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Interval type-2 fuzzy logic based radar task priority assignment method for detecting hypersonic-glide vehicles

Key words: Hypersonic-glide vehicle (HGV); Phased-array radar; Interval type-2 fuzzy logic system (IT2FLS); Priority assignment

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Motivation

1. The hypersonic-glide vehicle (HGV) has become a strategic weapon developed by many countries worldwide. There is no evidence that traditional ballistic missile defense systems can effectively intercept HGV targets. In response to the threat of attack from HGVs, ground-based phased-array radar is the main early warning method in addition to early warning satellites.

2. Although phased-array radar can perform a variety of radar tasks, its total resources are limited. Radar resources consumed by radar tasks are different. Effective management of radar resources is a significant issue to ensure sufficient resources for detecting high-value and high-threat targets.

Motivation (Cont’d)

3. Task priority assignment is an important sub-problem of radar resource management, related not only to the sequence of task scheduling, but also to the overall resource allocation effect and the operational effectiveness of phased-array radar. Therefore, it is necessary to design a radar task priority assignment method that can change in real time to meet the needs of the battlefield situation.

Main idea

1.The existing radar task priority assignment methods include mainly fixed priority methods, comprehensive priority methods, and fuzzy logic priority methods.

2. The fixed priority assignment method cannot make full use of the target information sensed by radar. For the comprehensive priority assignment method, the weighting coefficient of each factor in the calculation process is manually designated. In contrast, the fuzzy logic priority assignment method uses fuzzy reasoning to solve the problem that the weight of each factor cannot be specified accurately in priority assignment.

3. Compared with the traditional type-1 fuzzy logic system, the type-2 fuzzy logic system greatly improves the ability to deal with uncertainty. In this study, we design a radar task priority assignment method based on the interval type-2 fuzzy logic system (IT2FLS).

Method

1. The target threat of an HGV is divided into maneuver, speed, azimuth, and distance threats. In the radar task priority assignment method based on IT2FLS, the maneuver factor, speed, azimuth difference, distance, and initial priority are input variables. The radar task priority is the output variable. To reduce the number of fuzzy rules and avoid rule explosion, an IT2FLS with a hierarchical structure was designed.

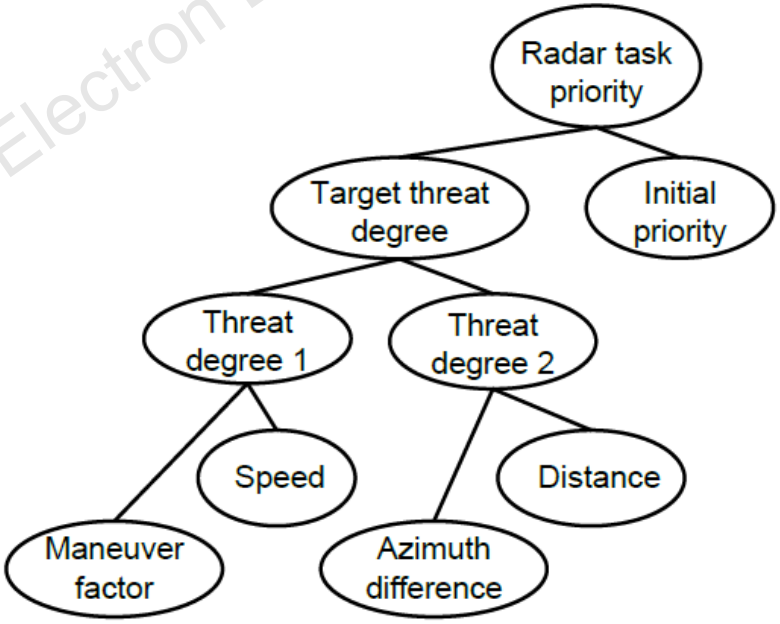

Fig. 6 Decision tree of priority assignment

Method (Cont'd)

2. Take a fuzzy subsystem composed of target threat degree, initial priority, and radar task priority as an example. The target threat degree and initial priority are the inputs of the fuzzy subsystem and the radar task priority is the output. Table 1 shows the fuzzy variables and fuzzy values of the fuzzy subsystem.

