Applicability of Swarm Intelligence to UAVs

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Abstract

Unmanned Aerial Vehicles (UAVs) are a type of aircraft that can be controlled remotely or programmed to fly in an autonomous way. This project investigated the applicability of biological swarm intelligence strategies in UAVs by visualizing these strategies using R language simulations. Results show that some biological strategies were translated as they were seen on animals and plants, while others were translated differently due to UAVs either having more or different capabilities than the different animals and plants in question. The applicability of biological strategies to UAVs is dependent on the capabilities of UAVs and the priority of the task that the swarm has to do. The visualizations of the strategies implemented using R language simulations enable better adaptation of biological intelligence to UAV swarms, which leads to improved UAV task performance and UAV security.

Introduction

Unmanned Aerial Vehicles (UAVs) are a type of aircraft that can be controlled remotely or programmed to fly in an autonomous way. They can be used for different types of applications as individual entities, both in military and civil tasks [1]. UAVs have been used for things like surveillance, search and rescue, agriculture, or forestry [2]. Swarm intelligence in UAV is categorized as an NP-hard problem that has been tackled by a number of different algorithms and models that deal with different areas of swarm intelligence. Some of these algorithms and models used have been inspired by different things that are seen in nature [3]. Some of these include Ant Colony Optimization (ACO) , Bee Colony Optimization (BCO), Particle Swarm Optimization (PSO), Flower Pollination Algorithm (FPA), and Generic Algorithm (GA) [4] [5]. The goal of the project is to test the applicability of the insights gained from looking at biological intelligence in swarm UAVs using simulations. This would allow for better visualization of the swarm intelligence strategies and stimulate our thinking about how to improve UAV task performance and UAV security.

Background

This work is based on the publication of the paper "Swarm Intelligence and UAV Security" on the The 23rd International Conference on Artificial Intelligence. An extensive literature review was conducted to investigate instances of swarm intelligence in biology. Intelligence of the following animals and plants were explored: ants, bees, fish, birds, wild guinea pigs, whales, dolphins, lizards, and wind-dispersed trees. The findings were organized into three categories: social structures, communication, and anti-predation.

Problem

Jackson & Ratnieks [6] makes the argument that, from a biological perspective, the work to use mathematical and computational models to show how ants solve problems such as selecting the shorter of two paths between food and nest or selecting the better food source when presented with two of differing quality oversimplify how these biological processes occur. The goal of the project is to test the applicability of the insights gained from looking at biological intelligence in swarm UAVs using simulations.

Methodology

The findings of the "Swarm Intelligence and UAV Security" paper were analyzed to choose six strategies to translate to UAVs using R language simulations:

1. Wild Guinea Pig Stop and Scan: Scanning strategy used by wild guinea pigs.
2. Decoy UAVs: Wind-dispersed trees seed distribution strategy.
3. UAV Group Change Strategy: Whale, dolphin, and fish groups that assemble and disassemble throughout the day.
4. Budding Strategy: Separation of UAVs from an original swarm to form their own based on ants.
5. Response to the leader going down: Strategy based on how ants from colonies with one queen respond to the queen dying.
6. Communication with Multiple Components: Multiple component communication strategy based on the *Aenictus* ant.

In the simulation, the swarm follows a leader that may or may not be visible. The leader follows a lissajous pattern back and forth and stays in the boundaries. Any UAV in the swarm that hits a boundary is reflected back like a billiard ball.

Results and Discussion

Figure 1 shows the UAV translation of the Wild Guinea Pig Stop and Scan strategy, where all the UAVs that are not intruders to stop moving after the squadron drops below the swarm. This allows the squadron to better scan for intruders.

Figure 1. The swarm freezes, while the intruders keep moving

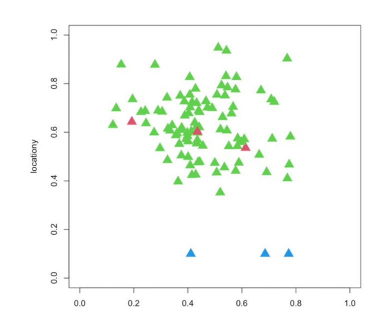


Figure 2 shows the implementation of the Decoy UAV Empty Seed Simulation, where twenty-five UAV decoys move towards the outskirts of the rest of the UAVs, taking the intruders with them. The squadron drops below the swarm some time after and takes the intruders down. As soon as the intruders are gone, the decoys and the squadron rejoins the rest of the swarm.

