

Distributed Automatic Target Recognition Using Multi-agent UAV Swarms

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ABSTRACT

In modern day warfare, reconnaissance operations such as automatic target recognition(ATR) using unmanned aerial vehicles(UAVs) constitute a strategic war tactic. Traditionally, ATR is performed by UAVs that fly within the reconnaissance area to collect image data through sensors and upload the data to a central base station for analyzing and identifying potential targets. The centralized approach to ATR introduces several problems including scalability with the number of UAVs, network delays in communicating with the central location, and, susceptibility of the system to malicious attacks on the central location. These challenges can be addressed using a distributed system for performing ATR. In this paper, we describe a multi-agent system called COMSTAR-UAV (COoperative Multi-agent System for automatic TARget Recognition using Unmanned Aerial Vehicles) that uses swarming techniques inspired from insect colonies to perform ATR in a distributed manner.

Categories and Subject Descriptors: I.2.11 Distributed Artificial Intelligence: Multi-agent Systems

General Terms: Experimentation.

Keywords: Collective and Emergent Behavior, Simulation and Modeling, Distributed automatic target recognition.

1. INTRODUCTION

Automatic target recognition (ATR) involves determining the visual and other distinguishing features of an object, usually from a distance, and using this signature to automatically identify the object as a potential target. Traditionally this is achieved using unmanned aerial vehicles(UAVs) that obtain image data through their sensors from objects within a reconnaissance area and uploaded the data to a central location such as a base station, where potential targets are identified using image analysis algorithms [2, 4, 6]. However, this centralized model for ATR introduces several problems such as scalability and network delays in communication with the central location.

With the advancement of technology, the computation power of processors on UAVs has improved significantly and mini-UAVs can perform moderate computation beyond the trivial image data acquisition. However, the processors on UAVs are still not sophisticated

enough to perform image identification solitarily on-board the UAV itself. We envisage that swarming[1, 3] provides a suitable mechanism to assimilate the capabilities of individual UAVs into a group of coordinating UAVs that perform ATR in a distributed manner. In a swarmed system, multiple mobile entities are directed to converge on a single point of interest, disperse and regroup again. To achieve distributed ATR using swarming, each UAV individually searches for potential targets within an area of interest using its image sensor. As soon as the image of an object is sensed to be a possible target by a UAV, other UAVs cooperate with it by swarming towards the potential target to collectively perform ATR and confirm the object as a target. In contrast to a centralized model for ATR, a distributed ATR model can: (1) scale up efficiently in the number of UAVs deployed and in the amount of data collected and processed for ATR, (2) improve the efficiency of the system because most computation is done locally within each UAV, which in turn reduces the time required to upload every image data from different UAVs onto the central location, and, (3) reduce the communication between the central location and individual UAVs so that the system is less susceptible to loss of data and failures due to wireless communication problems between an individual UAV and the central location. In this paper, we describe a multi-agent system called COMSTAR(Co-Operative Multi-agent Swarm for automatic TARget Recognition) that enables a group of UAVs deployed within a reconnaissance area to behave collectively as a swarm and perform ATR in a distributed manner.

Our swarming mechanism for ATR is based on the *stigmergetic* activity of social insects such as ants [1] to locate food. Stigmergy is a reinforcement learning mechanism that enables ants to indirectly communicate with each other about their environment using a chemical substance called pheromone. For example, while searching for food ants start from their nest and leave behind a pheromone trail along the path they traverse. The path leading from the nest to the food receives the highest amount of pheromone. Pheromone provides positive reinforcement to future ants, and, ants searching for the food later on use the trail as a positive reinforcement to reach the location of the food. To enable the ant algorithm in our system, we use pheromone to indicate potential targets while ants are implemented through software agents located within the computers on the UAVs. Software agents are characterized by a small footprint (few kilobytes) and are suitable for execution on computers within UAVs with limited computation power.

2. UAV OPERATION

We consider a battlefield scenario where UAVs are deployed from the base station into the area of interest(AOI). The AOI is logically divided into smaller sub-areas and a group of UAVs is deployed by the base station into each of these *home-areas*. We

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assume that each UAV is provided with the following equipment to enable it to perform ATR: (1) Wireless communication capability for sending and receiving messages from other UAVs and the base station. (2) One or more image sensors capable of capturing snapshots of the area over which the UAV flies. (3) Processor with limited computing capability. (4) Rudimentary image processing software that enables the UAV to identify objects obtained by its image sensors as potential targets. (5) A global positioning system (GPS) that returns the 3-d coordinates (latitude, longitude, altitude) of the UAV's current location. Because of limited computational resources available on a single UAV, we assume that for definite target identification, $(n - 1)$ other UAVs need to visit the location of a potential target reported by a single UAV to observe and confirm it as a definitive target.