Table 1 Fuzzy variables and fuzzy values

Fuzzy variable	Fuzzy value
Target threat degree (x_1)	$\tilde{X}_{11}$(weak), $\tilde{X}_{12}$(medium), $\tilde{X}_{13}$(strong)
Initial priority (x_2)	$\tilde{X}_{21}$(low), $\tilde{X}_{22}$(medium), $\tilde{X}_{23}$(high)
Radar task priority (y)	$\tilde{G}^1$(low), $\tilde{G}^2$(medium-low), $\tilde{G}^3$(medium), $\tilde{G}^4$(medium-high), $\tilde{G}^5$(high)

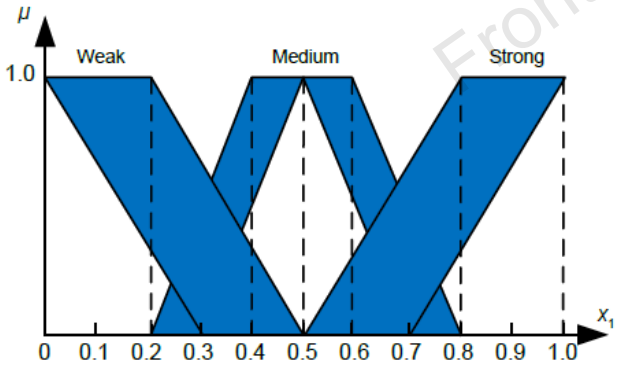

Fig. 8 The FOU of the fuzzy value for target threat degree

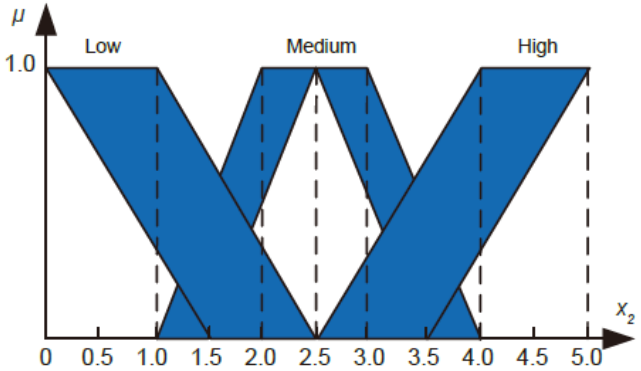

Fig. 9 The FOU of the fuzzy value for initial priority

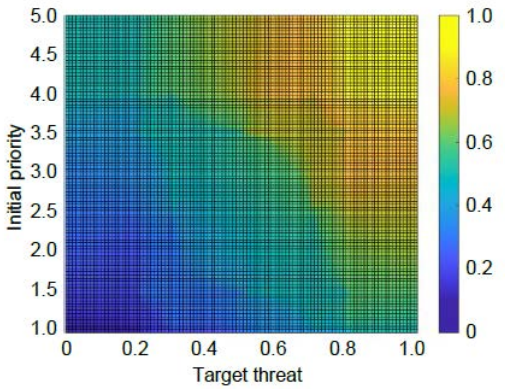

Fig. 10 The crisp output of radar task priority

Method (Cont'd)

3. Taking the hypersonic common aero vehicle (CAV-H) as an example, 100 batches of targets with random initial speeds and initial positions were generated. The trajectories of the partial targets are shown in Fig. 11. Fig. 12 shows the flight speeds of the HGVs. Fig. 13 shows the azimuth difference between the HGVs and the radar. Fig. 14 shows the distance between the HGVs and the radar.