Figure 2. The decoys and the intruders go towards the outskirts of the rest of the swarm

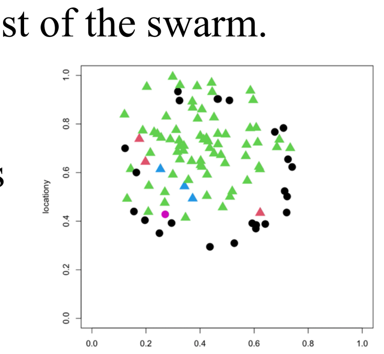


Figure 3 show the implementation of the homogeneous Group Change strategy. The red and blue UAVs come together in the middle of the space and both swarms stop movement to allow ten members of the red group UAVs to change groups.

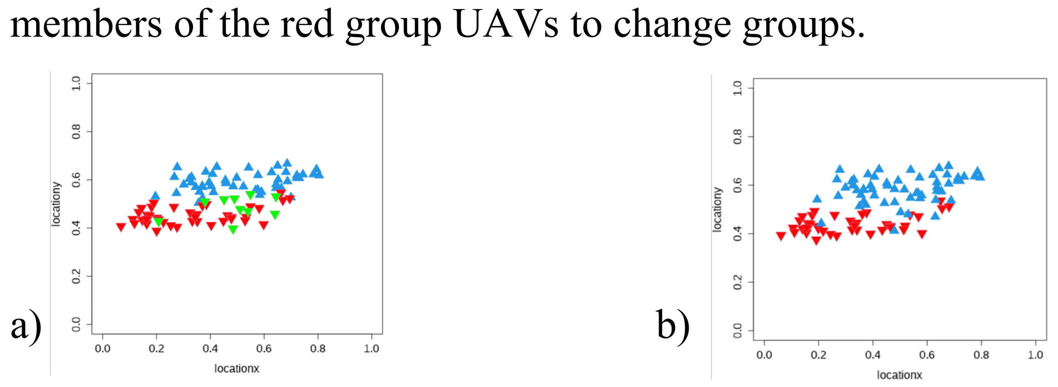


Figure 3. Group change with homogeneous swarm. a) Swarms beginning the group change. b) Finished group change

Results and Discussion (cont.)

Figure 4 show the implementation of the heterogeneous Group Change strategy. The red and blue UAVs come together in the middle of the space and both swarms stop movement to allow ten members of the red group UAVs to change groups.

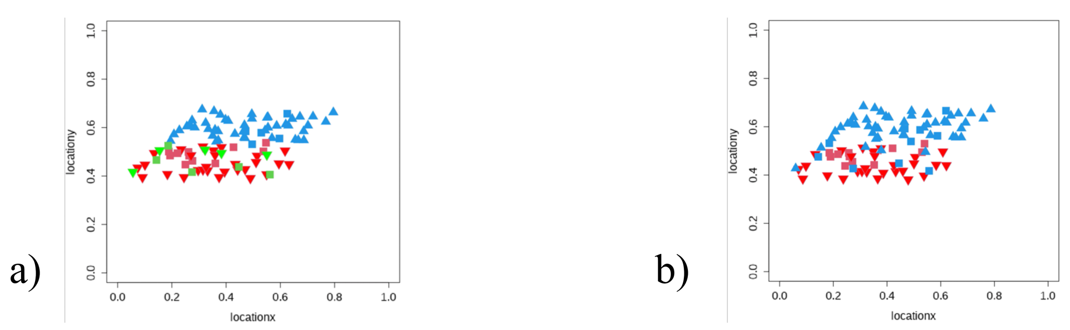


Figure 4. Group change strategy with heterogeneous swarm. a) Beginning the group change. b) Finished group change

Figure 5 shows the implementation of the Budding simulation, where a swarm of UAVs head from one task to another and ten UAVs would split from the original swarm, form their own mini swarm, and go in a different direction to the original swarm.

