Developing an Autonomous Swarm of Small Helicopters: Controlling Cooperative Team Behaviour for Search and Surveillance

Stephan K. Chalup, Zhiyong Chen, Jamil Khan, Alexandre Mendes and Christopher Renton
Newcastle Robotics Laboratory
Faculty of Engineering and Built Environment
The University of Newcastle
Callaghan, Australia
{Stephan.Chalup, Zhiyong.Chen, Jamil.Khan, Alexandre.Mendes, Christopher.Renton}@newcastle.edu.au

Abstract—**This paper describes components for controlling an autonomous swarm of small helicopters to execute search and surveillance tasks. The proposed system will be designed to support and be deployed by land forces. The aim is that the swarm can operate fully autonomously and use cooperative team strategies based on decentralized multiagent system control. The different components of the system are investigated by an interdisciplinary team in the Newcastle Robotics Lab comprising experts from computer engineering, computer science, computer vision, control, electrical engineering, machine learning, mechatronics, optimisation, wireless communications, signal processing and software engineering. The proposed system can help to reduce risk in land force missions that require search and exploration of dangerous or unknown environments.**

Keywords—Autonomous multi-agent system; decentralised control; reinforcement learning; wireless communication

I. Introduction

In nature there are many examples, including ants, birds, fish, honeybees, and human football teams where goal directed strategic team behaviour leads to outcomes that one individual could not achieve alone. This project is inspired by the abilities and behaviours of swarms in nature and implements the associated algorithmic concepts for an autonomous multi-agent system of unmanned aerial vehicles (UAV). If UAVs are able to operate fully autonomously and close to ground they do not require specialised air operators and can be deployed and operated by land forces. The potential for intelligent, fully autonomous vehicle use in situations where human supervision is not required or not possible is enormous [2, 4]. Using a swarm instead of an individual vehicle increases efficiency and operational capacity. The following sections describe different components, and concepts, that form the basis of the proposed system as well as possible applications.

II. Cooperative Strategy Learning

Goal directed cooperative team behaviour in autonomous multi-agent systems can be learned, for example, by suitable variations of Q-learning [1, 5, 9, 10]. Using this type of machine learning technique agents can develop cooperative strategies for tasks such as escaping a maze, avoiding obstacles, hunting prey, or searching an area of interest. In the research field of autonomous multi-agent systems these types of behaviour have been investigated, for example, within the framework of robotic soccer where a team of soccer agents is trained to play and score against an opponent team of autonomous agents [3, 10]. The key for developing appropriate team behaviour for a swarm of UAVs are extensive training sessions that first are executed in simulation software, then in a controlled lab environment and finally in an outdoor setting.

III. Energy And Wireless Network Communication

One of the challenges for the helicopters is to manage power consumption using energy scavenging mechanisms so that the swarm can operate for long periods of time and over long range. A possible solution can employ UAV attached solar panels acting as drip feed chargers to keep batteries fully charged. Depending on the environmental conditions the swarm behaviour may have to include resting and recharging periods [6, 7].

The internal communications of the UAV swarm can be regarded as a dynamic wireless machine to machine network that is based on a failsafe ad hoc routing algorithm than can compensate for loss of sensor nodes due to power loss or influence of hostile environments. The IEEE802.15.4 networking standard supports low power data rate sensor networks (within the 2.4GHz, 700MHz and 900MHz spectrums). Currently such nodes operate with a data transmission rate of 240 Kbits/sec within a range of 100 meters. This can be extended using ultra low noise power amplifiers. By increasing the size of the UAV swarm the node density and distance can be kept within the required range to maintain a connected network. If necessary and depending on the environmental and task conditions the UAV swarm could be supported by additional ground based sensors or network nodes that could be deployed by the swarm as part of the cooperative goal directed behaviour.

IV. Vision And Software Design

In order to reduce the load and power consumption on the UAVs e.g. a Raspberry Pi (http://www.raspberrypi.org/) based on-board computer vision system could be used. These systems are able to perform face detection and tracking.