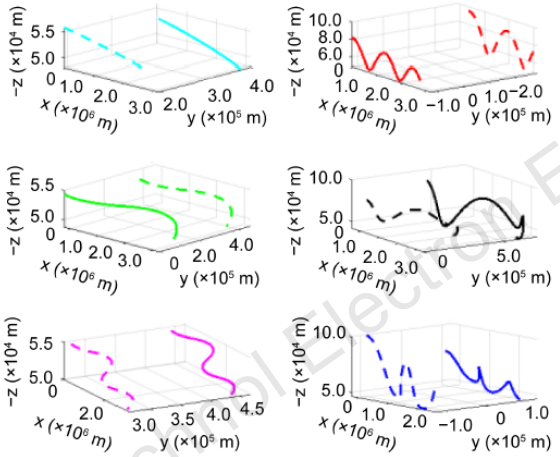

Fig. 11 The ballistic trajectories of the HGVs

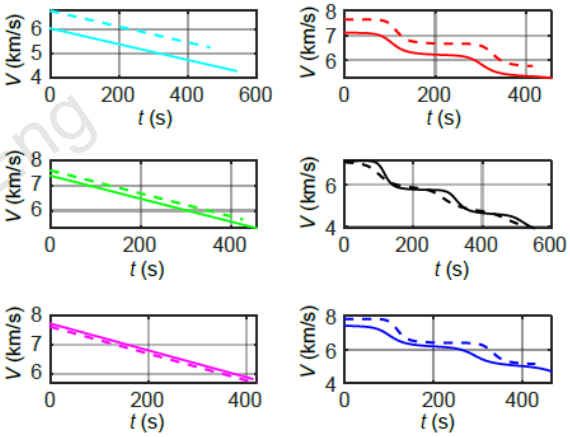

Fig. 12 The flight speeds of the HGVs

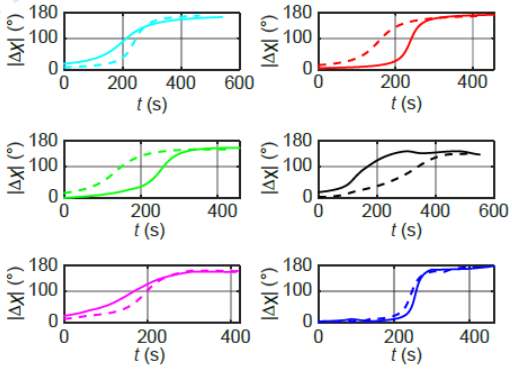

Fig. 13 The azimuth difference between the HGVs and the radar

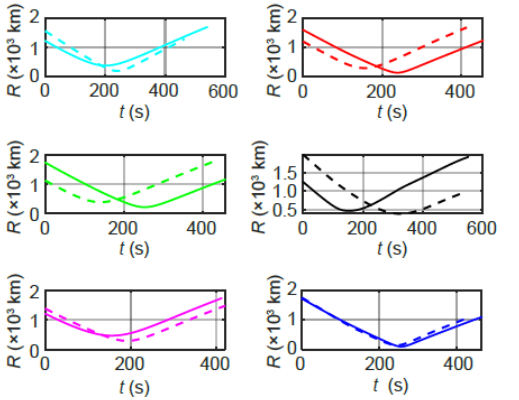

Fig. 14 The distance between the HGVs and the radar

Major results

The priority assignment methods of Lu et al. (2006) and Guo et al. (2013) were selected and marked as method 1 and method 2, respectively, for comparison with our proposed method.

