Dai LIU, Yong-bo ZHAO, Zi-qiao YUAN, Jie-tao LI, Guo-ji CHEN, 2020. Target tracking methods based on a signal-to-noise ratio model. *Frontiers of Information Technology & Electronic Engineering*, 21(12):1804-1814.
https://doi.org/10.1631/FITEE.1900679

Target tracking methods based on a signal-to-noise ratio model

Key words: Signal-to-noise ratio (SNR) model; Target tracking; Angle error; Range error; Nonlinear filter

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

Motivation

1. With the increasing requirements of weapon systems for tracking and guiding radar, improving the target tracking accuracy has become an important research topic.
2. With the rapid development of radar technology, it is possible to obtain the signal-to-noise ratio (SNR) information of the target with high precision.
3. Compared with traditional target tracking methods, SNR information is extended to the radar target tracking method in this study. The relationships among the range error, angle error, and SNR are analyzed. The SNR model is established, and the measurement noise matrix in the filter method is modified.

Main idea

SNR analysis:

$$\mathrm{SNR}_{\min} = \frac{P_t G_t G_r \lambda^2 \sigma}{(4\pi)^3 k_1 T_0 B F L R^4}$$

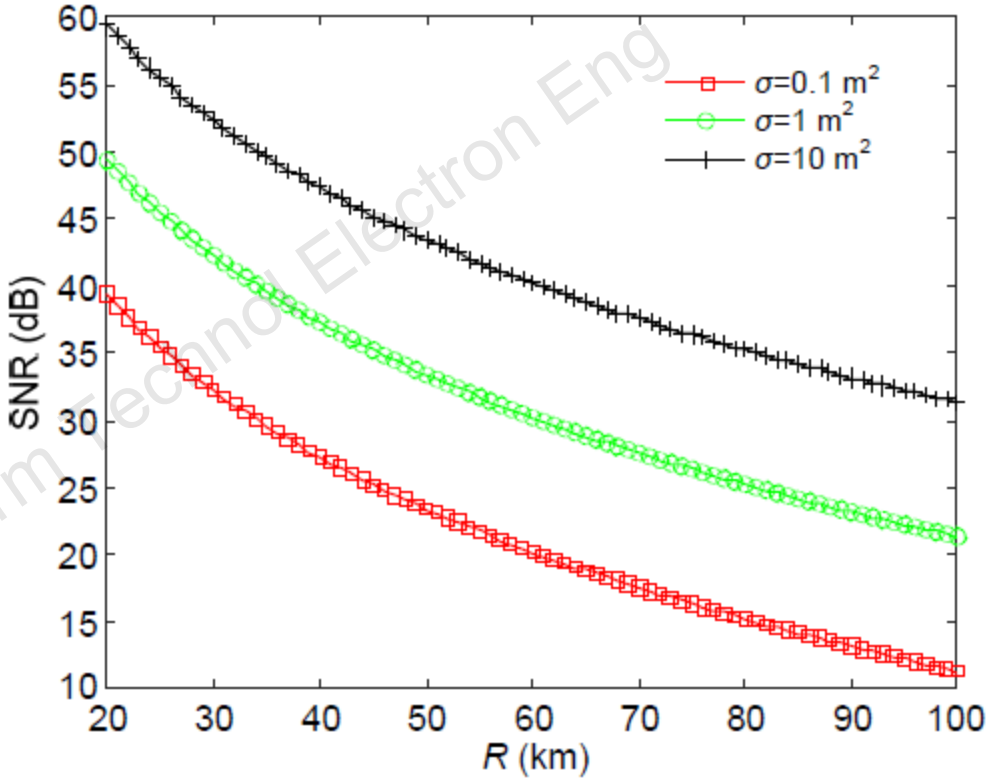

Fig. 1 Relationship between SNR and the target range at different σ's

Main idea (Cont'd)

