Distributed Situation Awareness for Multi-agent Mission in Dynamic Environments: A Case Study of Multi-UAVs Wildfires Searching

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Abstract

This thesis focuses attention on achieving Distributed Situation Awareness (DSA) with minimal resources (energy, processing cost, etc.) using small low-capacity agents (e.g., UAVs) coordinated in a decentralised fashion while conducting searching activity. This is in contrast to the existing works involving convoluted communication and information processing.

Introduction

The challenges of coordinating the activity of multiple Unmanned Aerial Vehicles (UAV) rely on a combination of robust communications and sophisticated processing of sensor data to maintain Situation Awareness. The focus of this research project is on the question of *How can we achieve an effective Situation Awareness with minimal resources for decentralised heterogeneous multi-agent searching mission?* The thesis main objectives are: (a) finding agents effective path planning strategies that optimise resources and support easy Distributed Situation Awareness (DSA) achievement in decentralised multi-agent searching activity (b) achieving more accurate information interpretation and prediction (DSA) for dynamic systems using heterogeneous agents.

In order to address these problems, this research is developing two lines of enquiry. The first concerns the implementation of a path-planning algorithm that ensures UAVs are able to navigate complex search spaces without performing complex calculations. I call the resulting algorithm Delaunay-Inspired and have demonstrated that it has similar coverage to search patterns used in Search and Rescue, as well as Levy-Flight or Delaunay search algorithms but at a fraction of the processing cost. This means that it could be implemented on small, disposable UAVs which might have limited payload, power or processing capacities.

The second concerns the collation of sensor data from these UAVs to create and maintain a detailed picture of a dynamic situation. This second line of enquiry is inspired by the concept of DSA developed by Stanton et al. (2006). Building on other theories of Situation Awareness (such as Endsley, 1995), DSA proposes that agents in multi-agent systems (whether these are human, UAVs or other intelligent entities) will only have a partial view of the situation (due to their location, sensor data, and knowledge). The implication is that 'situation awareness' need not reside in all agents in a system but comes from the combination of views. In order to draw together these views, one can either create a communications network in which all agents share and update each others' views, or assume that collation of information occurs in a scheduled and structured manner. For this latter, one might assume that reporting (from UAVs) would not be continuous, that not all UAVs will need to know (nor be able to process) the views of other UAVs, and there needs to be an ability to 'fill in the gaps' to create a detailed situation picture. This latter will involve the ability to combine the different views and to make predictions of likely changes to the situation picture. From this perspective, maintaining the situation picture involves the management of uncertainty, with tasking of UAVs to check aspects which have higher uncertainty in their prediction. The situation picture thus becomes both the product of the information gathering activity and the basis on which Situation Awareness (which involves the definition of the current state of the situation and the prediction of likely future states) is built and used for planning a mission.

Achieving DSA remains very difficult, especially in large systems (Baek and Lim, 2018;Bouvry et al., 2016; Endsley, 1995). The difficulty depends on a set of constraints imposed on the agents and their capacities. For instance, we took a multi-UAVs mission for responding to forest fire as our use case. The UAVs are to search for fire, roads, water, buildings etc., depending on their sensors (with no communication) in a decentralised fashion and report back their mission data to a various central server for analysis. This means the mission plan needs to utilise the UAV resources and achieve DSA in a decentralised fashion, e.g., ensuring minimal redundancy in search with maximised coverage and within the power and sensor constraints of the UAVs. Extending SA to a distributed agents with limited resources (computational capacity, memory, energy, communication range, etc.) and within dynamic environments has received limited attention (Baek and Lim, 2018; Bouvry et al., 2016).

The use case is implemented on the Aerospace Multi-agent Simulation Environment[1] (AMASE). The environ-

[1](https://github.com/afrl-rq/OpenAMASE, 2019)

mental variables (e.g., wind speed, wind direction, etc) and information heterogeneity, therefore, makes data validity dynamic which increases the challenge of maintaining Situation Awareness, and could impair coordination of decentralised agents.

Progress Report

To date, the project has implemented policies that implicitly coordinate the agents' behaviours cooperatively. Because of the inter-agent communication constraint, the agents' plan for achieving the joint goal depends on the policies governing the agents' actions. Additionally, the path planning strategy needs to be simple to utilise agents resources (e.g., by avoiding repetitive search and maximising coverage) and supports agents activities prediction for a better Situation Awareness.

Knowledge aggregation is implemented through the fusion of data from the various UAVs with knowledge held by the server, using Bayesian reasoning and learning. The focus is on achieving effective DSA with the minimal resources possible.The following contributions have been made so far:

- resource consumption performance comparison of different search patterns used in multi-agent searching activity (Yusuf and Baber, 2020a). The paper won the best paper award of the international conference on multi-agent systems and robotics (ICMASR), London 2020.
- a novel pseudo-flexible (pseudo-random) search pattern by inspiring the Delaunay triangulation process which exhibits the best features of flexible (e.g., naturally inspired strategies) and fixed pattern approaches.
- an architecture for resolving heterogeneous agents' sensor conflicts based on the environmental situation(Yusuf and Baber, 2020c).
- the application of Bayesian reasoning and learning to achieve DSA for multi-agent searching mission(Yusuf and Baber, 2020b, 2020d). For example, Bayesian Belief Network (BBN) was used for knowledge representation, and conjugate gradient descent (CGD) and expectation-maximisation (EM) algorithms were used for prediction and uncertainty handling, as well as knowledge reusability among similar environment.
- modelling agents' resource utilisation as Distributed Constraint Optimisation Problem (DCOP) and shows how it can be coupled with DSA in (Yusuf and Baber, 2020d). This is a new application of Bayesian learning and reasoning to DCOP and results show better prediction, knowledge presentation, and uncertainties handling. The use of the BBN for knowledge representation gives a more robust and probabilistic approach than the earlier propositional network approach in (Stanton et al., 2006). The ongoing work is looking deeply on the effective Bayesian learning process that will reduce the situation prediction error rate and allow a comprehensive information presentation using ontology and BBN, it will be achieved hopefully before February 2021. Ensemble styles, dynamic BBN and ontology, and Gaussian process will be used during nearly events predictions perfection and environment adaptation.The BBN and ontologies are expected to propose techniques that eases current situation understanding and information passing among agents.

The project will also develop theories on the proposed Delaunay-Inspired path planning algorithm and combined proposed approaches integration and evaluation on the designated use case.

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