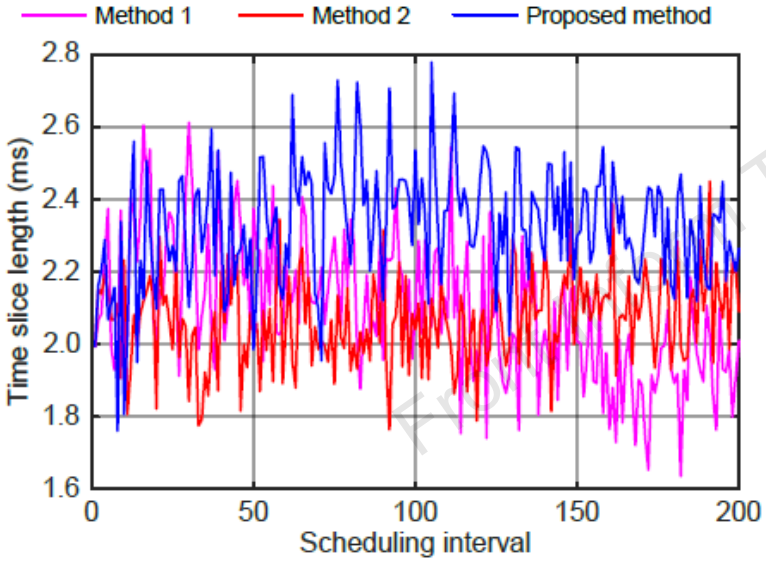

Fig. 21 The length of the remaining time slices in each scheduling interval

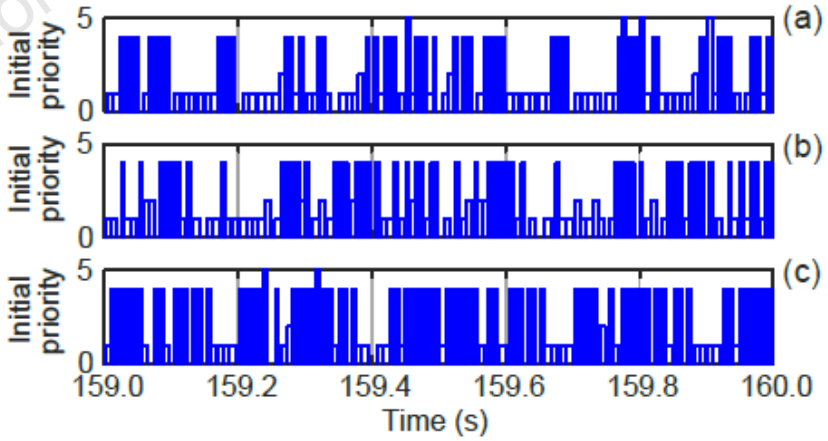

Fig. 22 The task scheduling results of method 1 (a), method 2 (b), and our proposed method (c)

Major results (Cont'd)

Initial priority

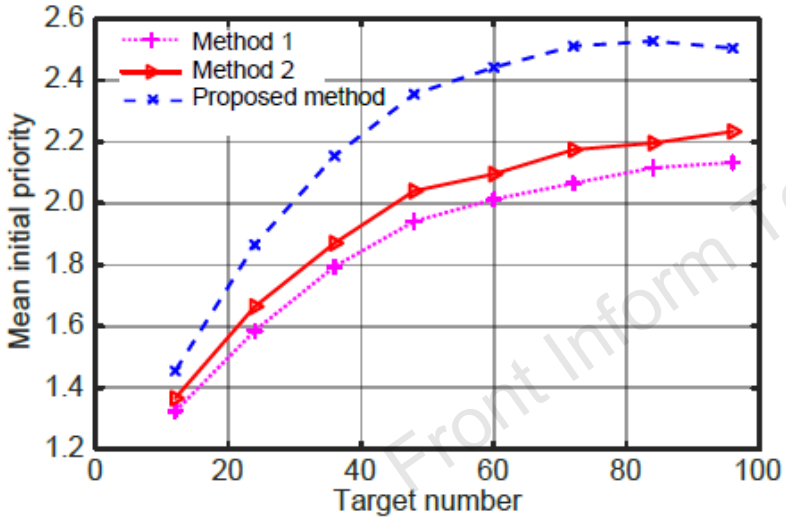

Fig. 23 The mean initial priority of radar tasks in the execution queue

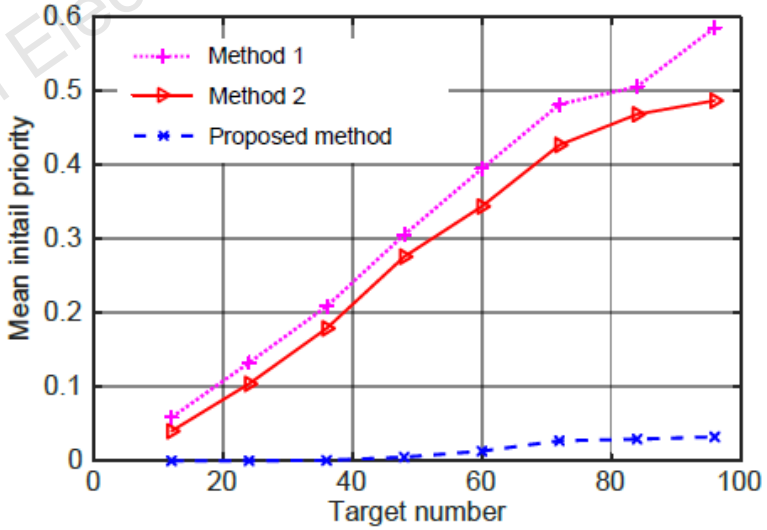

Fig. 24 The mean initial priority of radar tasks in the deleted queue

Major results (Cont'd)