Angle error analysis:

$$\sigma_{\phi 1} = \frac{\mathrm{BW}}{K_{\mathrm{m}}\sqrt{2\mathrm{SNR}}}$$

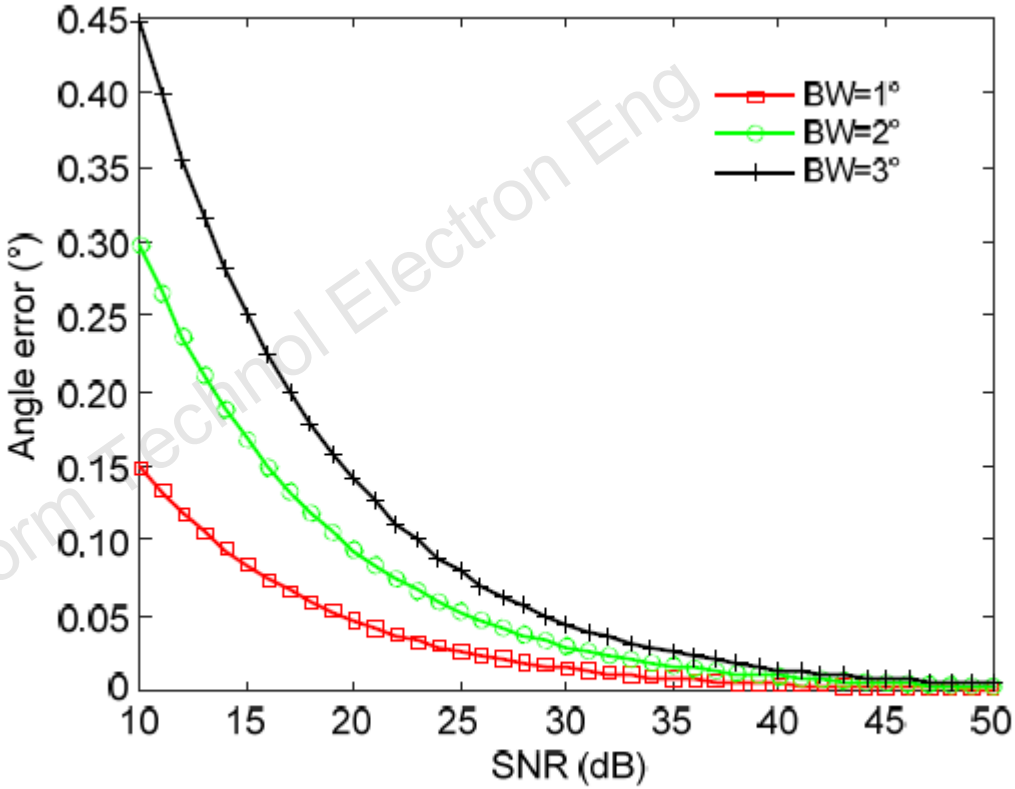

Fig. 2 Relationship between the angle error and SNR at different BW's when K_{m}=1.5

Main idea (Cont'd)

Range error analysis:

$$\sigma_{\rho 1} = \frac{c}{2B_s\sqrt{2\mathrm{SNR}}}$$

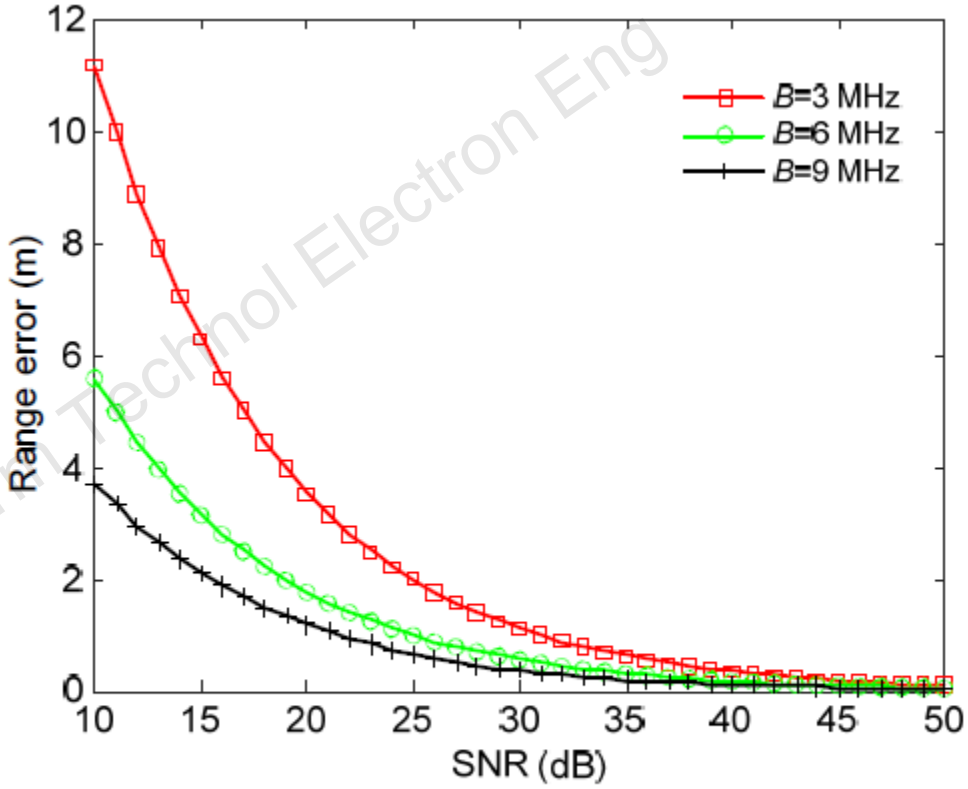

Fig. 3 Relationship between the range error and SNR at different *B*'s

Method

Selection of measurement noise covariance:

$$
\begin{aligned}
\boldsymbol{R}_k &= \begin{bmatrix} \sigma_{\rho_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi_k}^2 \end{bmatrix} \\
&= \begin{bmatrix} \sigma_{\rho 1_k}^2 + \sigma_{\rho 2_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta 1_k}^2 + \sigma_{\theta 2_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi 1_k}^2 + \sigma_{\varphi 2_k}^2 \end{bmatrix} \\
&= \begin{bmatrix} \sigma_{\rho 1_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta 1_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi 1_k}^2 \end{bmatrix} + \begin{bmatrix} \sigma_{\rho 2_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta 2_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi 2_k}^2 \end{bmatrix} \\
&= \begin{bmatrix} \dfrac{c^2}{8B_s^2 \mathrm{SNR}_k} & 0 & 0 \\ 0 & \dfrac{\theta_{\mathrm{H}}^2}{2K_{\mathrm{m}}^2 \mathrm{SNR}_k} & 0 \\ 0 & 0 & \dfrac{\varphi_{\mathrm{H}}^2}{2K_{\mathrm{m}}^2 \mathrm{SNR}_k} \end{bmatrix} + \begin{bmatrix} \sigma_{\rho 2_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta 2_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi 2_k}^2 \end{bmatrix} \\
&= \boldsymbol{R}_{k1} + \boldsymbol{R}_{k2}
\end{aligned}
$$

$$
\boldsymbol{R}_{k1} = \begin{bmatrix} \dfrac{c^2}{8B_s^2 \mathrm{SNR}_k} & 0 & 0 \\ 0 & \dfrac{\theta_{\mathrm{H}}^2}{2K_{\mathrm{m}}^2 \mathrm{SNR}_k} & 0 \\ 0 & 0 & \dfrac{\varphi_{\mathrm{H}}^2}{2K_{\mathrm{m}}^2 \mathrm{SNR}_k} \end{bmatrix}
$$

$$
\boldsymbol{R}_{k2} = \begin{bmatrix} \sigma_{\rho 2_k}^2 & 0 & 0 \\ 0 & \sigma_{\theta 2_k}^2 & 0 \\ 0 & 0 & \sigma_{\varphi 2_k}^2 \end{bmatrix}
$$

Extended Kalman filter method based on the SNR model (SNR-EKF)

Unscented Kalman filter method based on the SNR model (SNR-UKF)

Major results

Scenario 1: The range error remains unchanged at 30 m, and the angle error varies with SNR.

