection

Processing gain: The gain obtained in the received waveform due to processing algorithms is coherent and non-coherent integration gain. In coherent integration the samples are added in both amplitude and phase. It is obtained as a result of Doppler processing in the radar signal processor. It is as in (10).

$$G_c = N_f \qquad (10)$$

where N_f : number of Doppler filters meant for the waveform played by the Data Processor

In case of multiple bursts a non-coherent integration is done across the output of multiple bursts in the radar signal processor. Here only the power amplitudes get added. Non coherent integration gain G_{nc} is as in (11).

$$G_{nc} = \sqrt{(N_b)} \qquad (11)$$

where N_b : the number of bursts in the waveform

These two gains are considered for SNR computation as in (12).

$$G_p = G_c G_{nc} \qquad (12)$$

where G_p is the processing gain considered for SNR computation.

STC correction: Sensitivity Time Control (STC) helps in preventing the saturation of the receiver with the high power echo received from nearby targets. Based on the range of the target and the selected law STC attenuation is applied on the received echo. To simulate this attenuation in received echo power, STC correction is applied to the SNR computed from the range equation.

3. Threshold comparison

The detection threshold is modeled using Numerical technique. SNR computed with STC attenuation applied is compared against this threshold for detection.

4. Burst plot generation

Burst Plots or Detection reports are simulated for the detected targets according to Figure 3. The Plot contains a list of target attributes required by the Data Processor to establish the track. The attributes are Range, Azimuth and Elevation of the target, Doppler processing output, the spread of the target in range cells, how good the target's SNR is for detection etc.

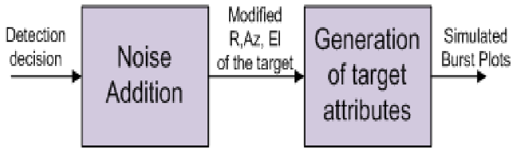

Figure 3. Burst plot generation

To make the detection simulation more realistic, noise is generated and added to Range, Azimuth and Elevation of the target. To simulate range straddling, true range is added with noise drawn from Uniform Distribution over the range cell and considered for the Plot. Due to Range-Doppler coupling, the radar's Signal Processor fails to report the true range of the target. To simulate this aspect a range error is computed as a function of radial velocity of the target, transmission frequency and bandwidth of the waveform played as shown in equation (13).

$$\text{Range bias} = \frac{\tau v_r f}{\Delta f} \qquad (13)$$

where τ : pulse width
v_r : Radial velocity of the target
f : current transmit frequency
Δf : Bandwidth of the transmit pulse

Considering the calibration defects in the Sum and the Delta channels, the azimuth and elevation results reported by Signal Processor would deviate from the true angular locations. To consider these deviations, random numbers drawn from Gaussian distribution is added to the true azimuth and elevation of the target.

The spread of the target in range is computed based on the difference between the SNR of the detected target compared to the threshold.

5. Appending of simulated Burst plots

The simulated plots are appended to the real target detection reports if any obtained from the Signal Processor. The modified detection reports are sent to the Data Processor.

In the absence of Signal Processor the simulated burst plots are sent to the Data Processor directly.

III. RESULTS

The SNR of the detected target computed by the target simulator has been plotted against the target Range and is as indicated in the Fig 5.

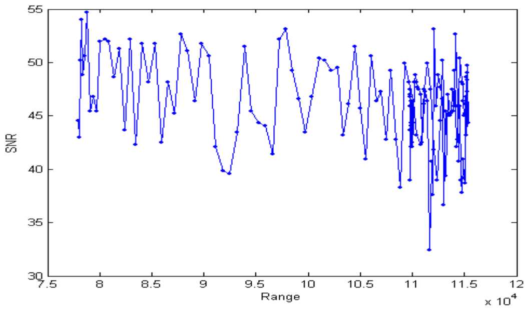

Fig 4. SNR computed by the Data Level Target Simulator vs Range

CONCLUSION

The system is designed, developed, and integrated and is at present operational in the radar. The Data Level Target Simulator is an extremely useful tool to test and validate the Radar Data Processor algorithms with different target trajectories.

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