Target threat degree

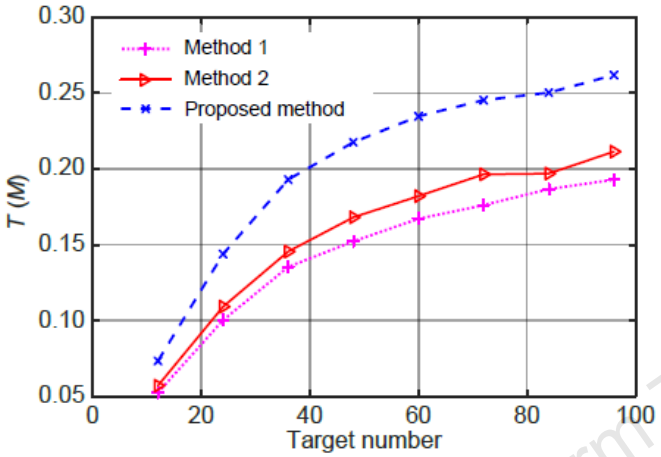

Fig. 25 Maneuver threat of the radar tasks

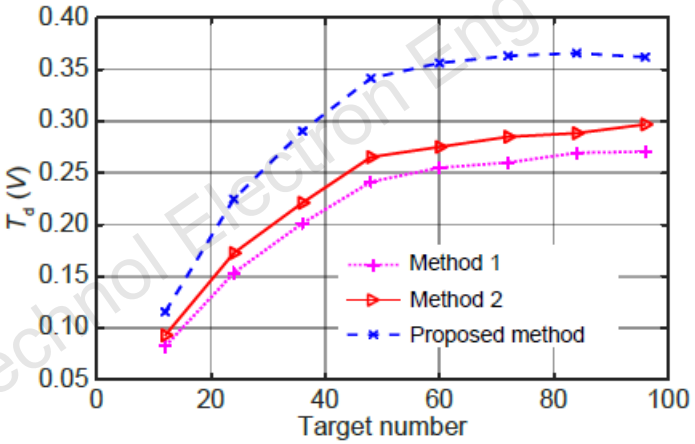

Fig. 26 Speed threat of the radar tasks

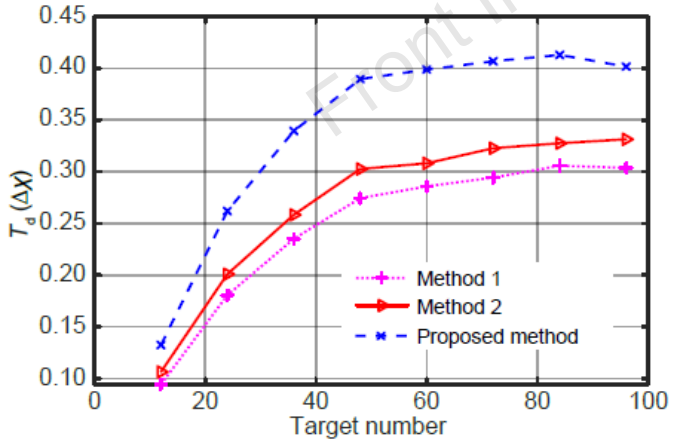

Fig. 27 Azimuth threat of the radar tasks

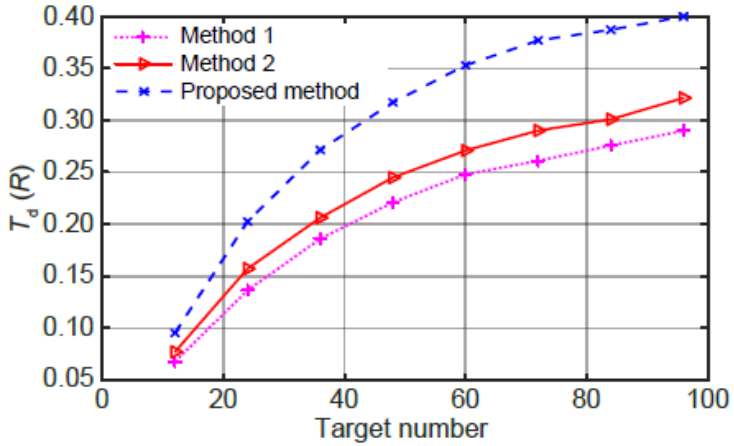

Fig. 28 Distance threat of the radar tasks

Major results (Cont'd)

