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NAVIGATING THE SKIES: AN ADAPTIVE APPROACH TO UAV INTERACTION VIA SWARM INTELLIGENCE

Analysis of UAV Thermal Soaring Via Hawk-Inspired Swarm Interactions

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I. INTRODUCTION

Unmanned aerial vehicles (UAVs) have the potential to be a key component in several sectors and applications as technology advances. Longer flying periods, better sensors, and enhanced control are anticipated along with a more complex design. Gupta (2023) further described that UAVs are beginning to be utilized for delivery, inspection, and surveillance, potentially in the future, they will also be employed for disaster response, monitoring of agriculture, and search and rescue missions. It is expected that UAV technology may improve in all conceivable areas, influencing the way individuals live in the future. A primary challenge facing UAVs is their limited flight endurance, which stems from the constraints imposed by batteries as their power supply. This results in some UAVs having limited flight time, autonomy, mobility, and battery endurance. Furthermore, harsh weather conditions and environments can further impede UAV performance. Consequently, mission time is restricted by low battery endurance, challenging atmospheric conditions, and sensor accuracy issues.

Researchers have worked with biomimicry, drawing inspiration from nature to improve UAVs, in order to address this problem. According to Ákos et al. (2010), the solution to this issue is to imitate soaring birds' actions, which serve as an illustration of how to use a thermal updraft to fly higher and stay in the air considerably longer. Researchers have been attempting to reproduce this behavior in UAVs recently by employing thermal sensors and analysis to find and take advantage of updrafts.

This research analyzes how a swarm of UAVs can work together to make optimal usage of thermal updrafts while also highlighting the variety of scientific concepts that has been observed. The project operates this by Analyzing UAV Thermal Soaring via Hawk-inspired Swarm Interaction. The movement of the UAVs was simulated using a Boids model, which imitates the behavior of birds in a flock by utilizing forces of cohesion, separation, and alignment, which indicate that it may significantly affect the endurance and range of UAVs while lowering their energy consumption. By integrating an adjusted behavioral model into the agents, they showed a dynamic flocking behavior that involved maintaining proximity based on their altitude, separation, and alignment. The simulation results demonstrated that the agents clustered together around thermal air currents, thereby enhancing their chances of survival. These results suggest that this method has the potential to increase the flight time of autonomous UAV swarms, offering an encouraging prospect for future research.

II. SCIENCE CONCEPTS INVOLVED

This study is an interdisciplinary research, mainly focusing on concepts found within the fields of physics and biology, although chemistry is also touched. This allows for a broader and more complex view of the problem, possibly leading to a better and simpler solution. These different fields of study all work together to generate the behavioral model that, theoretically, could improve the flight times of UAV swarms.

Hawks are recognized for their efficient long-distance flight accomplished through thermal soaring, wherein they take advantage of rising columns of air known as thermals . By adjusting their flight path and speed, hawks stay within the thermal column, thereby gaining or maintaining altitude with minimal energy expenditure. The birds optimize their wing and body positions to maintain a constant angle of bank and pitch, maximizing the thermal's upward-moving air currents to remain aloft (McDonald, 2016). Thermal soaring conserves energy, which is especially beneficial during food-scarce winters or migratory periods when hawks require significant energy reserves for long flights (Addison, 2022).

In group settings, hawks use flight patterns to communicate with each other. These flight patterns can be described using Craig Reynolds' (1987) three rules of flocking behavior, known as the Boids Rules, a set of rules that are mainly focused on calculations regarding vectors that allow the individual agents to flock together. These make the Boids Rules relevant to both biology, as a behavioral rule, and physics, through vector calculations.

In order to determine the velocity of nearby UAVs, the paper explains how an algorithm is used. To calculate the desired velocity of each UAV, the algorithm considers Boid rules and a migration rule. Cohesion, separation, and alignment are some of the Boid rules, which imitate the flocking behavior of birds. The migration rule calculates the desired velocity vector while taking the UAVs' surroundings into account. Together, these rules allow the algorithm to precisely determine the UAVs' velocities, enabling them to move and navigate in unison.