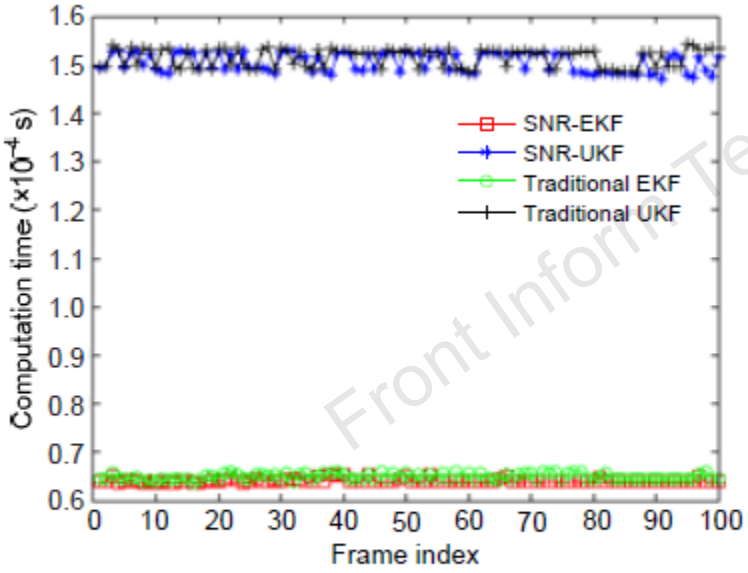

Fig. 10 Computation time of the four methods for scenario 1

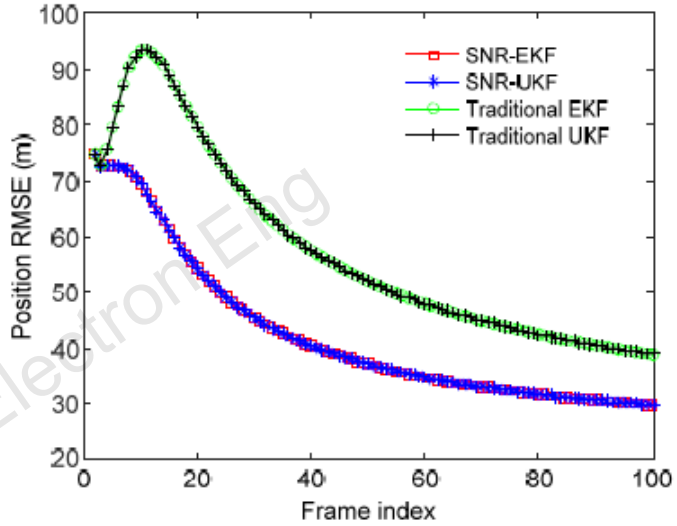

Fig. 8 RMSEs of the target position for scenario 1

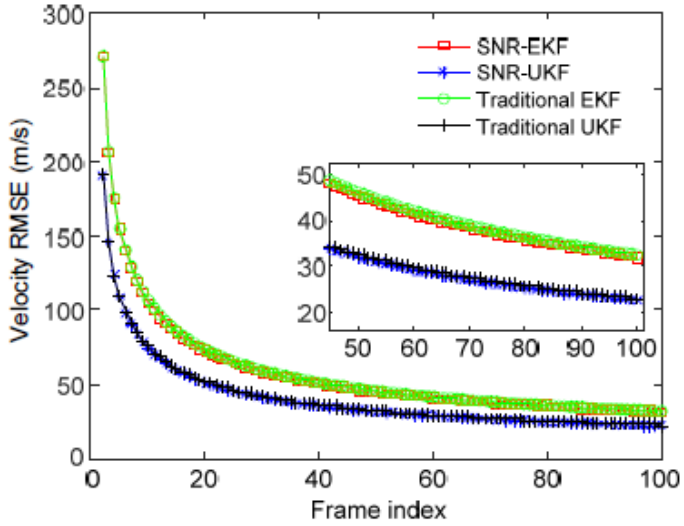

Fig. 9 RMSEs of the target velocity for scenario 1

Major results (Cont'd)

Scenario 2: The angle error remains unchanged at 0.0432°, and the range error varies with SNR.