Search rate and precise tracking rate

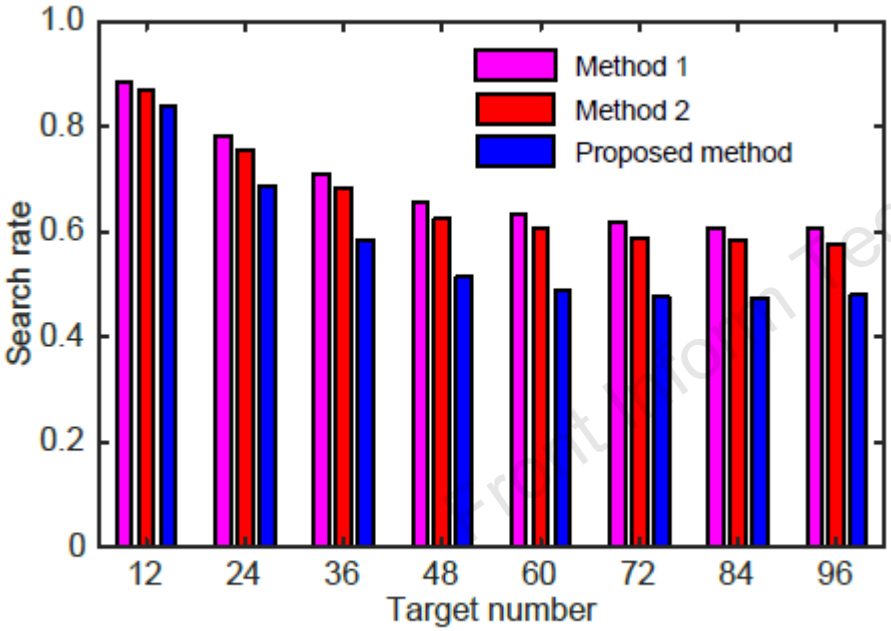

Fig. 29 Search rate of the radar tasks

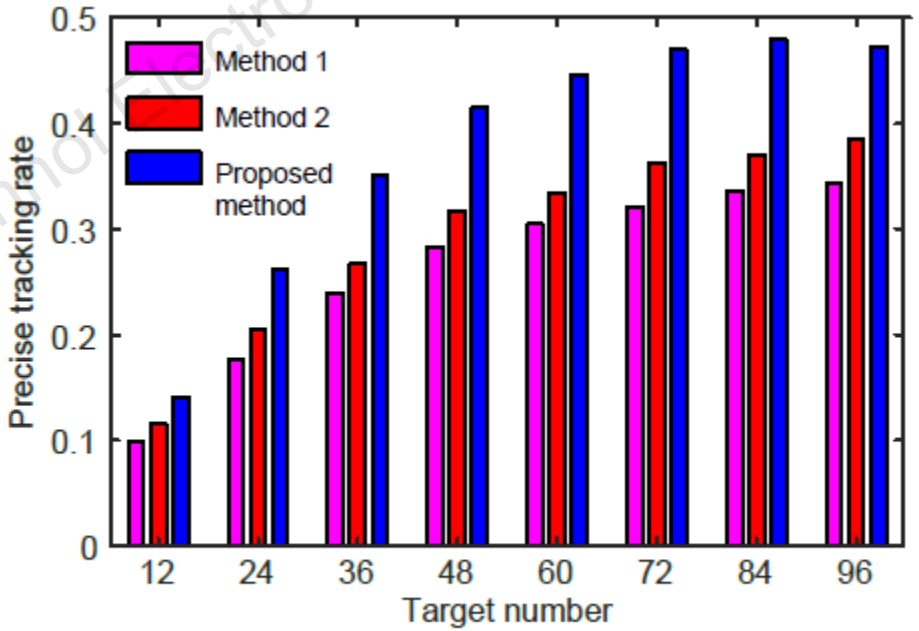

Fig. 30 Precise tracking rate of the radar tasks

Major results (Cont'd)

