Chenghu CAO, Yongbo ZHAO, 2022. Range estimation based on symmetry polynomial aided Chinese remainder theorem for multiple targets in a pulse Doppler radar. *Frontiers of Information Technology & Electronic Engineering*, 23(2):304-316. https://doi.org/10.1631/FITEE.2000418

Range estimation based on symmetry polynomial aided Chinese remainder theorem for multiple targets for a pulse Doppler radar

Key words: Range ambiguity; Erroneous range; Multiple targets; Symmetry polynomial aided Chinese remainder theorem

Corresponding author: Yongbo ZHAO
E-mail: ybzhao@xidian.edu.cn
ORCID: https://orcid.org/0000-0002-6453-0786

Motivation

- To avoid Doppler ambiguity, pulse Doppler radar may operate at a high pulse repetition frequency (PRF). The use of a high PRF can, however, lead to range ambiguity in many cases. At present, the major efficient solution to range ambiguity is based on a waveform design scheme. It adds complexity to a radar system.
- The traditional multiple-PRF-based scheme is difficult to apply for multiple targets because of unknown correspondence between the target range and measured range, especially when using the Chinese remainder theorem (CRT) algorithm.

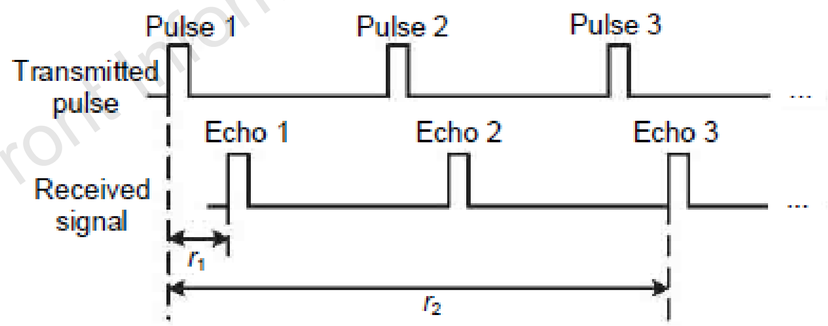

Fig. 1 Illustration of range ambiguity

The reflected signal (echoes 2 and 3) corresponding to the first pulse (pulse 1) is received when the radar has already transmitted other pulses (pulses 2 and 3)

Scheme design

- A symmetry polynomial aided robust CRT algorithm is used to realize range estimation of multiple targets, where the symmetry polynomial is used to recover the folding numbers.
- A closed-form and robust CRT algorithm for a single target and the Aitken acceleration algorithm for finding roots of a polynomial equation are used to decrease the computational complexity of the proposed algorithm.

