High-Level Control of UAV Swarms

Märta Paulsson
Lund University

Search and rescue (SAR) operations are often tedious and may run under extreme conditions. During natural catastrophes and nuclear breakdowns, unmanned aerial vehicles (UAVs) may be considered for SAR applications, especially if the area is toxic to humans and dangerous for manned search operations. UAVs can provide critical support as they are agile, fast, and able to perform operations that are hard, or even impossible, to execute by human operators. This Master's thesis investigates swarm control algorithms for autonomous UAVs and exhibits the compatibility of aerial SAR operations.

A UAV is an aircraft designed to operate without a human pilot on board and can be autonomous, semi-autonomous, or controlled remotely by an operator. In a typical SAR scenario, UAVs are deployed in an area of interest and perform necessary sensory operations to collect evidence of the presence of victims. The information is thereafter reported to a remote ground station or to a rescue team. Using multiple UAVs enables the designer to create agents which are generally cheaper and less complex compared to a single agent. Search and rescue operations can greatly benefit from the use of cooperative swarms of autonomous unmanned aircraft since the time to fully cover a specific area decreases significantly.

Most of the existing work related to swarm intelligence is derived from the social behavior of animals or insects. Examples of swarm intelligence in nature include flocks of birds, schools of fish, herds of animals, and colonies of ants or bacteria. The evolution of such behavior is due to its inherent advantages, such as increasing the chance of finding food and avoiding predators. A swarm typically consists of simple agents interacting locally with one another and their environment. Swarm members are naturally disorganized and perform very simple tasks in response to environmental information as well as local information from other group members. Some biological swarms fly in formations, i.e. follow a geometric configuration. In this thesis, the UAVs travel in a cluster, similar to the behavior of bee swarms.

A simulation of a swarm consisting of 15 low-cost collaborative fixed-wing aircraft is developed in this thesis. The swarm algorithms are investigated when collisions are prevented both between agent pairs and between agents and static obstacles. The agents are unaware of what problem they are collectively working on, but based on local communication with nearby members and the actions that they exhibit, an individual evaluates an appropriate behavior that will contribute to the swarm's objective.

In most outdoor environments, the Global Navigation Satellite System provides localization by using GPS signals. These systems require signal connections to satellites to operate and in obstructed areas, the signals may be reflected and absorbed by different objects. This results in a positioning error, i.e. the position accuracy worsens near buildings and obstacles, such as bridges, mountains, and trees, due to satellite signal blockage or reflections and absorption. In this thesis, an attempt to estimate the positions of the UAVs in a GPS denied environment is considered.

To obtain position estimates of the UAVs, wireless signal measurements are used. More specifically, to limit the costs of the devices involved in the positioning operations, an approach based on received radio signal strength (RSSI) is considered. The UAVs are assumed to be equipped with communication devices, which allow them to communicate with each other in order to improve their cooperation abilities. The RSSI approach uses a simple signal propagation model but adapts to different environments in terms of size, shape, and number of obstacles. The strength of a radio signal decreases as the distance increases. By sending data packages and measuring the signal strength between two communication devices, a model for the relationship between signal strength, distance, and the attitude of the aircraft is evaluated.

When the true UAV positions are provided, the developed swarm algorithm did show promising results in terms of controlling the swarm. No collisions occurred between agent pairs or agents and obstacles. The agents did not go out of bounds, and the swarm was robust as it was able to handle the loss of individual members.

For the approach of RSSI based position estimates, further development of the swarm behavior was required. In combination with a dynamic model of the aircraft kinematics, the resulting algorithm produced a position estimate with a mean error of approximately 9 meters. This position error will not lead to collisions within the swarm, since agents generally operate at a distance of 120 m to their closest neighbor. No significant difference was found regarding the efficiency of scanning the area when the positions were estimated by RSSI values compared to when the positions were known. However, victims might go undetected when using estimated positions if the position error results in UAVs believing they have visited certain areas they have not yet scanned.

RSSI based position estimation is useful for a considerable amount of applications within civilian use with low accuracy requirements of the position.

This thesis has shown that swarm algorithms can be applied to successfully achieve cooperative behavior of unmanned aerial vehicles. The algorithm developed in this thesis demonstrates that the UAV swarm completes the desired task, i.e. surveys an area collaboratively. This method can handle the loss of units and is potentially scalable to large, distributed networks of devices.