Offset time and scheduling success rate

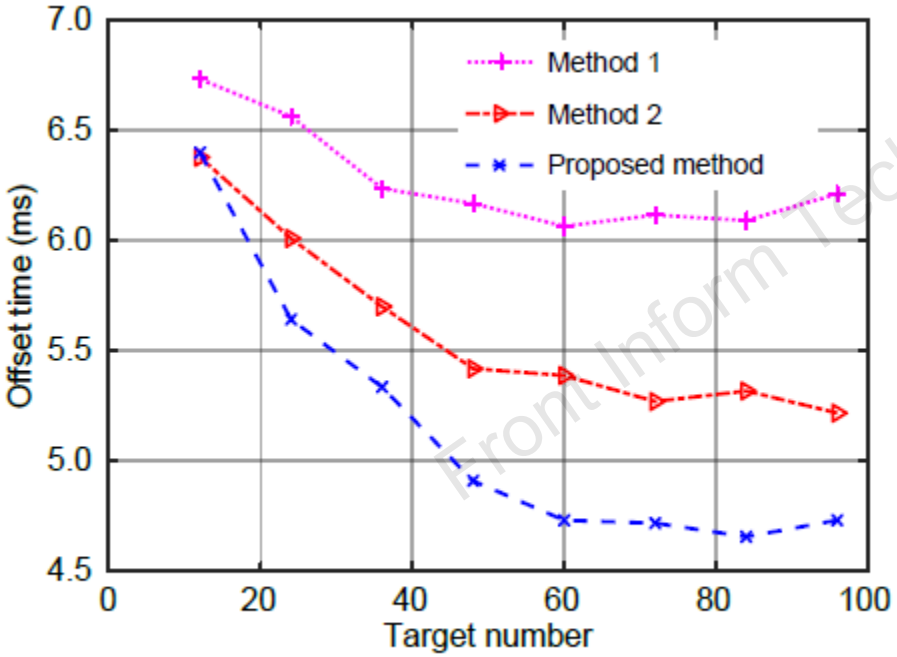

Fig. 31 Offset time of the radar tasks

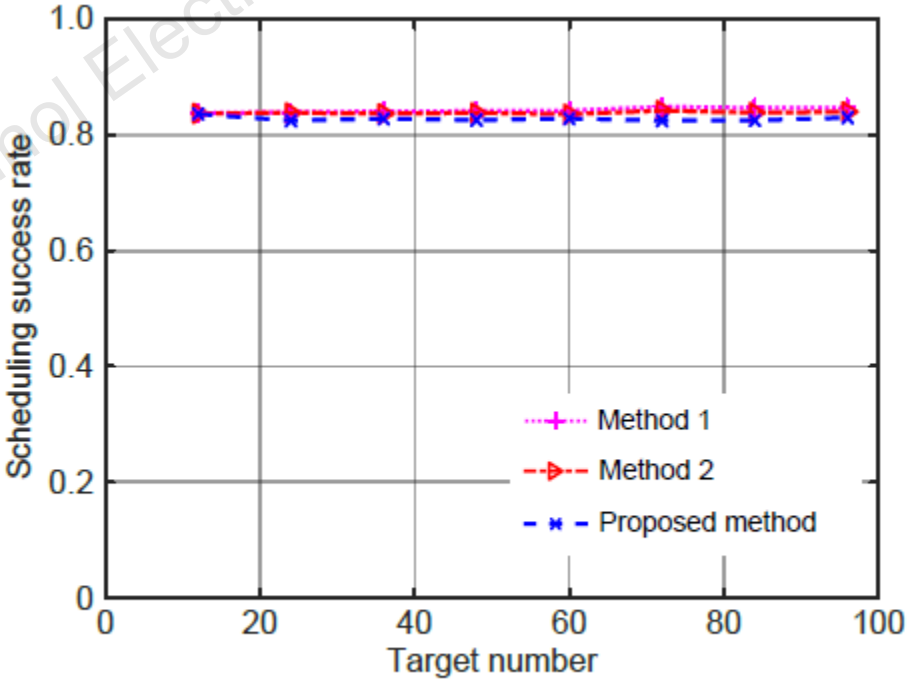

Fig. 32 Scheduling success rate of the radar tasks

Conclusions

1. In this research we designed a task priority assignment method based on IT2FLS with the aim of alleviating the radar resource management problem when ground-based phased-array radar detects HGVs in near space.

2. When the targets were greater than 50 batches, the mean initial priority, target threat degree, and precise tracking rate of our proposed method were significantly higher.

3. While maintaining an equivalent scheduling success rate, the task offset time of our proposed method was significantly lower.