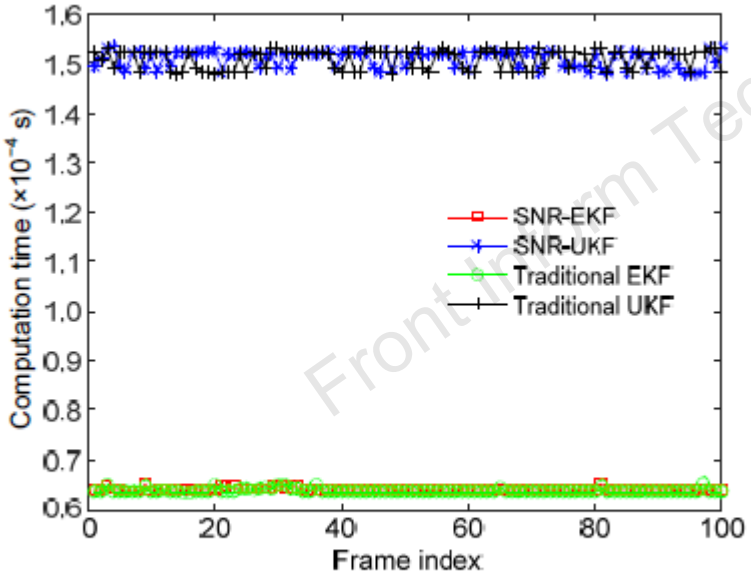

Fig. 13 Computation time of the four methods for scenario 2

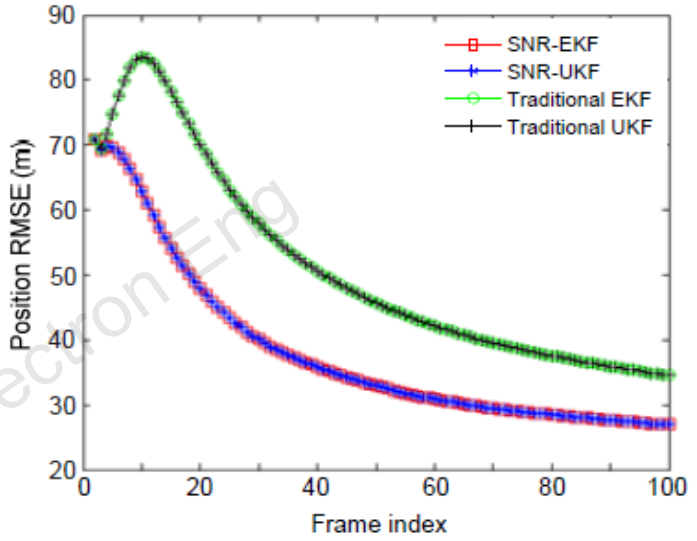

Fig. 11 RMSEs of the target position for scenario 2

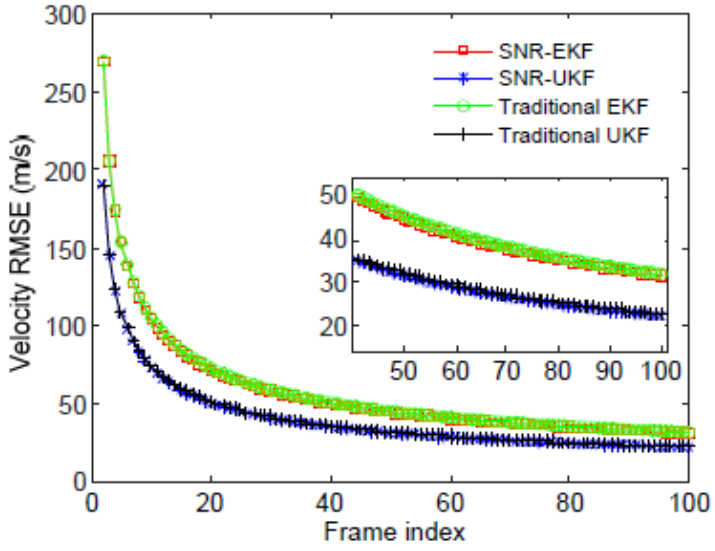

Fig. 12 RMSEs of the target velocity for scenario 2

Major results (Cont'd)

Scenario 3: The angle error and range error vary with SNR.