After being deployed within its home-area, each UAV uses a deterministic foraging algorithm to navigate within its home area while searching for potential targets. When a UAV locates a potential target it associates a particular amount of pheromone with the target. Each UAV continuously exchanges information about targets it is aware of with other UAVs within its communication range using a gossip mechanism. The local map for potential targets that a UAV is aware of is maintained within it on a *pheromone landscape*. A UAV's task is to plan a navigation route by prioritizing the points on its pheromone landscape. The individual behavior of each UAV results in the movement of multiple UAVs towards the most prominent unconfirmed potential target in their vicinity, thereby manifesting the swarming behavior of the system. Because the computations on a UAV are performed by the agent located on it, we have used the terms agent and UAV interchangeably in the rest of the paper.

3. MODEL

We consider a set of $\mathcal{A}$ agents. Each agent $i \in \mathcal{A}$ maintains two sets: Ψ_i : Pheromone landscape of agent i comprising the set of potential targets agent i received through gossip or discovered through its sensors, and, Γ_i : set of tasks corresponding to the targets agent i is aware of. Each point $\psi \in \Psi_i$ corresponds to a potential target and is defined as $\psi = \{pher, loc, hops, time, vel, bearing\}$, where $pher \in [0, 1]$ is the amount of pheromone associated with the potential target, $loc \in L \subset \mathbb{R}^3$ is the location of the potential target in 3-d coordinates (latitude, longitude, altitude) obtained through the UAV's GPS, $hops$ is the number of agents that have forwarded the pheromone point ψ using the gossip mechanism before it reached agent i , and $time$ is the time at which this pheromone was last updated. The parameters vel and $bearing$ are used for mobile target tracking. In our system, time is measured in logical units called *ticks*. Every entity receives the current time measured in ticks from a globally available clock in the COMSTAR simulator. The availability of globally available clock avoids synchronization problems between different UAVs. Each task $\gamma \in \Gamma_i$ corresponds to a pheromone-point on the pheromone landscape Ψ_i of agent i and is defined as $\gamma = \{\psi, prio, status\}$ where $\psi \in \Psi_i$ is the pheromone corresponding to the task, $prio \in [0, 1]$ is the priority of task γ , and, $status = \{Potential, Definite\}$ gives the identification status of the target. The priority of each task $\gamma \in \Gamma_i$ is recalculated every time the pheromone landscape of agent i gets updated. An agent's set of actions is given by: (i) *Navigate* to the location of the highest priority task within its task set, (ii) *Gossip* pheromone values that it is aware of, and, (iii) *Forage* deterministically to explore the AOI when the task set is empty.

Deterministic Foraging: When an agent is not swarming towards a pheromone point, it uses the deterministic foraging algorithm to navigate itself while avoiding flight-path conflicts with

other agents. The deterministic foraging algorithm divides the immediate vicinity of an agent into sectors and then selects the least dense sector to move to. This ensures that each agent moves in a direction away from its neighboring areas that have higher concentration of agents.

Pheromone Landscape Update: The pheromone update equation used by agent i for pheromone point ψ is given by:

$$\begin{aligned} \psi.pher &\leftarrow \lambda\psi.pher + (1 - \lambda)(w_1s + w_2c) \\ \psi.time &= currentTime; \\ \psi.loc &= currentLocation, \end{aligned} \quad (1)$$

Parameters $s \in \mathbb{R}$ and $c \in \mathbb{R}$ in Equation 2 represent the severity of the potential target and the confidence in identifying the image from the sensor as a potential target. Weights w_1 and w_2 represent agent i 's belief in the parameters s and c , while the parameter λ controls the preference between agent i 's own perception and other agents' perception (pheromone value) of the potential target. The pheromone decay equation used by agent i is given by:

$$\begin{aligned} \epsilon &= currentTime + time\ to\ reach\ \psi.loc - \psi.time, \\ \psi.pher &\leftarrow \psi.pher.e^{-\beta\epsilon} \end{aligned} \quad (2)$$

where β is a control parameter, and, ϵ gives the time required by a UAV to reach the location $\psi.loc$ corresponding to pheromone point ψ that was last updated at $\psi.time$.

Gossip mechanism: Each agent employs a gossip mechanism[5] to exchange pheromone information with other agents. To set up a communication channel with other agents for sending the pheromone information, an agent broadcasts a *ping* message at regular intervals. Other agents that are within communication range of the agent originating the ping message respond with a *ping-ack* message that sets up the wireless communication channel. To disseminate gossip information across the system, each agent forwards gossip information it receives using a controlled flooding mechanism.

Task Prioritization: We consider two task prioritization strategies: **(1) Myopic Strategy:** For a myopic agent, the priority of its tasks is determined from the pheromone value of a point on its pheromone landscape perceived by itself only. The priority function of a myopic agent gives a higher preference to pheromone points that are significantly prominent than the agent's current destination, or, are en-route to the agent's current destination. **(2) Look-Ahead Strategy:** In the lookahead strategy, before prioritizing a new task, an agent takes into account the intention of other agents to perform that task. If the agent discovers that $(n - 1)$ other agents (n agents are required to confirm a target) are already performing or planning to perform the task, it continues with its current mission and does not consider the new task for prioritization.

