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Decentralized runtime enforcement for robotic swarms

Key words: Runtime enforcement; Multi-level property; *D*-time enforcement; Robotic swarm

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Motivation

1. Robotic swarms are usually designed in a bottom-up way, which can make robotic swarms vulnerable to environmental impact.

2. Securing swarm tasks at runtime is particularly difficult, especially in the cases of external attack, bad environment, partial robot failure, and event/state temporal error.

3. It is difficult to guarantee the safety of agent interaction under the usual control model.

Main idea

1. A macro-micro (two-level) swarm runtime monitoring approach, which observes sequence violations in the overall swarm tasks and single-agent violations under sudden perturbations, is implemented by monitoring hierarchical interfaces that can retrieve the needed states of a swarm.

2. A property enforcement mechanism called *D*-time enforcement is proposed for the continuous-time state changing characteristics of swarms.

3. A monitor specification language is designed that can specify safety properties and enforcement behaviors for robotic swarms with temporal and timed requirements.

Major results

1. Enforce a swarm safety moving task

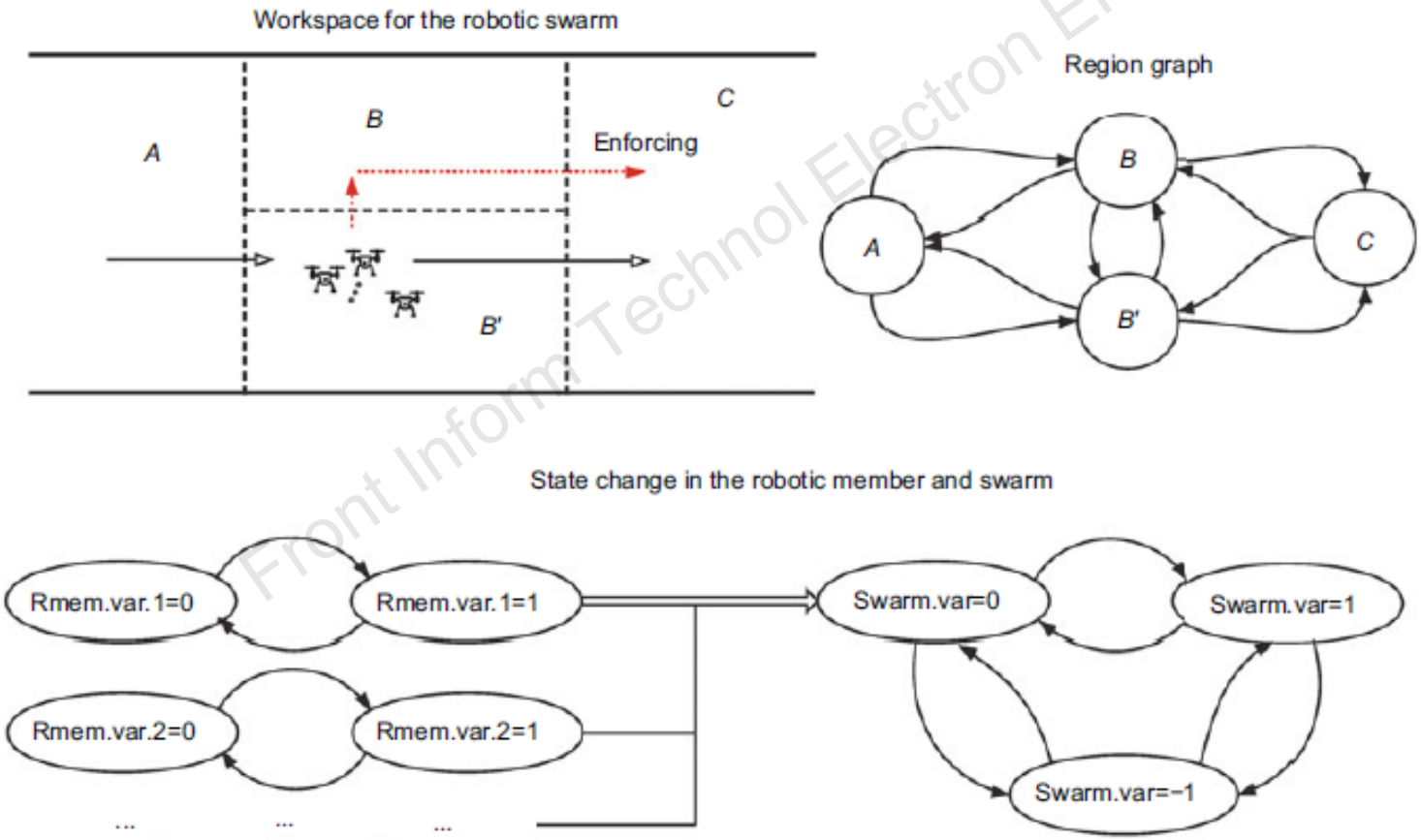


Fig. 2 An illustrative example in the robotic swarm safety moving task

Major results (on robotflocksim)