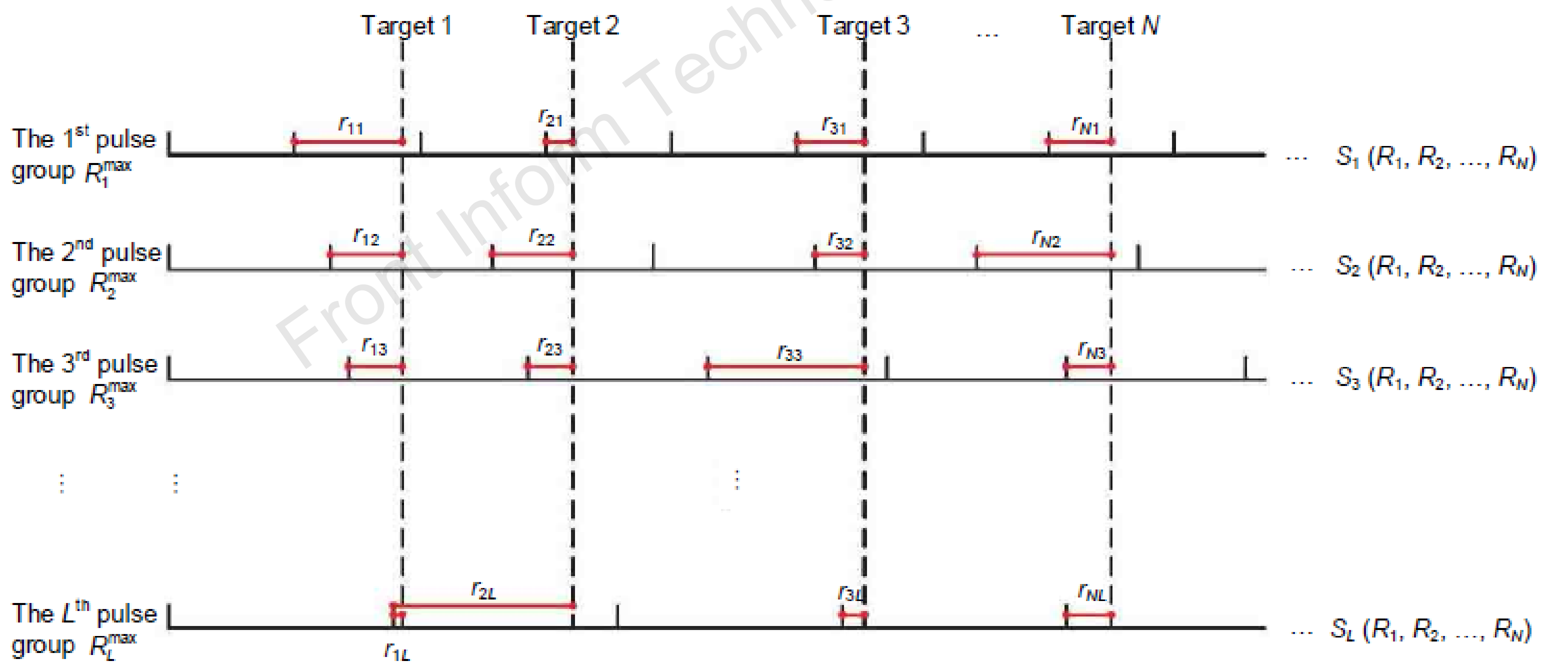

Fig. 2 Signal model for range estimation for multiple targets when there exists range ambiguity

Simulation results

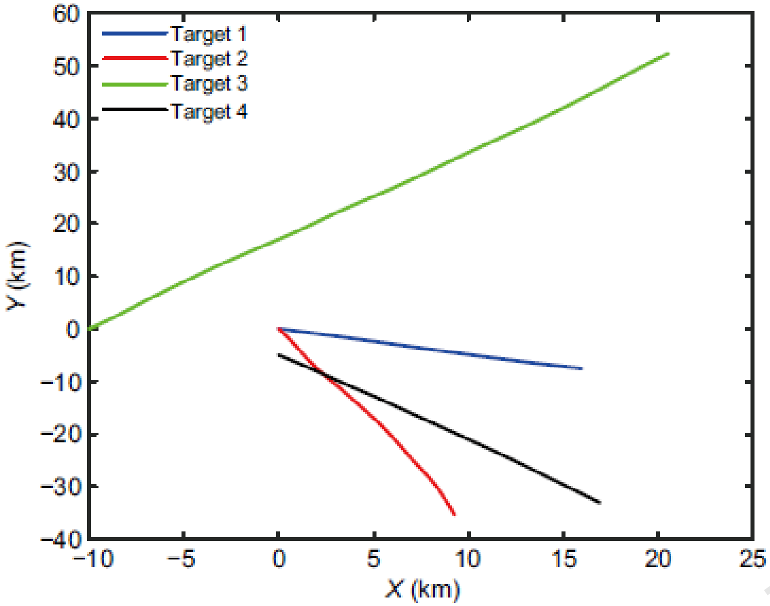

Fig. 4 Trajectories of the detected targets

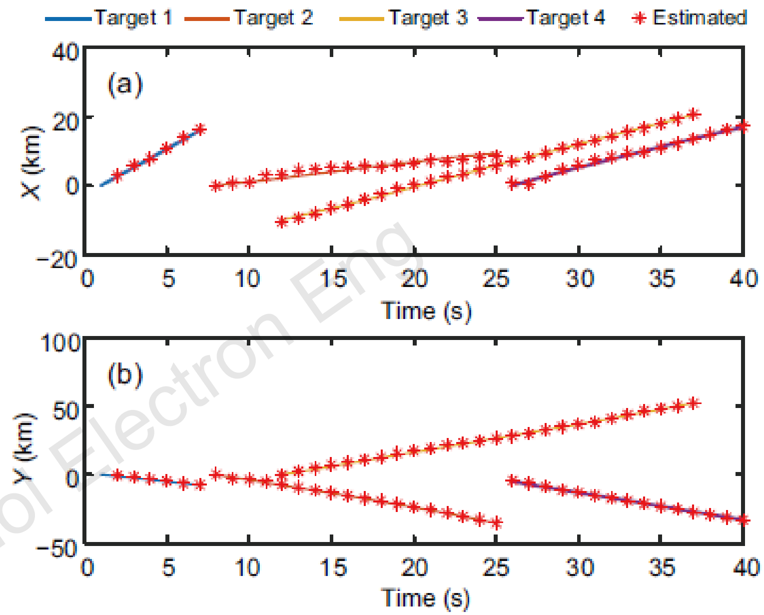

Fig. 5 X (a) and Y (b) directions of range estimation using the proposed algorithm

Consider a set of multi-target trajectories on a two-dimensional region [−10, 25] km×[−40, 60] km. There are four targets entering and exiting the surveillance region at different time, and each target travels from different initial positions.