Mobile Target-Tracking With Anti-Pheromone: In our mobile target identification algorithm, the most recently observed location of a mobile target is marked with pheromone as before while the previous locations of the target are marked with anti-pheromone. Unlike pheromone, anti-pheromone provides negative reinforcement and prevents an agent from visiting the point marked with anti-pheromone on its pheromone landscape. Our anti-pheromone based target tracking mechanism directs the UAV swarm towards the estimated location of a mobile target based on the target's most recently observed location and dynamics, and, is capable of tracking targets that are both continuously and intermittently mobile.

4. SIMULATION RESULTS

For all our experiments we have considered the time (measured in no. of ticks) required to confirm all targets within an AOI as

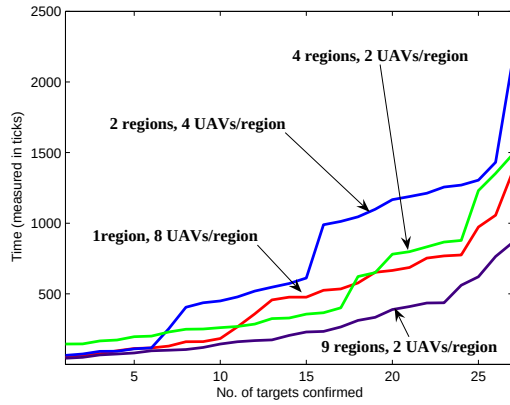


Figure 1: Time required to confirm targets in an AOI for different number of home-areas(regions) into which the AOI is sub-divided.

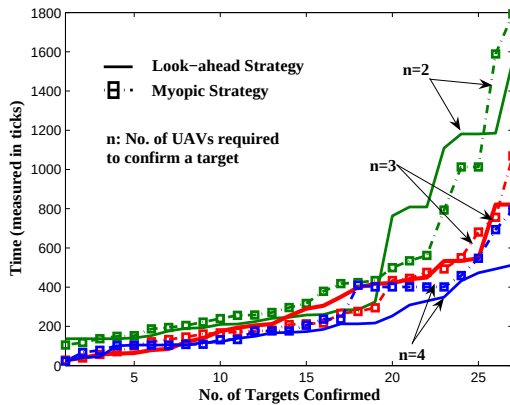


Figure 2: Time required to confirm targets in an AOI with myopic and lookahead strategies for different initial UAV densities per region.

the metric for quantifying system performance. The AOI is considered to be an invariant square region. However, the number of regions or home-areas into which the AOI is subdivided is varied to measure the effect of the size and number of home-areas on system performance. Targets are assumed to distributed randomly within the AOI. The communication range of each UAV is assumed to be 1/3 of one side of the square AOI. The pheromone decay rate is set at 1/200 per tick. Our experimental results are reported in Figures 1 through 4.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we have reported the results from software based simulations for a swarmed model of ATR and shown that it compares favorably with existing ATR strategies. In the future, we are investigating mechanisms to improve the lookahead strategy using a temporal inference technique, improve the communication protocol using a decision theoretic mechanism, and, address issues related to security and fault tolerance in the system.

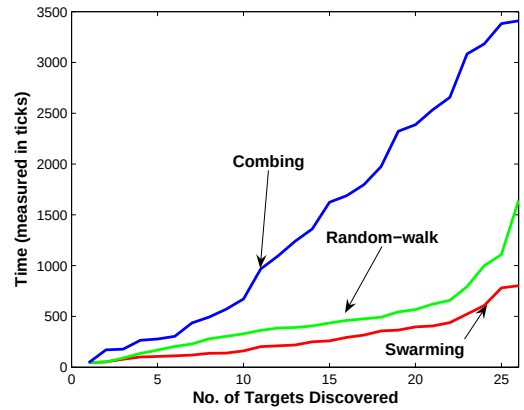


Figure 3: Time required to cover a square AOI using three different coverage strategies.

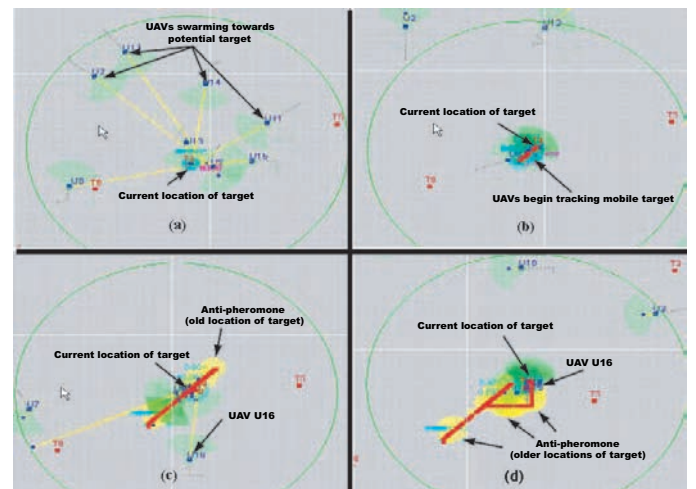


Figure 4: Snapshots illustrating the anti-pheromone update by different UAVs while tracking a mobile target.

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