Figure 5. Budding simulation

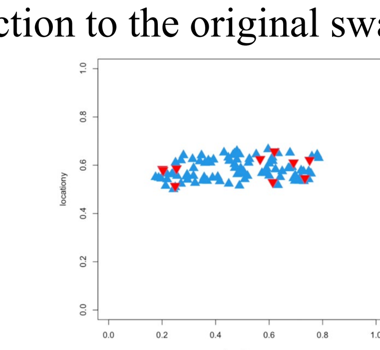


Figure 6 shows the Leader goes down simulation, where the lead UAV gets taken down (Figure 6a) and then another UAV emerges as a leader (Figure 6b). The other UAVs then stop following the initial leader and follow the new UAV leader.

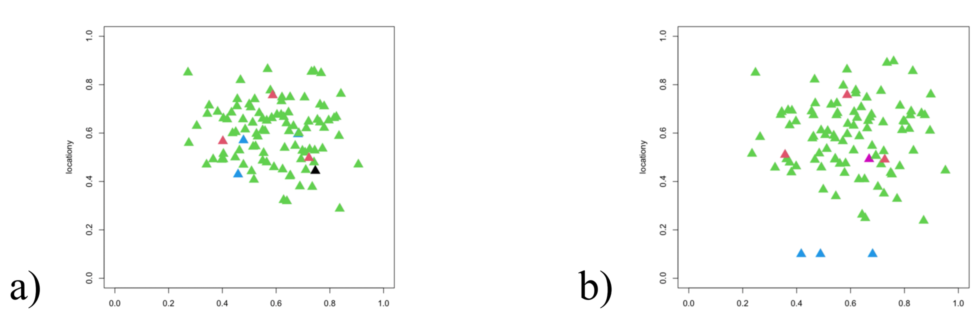
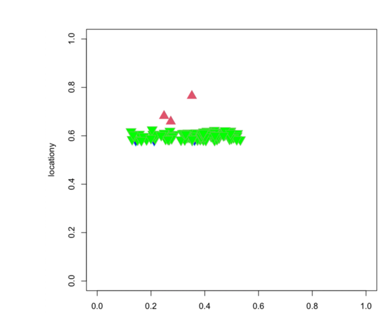


Figure 6. a) Leader gets take down. b) A UAV has detected that a leader is not present and steps up as a leader

Figure 7 shows the Communication with Multiple Components simulation, where UAVs receive two "digital messages". The first is to change a boolean variable to "TRUE", After the first message gets executed, a second "digital message" is sent for the UAVs that have that boolean variable set to "TRUE" to change direction, shape, and color. The result of this change is that anyone that still has the original shape, the original color, and is still heading in the original direction is an intruder that the squadron should target.

Figure 7. Communication with multiple component simulation: UAVs responding to the second set of instructions



The Wild Guinea Pig Stop and Scan, UAV Group Change, and Budding strategies were applicable to UAVs as seen in biology. The Decoy UAV, Response to a Leader Going Down, and Communication with Multiple Components strategies were applied to UAVs differently than how animals and plants execute the strategy due to differences between those animals and plants and UAVs.

Conclusions

Six strategies were tested to determine the applicability of biological intelligence to UAVs. The results show that some areas of the biological strategies translated were translated as they are exhibited on animals and plants. Other areas are translated differently since UAVs have either more capabilities than the different animals and plant in question or different capabilities. The applicability of biological strategies to UAVs is dependent on the capabilities of UAVs and the priority of the task the swarm executes in a simulation. In applying these strategies of biological intelligence to UAVs, new possibilities can be introduced that will allow the UAVs to perform tasks in different ways and use different strategies that will improve UAV security.

Future Work

Future work in this research involves further experimentation with the simulations by experimenting with the parameters and explore different ideas of motion and behavior and visualization.

Another area for future work involves translating three additional biological strategies to UAVs. The first is the ant monogyne social structures. The second is the polygyne social structures. Both strategies would cover the social structure itself and how those colonies' respond to intruders. The third strategy is the killer whale strategy of selecting hunting strategies based on the prey that they are hunting.

Acknowledgements

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