The true range in both X and Y directions of the target is larger than the maximum unambiguous range of the pulse Doppler radar. This will lead to range ambiguity. To solve the range problem, the proposed algorithm is used to estimate the range of the time-varying targets, and the proposed algorithm achieves a satisfactory result in estimation precision.

Transient results

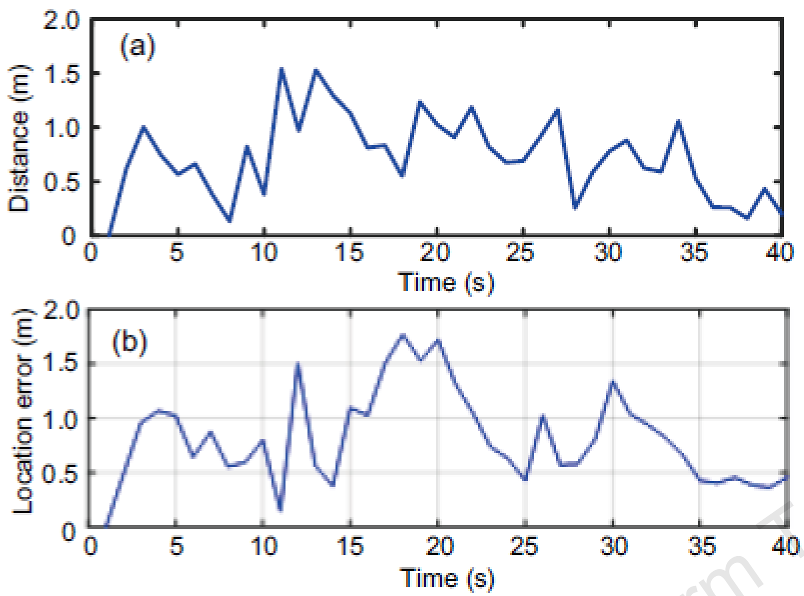

Fig. 6 OSPA distance (a) and location error (b) of range estimation of multiple targets

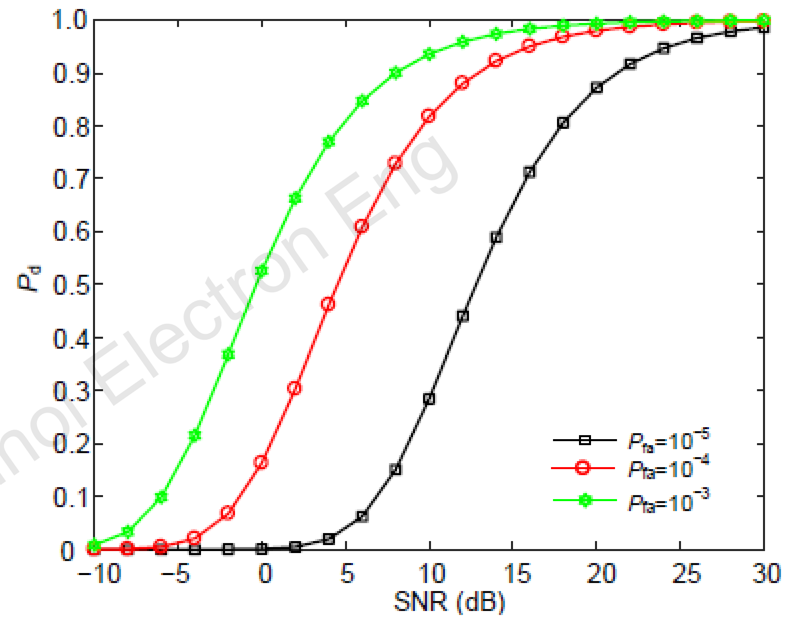

Fig. 8 Probability of target detection P_d with different probabilities of false alarm rate P_{fa}

To rigorously evaluate the performance of the proposed algorithm in the scenario with fixed SNR=22 dB, the results exhibit the distance and localization errors between the real range and the estimated range. The detection probability can reach 88% when SNR=20 dB for $P_{fa}=10^{-5}$. The proposed algorithm is effective in improving the accuracy for range estimation of multiple targets when there exists range ambiguity.