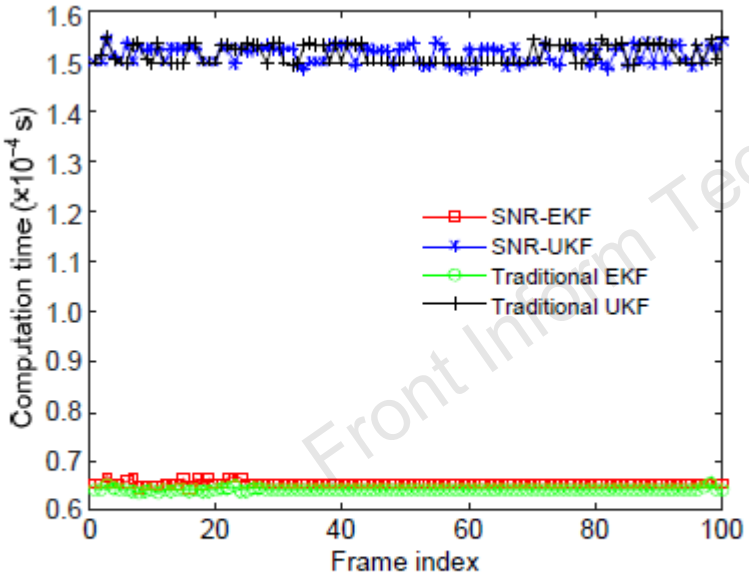

Fig. 16 Computation time of the four methods for scenario 3

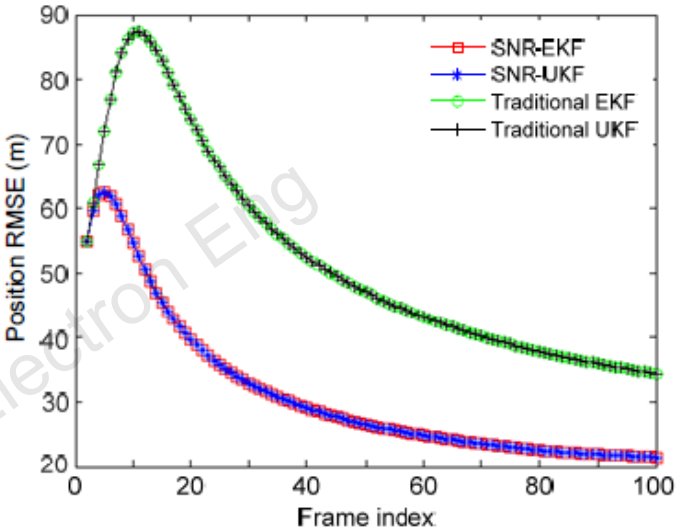

Fig. 14 RMSEs of the target position for scenario 3

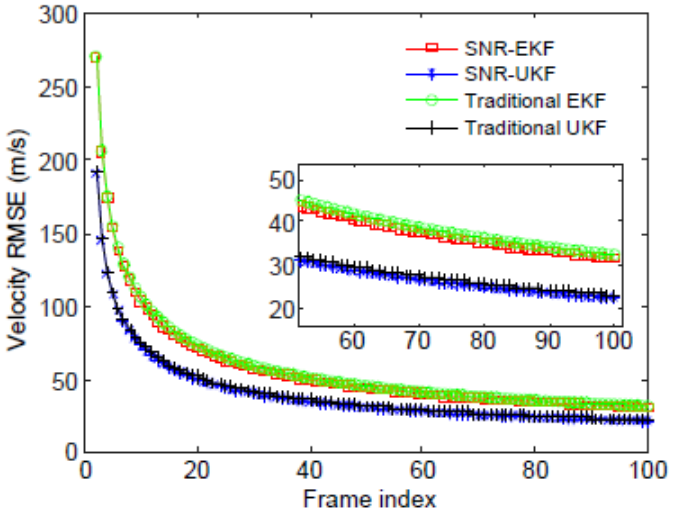

Fig. 15 RMSEs of the target velocity for scenario 3

Conclusions

1. Compared with the traditional EKF and UKF methods, the SNR-EKF method and the SNR-UKF method have superior performance (higher prediction accuracy and higher convergence speed) and little influence on computation time.

2. Compared with the SNR-EKF method, the SNR-UKF method has higher velocity precision, but longer computation time, and their position precision is almost the same.

Dai LIU received the B.S. degree from Shandong University, Weihai, China, in 2006, and the M.E. degree from Xi'an Electronic Engineering Research Institute, Xi'an, China, in 2009. He is currently pursuing the Ph.D. degree at the Department of Electrical Engineering, Xidian University. His research interests include radar data processing and signal processing.

Yong-bo ZHAO was born in Xinxiang City in Henan Province, China. He received the M.E. and Ph.D. degrees both in Electrical Engineering from Xidian University, Xi'an, China, in 1997 and 2000, respectively. He is now a professor with the National Lab of Radar Signal Processing, Xidian University. His research interests include adaptive signal processing, array signal processing, MIMO radar, and advanced radar concepts.