International Journal of Control and Automation
Vol. 7, No. 12 (2014), pp. 231-238
http://dx.doi.org/10.14257/ijca.2014.7.12.21

Multi-UAV Distributed Cooperative Detection Based on Consensus

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Abstract

This paper presents an analysis method aiming at UAV cooperative detection problem. The UAV detect the target and establish the state information respectively, and send the message to the adjacent friendly aircraft. The friendly aircraft judge if there are repetition between their own information and the message they have received after they receive the message, and re-order the target till the state information of all UAV are same and complete the mission of multi-UAV distributed cooperative detection. The simulation shows that the algorithm presented in this paper could accomplish the cooperative detection mission effective and reasonable.

Keywords: *Consensus, Cooperative Detection, Distributed Count*

1. Introduction

The one of main development direction of modern high-tech combat is multi-UAV cooperative air combat. Discovery before enemy is the primary part of cooperative air combat and the key issues to obtain the initiative in air combat, it is also the basis of the cooperative task allocation [1-5]. Multi-UAV cooperative detection with the better performance than a single UAV could expand the search scope of UAVs, and improve the reliability and accuracy of the information [6]. But there is litter literature about multi UAV cooperative detection reported at present, and most of the literature studied the probability of cooperative detection and the model of assign the detection missions [7]. Such as documents [8-9] introduced the problem of cooperative detection for Unmanned Underwater Vehicle (UUVs), document [1] analyzed the probability of cooperative detection and the geometrical method of cooperative detection for three UUVs, then the model of UAV formation cooperative search under the conduct of the early warning aircraft (AEW) is given in the paper. A model of cooperative search is established based the performance of the airborne radar and the geometry situation of the air combat in document [10].

Scholar domestic and overseas have pay high attention to the problem of consensus [11-12], and put the consensus theory into practical application widely in recent years. Fuxiao Tan and Xinping Guan established a first-order mathematical model for network system counter multi-agent system and propose the rule for consensus convergence for multi-agent network system in document [13]. Long Wang and Guangming Xie present a numerical simulation results for the complex action of aggregation-oscillation for the system in case of asymmetric coupling and delay in document [14]. Jun Zhen present a distributed algorithm with discrete form based on center-based nearest neighbor method, and its global stability was verified in document [15]. A model for multi-robot formation control is discussed in Literature [16] accomplished by Zhengping Wang and Zhihong Guan. HuiYu and Yongyi Wang had considered the consensus question of weighted directed network comprised by multi-agent,

ISSN: 2005-4297 IJCA

however it is only for first-order system certainly not with second order or high order consensus question [17]. Peng Lin and Yingming Jia researched the average consensus problem of second order system composed by multi-agent and definition of the P the average consensus problem and VP the average consensus problem of second-order multi-agent network respectively, and a solution agreement was put forward in Literature [18].

Currently the research for multi-UAV cooperative detection mainly on the probability of cooperative detection and the model of assign the detection missions has not given the method for multi-UAV cooperative detection. Arithmetic for multi-UAV cooperative detection is proposed based on consensus in this paper. The UAV built the status information of the target after explore it, and send the message to neighbors friendly aircraft. The receive UAV judge the target repetition or not after receive the message, and count and sort the targets again, until all UAVs carry the same information, and accomplish the detection missions.

2. Distributed Cooperative Detection

It is assumed that there are n UAVs marked for $R=\{R_1,R_2,\cdots,R_n\}$ detecting somewhere, and the radar detection range of UAV R_i is $D_{R\max i}$, namely could detects the target in the circle that the original point is its own and the radius is $D_{R\max i}$.

There are 6 status information of the target that each UAV detected included:

(1) Coordinate information $O_{ij}(t)=(x_{ij}(t),y_{ij}(t),z_{ij}(t))$, express the coordinate of target B_j that UAV R_i had detected at time t.

(2) Speed information $v_{ij}(t)$, express the speed of target B_j that UAV R_i had detected at time t.

(3) Property of target N_{ij}, express the nature of target B_j that UAV R_i had detected such as early warning airplane, helicopter, missile and so on.

(4) Temporal information s_{ij}, express the time that UAV R_i had detected target B_j.

(5)Target number m_i, express how many targets that UAV R_i had.

(6)Target label n_{ij}, express the label of target B_j given by UAV R_i, and will be not more than m_i.