Measurement results

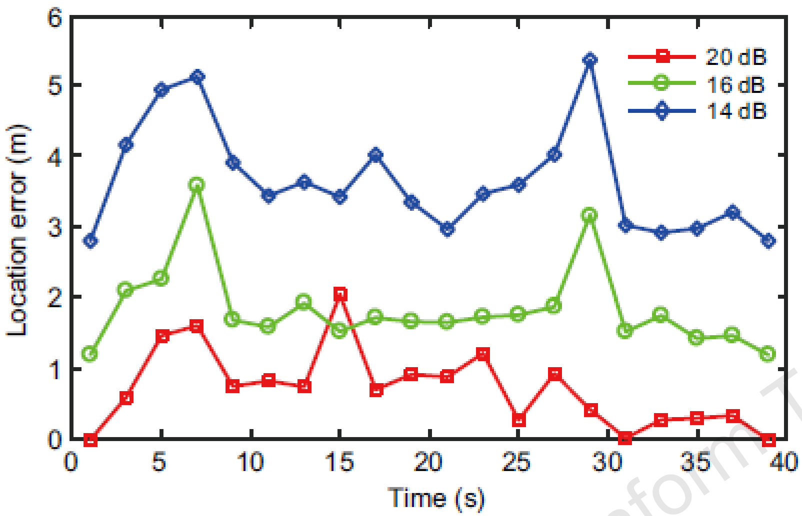

Fig. 7 OSPA error of the proposed algorithm with different SNRs

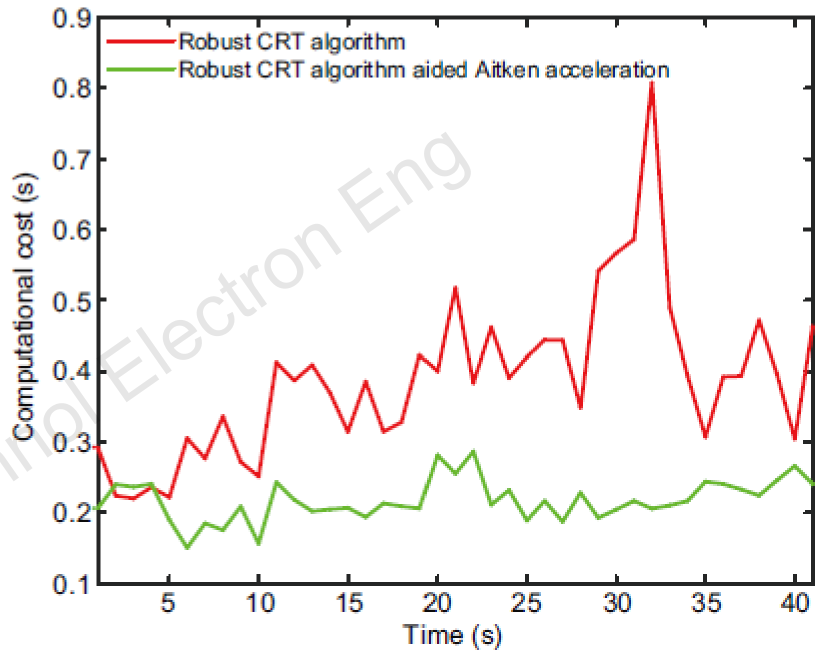

Fig. 9 Computational cost for two algorithms

The proposed algorithm can realize effective estimation of the target position in different SNRs. The higher the SNR is, the more precise position the proposed algorithm can achieve. The robust CRT algorithm aided Aitken acceleration is able to decrease the computational complexity. At the same time, real-time processing can be guaranteed at low time cost with a quantum level of 10^{-1} s for each trial.

Conclusions

- The proposed algorithm can correctly and robustly reconstruct the range of multiple targets without knowing the correspondence between the target and the remainder.
- A closed-form and robust CRT algorithm for a single target and the Aitken acceleration algorithm for finding roots of a polynomial equation are used to decrease the computational complexity of the proposed algorithm.
- The simulation results verify the efficacy of the proposed algorithm in reconstructing ranges for multiple targets on the assumption that all the measured ranges in the four PRFs are obtained ignoring range blindness due to eclipsing.

Future work

- In practical implementation, the proposed algorithm can be performed for three or more targets on the assumption that the number of targets is known in advance. Hence, the requirement to know in advance the number of targets detracts from a good and important method.
- The proposed algorithm does not function if the returns from multiple (three or more) targets coincide. More importantly, the proposed algorithm may be invalid when range blindness arises from eclipsing.

Chenghu CAO was born in 1987. He received his ME degree in Signal Processing from Fuzhou University, Fuzhou, China in 2015. He is currently pursuing the PhD degree with the Department of Electrical Engineering, Xidian University, Xi'an, China. His research interests are parameter estimation and multi-target detect and tracking.

E-mail: 764161366@qq.com

Yongbo ZHAO was born in Xinxiang, Henan, China. He received his ME and PhD degrees in Electrical Engineering from Xidian University, Xi'an, China, in 1997 and 2000, respectively. He is currently a professor with the National Laboratory of Radar Signal Processing, Xidian University. His research interests include adaptive signal processing, array signal processing, MIMO radars, and target tracking.

E-mail: ybzhao@xidian.edu.cn