2. Test results of the collisions with or without our enforcement method

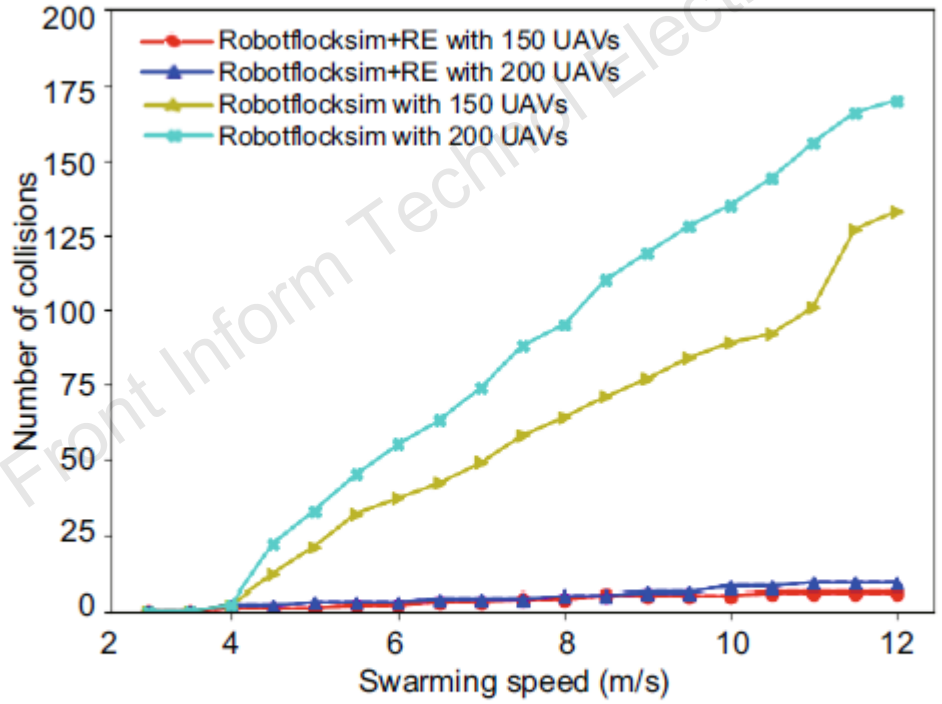


Fig. 9 Number of collisions under different swarming speed conditions and different numbers of UAVs

Major results (on robotflocksim)

3. Test results of overhead on robot task under enforcement methods

Table 1 Runtime enforcement overhead evaluation of the UAV mission properties P1–P4 developed on the robotflocksim simulation tool

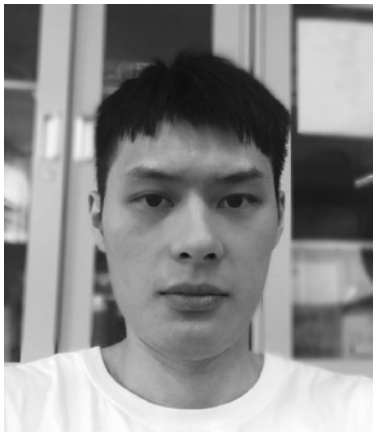
Property	$\|Q\|$	$\|S\|$	Time.Task (s)	Time.Overhead (s)
P1	202	100	240	0.32
P2	202	100	600	0.01
P1+P3	302	112	240	1.05
P1+P4	302	101	240	0.12
P1+P3+P4	402	121	240	1.21

Conclusions

1. Our approach is able to correct mission planning under uncertain external environments and mitigate the collision effect of a swarm.

2. Experimental results showed that our approach is feasible and that the overhead is low.

3. In the future, we will consider the approach of anticipatory active monitoring on robotic systems and generating shields without definite enforcement information.



Chi HU received his BS degree In Computer Science and Technology from the University of Electronic Science and Technology of China (UESTC) in 2010, and his MS degree from the College of Information and Software Engineering from UESTC in 2013. He is a PhD candidate at the National University of Defense Technology and an engineer of the China Academy of Engineering Physics. He has three years of experience in CPS system safety and security evaluation. His research interest is formal method.

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