If UAV R_i detected m_i targets in the aggregate, the status information are established as:

$X_i(t)=\left(X_{i1}^T(t),X_{i2}^T(t),\cdots,X_{im_i}^T(t)\right)$, where $X_{ij}^T(t)=\{O_{ij}(t),v_{ij}(t),N_{ij},s_{ij},n_{ij},m_i\}$. The system reach agreement when all status information of UAVs verge to identical, immediate $\|X_i(t)-X_k(t)\|\to 0$,then the detection missions is finished, the consensus model of the system is as following

$$X_i(t)-X_k(t)=\mathbf{O} \tag{1}$$

The error exists in the information that each UAV detects on account of the complex environmental, sensor sensitivity, communication time delay and so on. So the model is definite as following:

$$\begin{cases} x_{ij}(t) - x_{kj}(t) < \varepsilon_x \\ y_{ij}(t) - y_{kj}(t) < \varepsilon_y \\ z_{ij}(t) - z_{kj}(t) < \varepsilon_z \\ v_{ij}(t) - v_{kj}(t) < \varepsilon_v \\ N_{ij} - N_{kj} = 0 \\ s_{ij} - s_{kj} = 0 \\ n_{ij} - n_{kj} = 0 \\ m_i - m_k = 0 \end{cases} \tag{2}$$

Where ε_x , ε_y , ε_z and ε_v are the permissible error of location information velocity information of the same target that detected by different UAV, whereas the property of target, timestamp target label and the target number must be same, multi-UAV system achieve consensus state.

3. Method of Cooperative Detection for Multi-UAV based on Consensus

The system is comprise by n UAVs, and it communication network topology is $G = (V, E)$, where $V = \{1, 2, \cdots, n\}$ is *a* non-null set of the node which stand for a UAV, $E \subseteq V \times V$ is the set of edges which stand for the communication network, adjacency matrix of the topology is $G(t) = [g_{ik}(t)]$, if UAV R_i and UAV R_k could contact to each other, then $g_{ik}(t) = 1$, otherwise, $g_{ik}(t) = 0$, the Laplace matrix L of the topology is $L = [l_{ik}]$,and

$$l_{ik} = \begin{cases} \sum_k a_{ik}, & i = k \\ -a_{ik}, & i \neq k \end{cases} \tag{3}$$

UAV R_i sends the information to friendly aircraft after it detected the target j . The aircraft after judge if there is conflict among the targets and re-order them. It is assumed that the airborne radar of UAV R_i would detect and trace the target real time, the fatter discover the target.

Assuming that UAV R_i sent the information of the target j that have detected to the partner R_k , R_k compare information j with its original information q , if the following conditions are met:

$$\begin{cases} |x_{ij}(t) - x_{kj}(t)| < \varepsilon_x \\ |y_{ij}(t) - y_{kj}(t)| < \varepsilon_y \\ |z_{ij}(t) - z_{kj}(t)| < \varepsilon_z \\ |v_{ij}(t) - v_{kq}(t)| < \varepsilon_v \\ N_{ij} - N_{kq} = 0 \end{cases} \tag{4}$$

The target q and the target j are judged same if their coordinate and seep are within a certain error range and with the same character, otherwise they are different targets. Whether the target q and the target j are the same or not, the UAV R_k need re-order the target after it receives the information sent by UAV R_i. If the target q and the received target j detected by UAV R_k are the same, then compare their timestamp. If $s_{ij} < s_{kq}$, so

$$s_{kq} = s_{ij} \tag{5}$$

If timestamp satisfied $s_{kq} = s_{ij}$, then the priority of the UAV compared. Then targets are re-ordered based on the timestamp. If the target q detected by UAV R_k is not the same as the target j recipient, then add the target j to the detection list.

$$\begin{cases} m_k = m_k + 1 \\ O_{kq}(t) = O_{ij}(t) \\ v_{kq}(t) = v_{ij}(t) \\ s_{kq} = s_{ij} \end{cases} \tag{6}$$

The targets are re-ordered based on the timestamp, and the reset the new serial number. The UAVs transitional information to each other till the information state of the UAV are all the same, then accomplished the cooperative detection missions.

4. Simulation

Consider three drones on a particular area of detection, notes for UAVs $R_1 \sim R_3$. The maximum search range is $D_{R\max} = 200km$. Assumes that the UAV would be able to detect the maximum search range targets. Assumes that 3 drones detected 3, 5, 3 target respectively. The detected target information is shown in Table 1.