The cohesion rule explains how hawks coordinate their movements and maintain group integrity while searching for thermals. By adjusting their flight direction and speed to match the average flight direction and speed of the group, the hawks fly in a coordinated manner and maintain a relatively constant distance between themselves and neighboring hawks, even in turbulent air conditions.

The separation rule details how hawks adjust their flight paths and speed to ensure a safe distance from neighboring hawks based on the principle of local avoidance. The alignment rule explains how hawks adjust their flight paths to align with their neighbors' movements based on the principle of local attraction. Hawks are drawn to their neighbors' movements and try to align their flight path with theirs. Following these rules, the hawks conserve energy and improve their chances of finding thermals while maintaining a stable structure within the group, avoiding unnecessary conflict or collisions.

The concepts of meteorology and fluid dynamics are also present. Meteorology focuses on the atmospheric conditions that affect thermals such as weather patterns and strong winds. Strong winds, in particular, can affect the shape of thermals, leading to changes in flight patterns for both hawks and UAVs. According to a recent paper on thermals (Predelli and Niederhagen, 2021), the buoyancy that drives thermals is primarily caused by differences in temperature and humidity, which result in differences in air density. Fluid dynamics is the study of how fluids, including liquids and gasses, flow and interact with each other. In the context of UAVs and thermals, fluid dynamics helps to understand how UAVs interact with the thermal column. According to NASA (n.d.), when air moves at a faster speed (higher temperatures), it results in a decrease in air pressure. As a result, the air pressure on the top surface of a wing, due to the upward rising of warm air in thermal updrafts, becomes lower than that on the bottom surface, which creates an upward force on the wing, allowing it to lift off the ground. When encountering a thermal, the UAVs flight pattern must be adjusted to remain within the heated rising column of air. Researchers can acquire insights on hawk instincts and flying behavior by studying air flow and improving thermal usage.

Other physics concepts involved are aerodynamics and thermodynamics. The paper investigates the sustained flight of drones using thermal updrafts. The authors go on to explain how drones can fly into thermal updrafts and then circle inside them for sustained flight. The drone increases its altitude as it circles by riding upstream air currents. The drone can maintain flight for long periods of time in this way without using a lot of energy.

Thermodynamics is also touched in chemistry, a field that is also related to this study. Thermodynamics is the study of the transfer of energy and heat, which is necessary for understanding thermal behavior. As previously stated, thermals are the upward-moving columns of rising warm air that hawks use to achieve and maintain altitude as well as travel large distances with low energy expenditure. These thermals occur when there is heat caused by the uneven heating of the Earth's surface by solar radiation (Vishwajith, 2021). As the warm air rises, it expands and cools, leading to a decrease in pressure. This decrease in pressure generates lift, which allows the hawks and UAVs to gain altitude.

Another field that is related to chemistry is materials science. Material science is the study that is involved with the application of the properties of matter. In regards to this, the materials used in the making of the UAV would also be considered. The materials must be lightweight enough for it to be able to ride the thermals, yet strong enough to be able to endure long hours of possibly damaging conditions such as dust particles or the heat of the thermal updrafts.

III. APPLICATION

This study shows insights on possible concepts and behaviors that can be applied to real world UAV agents. The agents showed a level of swarm intelligence that was powerful enough to not need any communication between the agents. This means that the model provided in the study is capable of being implemented in a system consisting of multiple agents that do not have any direct communication with each other. The study also showed that the more agents there were in a system, the better the swarm's effectiveness. This means that the behavioral model improves if there are more agents available, meaning that UAV agents can be made using cheaper and less sophisticated technology in favor of this emergent swarm behavior. The study can also be applied to biology, specifically to the study of hawk behavior. Studying the model may provide insights on the emergent behaviors of a hawk swarm, as the model was itself inspired by hawks.

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