Table 1. Detection Results of all UAVs

	Target label n_{ij}	Target coordinate $O_{ij}(km)$	Target speed $V_{ij}(m/s)$	Timestamp $s_{ij}(s)$
U1	1	(0.37,65.29, 73.56)	320	3
	2	(20.56,80.21,50.59)	320	8
	3	(38.02,48.97,85.54)	310	14
U2	1	(37.99,49.01,85.51)	310	2
	2	(20.56,80.21,50.61)	320	6
	3	(69.47,92.08,40.28)	325	15
	4	(72.51,80.25,90.94)	315	21
	5	(84.56,68.73,71.84)	320	30
U3	1	(84.59,68.70,71.90)	320	5
	2	(91.11,92.25,50.38)	310	11

3	(95.59,86.15,74.16)	325	19

The algorithm proposed in this paper is simulated for the problem. Due to different detection of UAV on the same target information, Assumes that the UAV to detect the error of the location is $\varepsilon_x = \varepsilon_y = \varepsilon_z = 0.05km$, the error of speed is $\varepsilon_v = 5m/s$. The results are as shown in Table 2 ~ 4.

Table 2. Detection Results of UAV1

Target label n_{ij}	Target coordinate $O_{ij}(km)$	Target speed $V_{ij}(m/s)$	Timestamp $s_{ij}(s)$
1	(38.02,48.97,85.54)	310	2
2	(0.37, 65.29,73.56)	320	3
3	(20.56, 80.21, 50.59)	320	6
4	(84.59, 68.70, 71.90)	320	5
5	(91.11, 92.25, 50.38)	310	11
6	(69.47, 92.08, 40.28)	325	15
7	(95.59, 86.15, 74.16)	325	19
8	(72.51, 80.25, 90.94)	315	21

Table 3. Detection Results of UAV2

Target label n_{ij}	Target coordinate $O_{ij}(km)$	Target speed $V_{ij}(m/s)$	Timestamp $s_{ij}(s)$
1	(37.99,49.01,85.51)	310	2
2	(0.37, 65.29, 73.56)	320	3
3	(20.56, 80.21,50.61)	320	8
4	(84.56, 68.73, 71.84)	320	5
5	(91.11, 92.25, 50.38)	310	11
6	(69.47, 92.08, 40.28)	325	15
7	(95.59, 86.15, 74.16)	325	10
8	(72.51, 80.25, 90.94)	315	21

Table 4. Detection Results of UAV3

Target label n_{ij}	Target coordinate $O_{ij}\left(km\right)$	Target speed $V_{ij}\left(m/s\right)$	Timestamp $s_{ij}\left(s\right)$
1	(37.99,49.01,85.51)	310	2
2	(0.37, 65.29, 73.56)	320	3
3	(20.56, 80.21, 50.59)	320	8
4	(84.59, 68.70, 71.90)	320	5
5	(91.11, 92.25, 50.38)	310	11
6	(69.47, 92.08, 40.28)	325	15
7	(95.59, 86.15, 74.16)	325	19
8	(72.51, 80.25, 90.94)	315	21

Three drones detect a total of eight goals through the simulation result. Where target 2 and 3 detected by UAV R_1 are as same as target 2 and 1 detected by UAV R_2; target 5 detected by UAV R_2 is as same as target 1 detected by UAV R_3. The simulation results show that this algorithm can eliminate the repetition of target information between UAV, implement cooperative detection between multi-UAV effectively.

5. Conclusion

This paper presents a distributed collaborative detection method using the consistency principle. The UAV establishes the state information of the target detected by UAV after the UAV detects a target, and sends this information to the adjacent friendly aircraft. Friendly aircraft judge the target if there is a repeated or not after they receives the target information, then count and sort anew, until all the UAV have the same target information, perform multi-UAV collaborative detection task. But, due to the limit of UAV airborne equipment, and the problem of target stealth performance and environmental factors, we should consider that the probability of UAV was detected. The mathematical model of distributed collaborative detection needs further improvement. At the same time, in air combat, the number of UAVs is more, or UAV is close formation, distributed detection method proposed in this paper could detect the error results. Further studies are needed in this area.

Acknowledgements

The research work reported in this paper is supported by the National Natural Science Foundation of China (61074159),and thanks to the researchers for the suggestions, research samples and experimental data.

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