V. Mechatronic Control

There are various advanced control challenges for navigation, stabilizing, starting and landing of the individual UAVs. Many of these have been solved before but they require adaption, further development, implementation and testing in order to work with the planned system. A background study that outlines energy-based positioning control using manifold regulation for a quadrotor helicopter example is given in [8].

VI. Decentralised Control

Inspired by the research on collective behaviors of natural systems, control engineers became more interested in studying control mechanisms for coordination of autonomous multi-agent systems to generate a certain collective motion pattern. The major efforts over the past years have been devoted to design of decentralised controllers for various motion patterns such as flocking, swarming, torus, and their derivatives including obstacle avoidance, foraging and target tracking, etc. The research themes include agent dynamics (e.g. linear vs. nonlinear, homogeneous vs. heterogeneous), network topology (e.g. connectivity), feedback manner (e.g. state or output feedback, sampled data and quantized control), etc. Many mature theoretical frameworks have been implemented in experimental platforms. For instance, a group of autonomous robots was designed to successfully realize flocking and torus behaviors in our recent work [11, 12].

VII. Applications

The proposed autonomous helicopter swarm can support land forces in various ways. UAV systems that are currently used by the military around the world are either remotely controlled, or require intensive human intervention for most of their operations. The list of possible applications of UAV in the military is extensive [2, 4]. *Surveillance* typically involves one or more UAV hovering over a location, or following a pre-defined set of waypoints, and communicating information of interest back to a command centre, e.g. activity of enemy troops within an active theatre of operations. If the UAVs become autonomous they can be used by land forces more easily and are more suitable for long-term and long-range tasks. They then have the potential to enter underground areas or buildings. *Reconnaissance* can be quite dangerous, especially when there is little knowledge about the area to be scanned; for instance, what types of enemies or hazards might be found. In that case, instead of risking human life, autonomous systems are the ideal tool. There are many examples of UAV systems in several armies that can be carried by ground troops and used in the battlefield for short-range situation awareness, among them the RQ-11 Raven and the WASP III. Both of them are used by the Australian Defence Forces, are remote-controlled and carry a load of sensors that transmit data back to the operator. *Search-and-rescue* missions can be time-consuming and normally require lots of resources. Consider the situation of a combat unit or soldier that is uncommunicable and in enemy territory. A search-and-rescue mission needs to be arranged and the search area might be large and dangerous. In this case, a swarm of fully autonomous UAVs capable of cooperative optimised team behaviour could quickly and safely cover large geographical areas at a much lower operational cost than a human-controlled search. To the authors' best knowledge currently there is no system in use that could accomplish such task.

VIII. Summary and Conclusion

The proposed system includes several challenging problems and at this stage no such system has been developed anywhere in the world. In order to achieve the overall goal, the project can be broken down in stages that include: remotely controlled or semi-autonomous behaviour, simulations, short-range tasks, and pilot tests with small numbers of UAVs. The interdisciplinary team at the Newcastle Robotics Lab comprises experts from six different areas that collaborate on the proposed system. The University of Newcastle ranks ERA 5 (*well above world standard*) in several relevant areas, including control engineering and applied mathematics.

References

[1] C. Amato, G. Chowdhary, A. Geramifard, N. K. Ure. *Decentralized Control of Partially Observable Markov Decision Processes*. 52nd IEEE Conference on Decision and Control (CDC), Florence, Italy, 2013.

[2] R. Austin. *Unmanned Aircraft Systems: UAVS Design, Development and* Deployment. Wiley, 2011.

[3] S. K. Chalup, C. L. Murch, M. J. Quinlan. *Machine learning with Aibo robots in the four legged league of RoboCup*. IEEE Transactions on Systems, Man, and Cybernetics-Part C, 37(3):297-310, 2007.

[4] P. Fahlstrom, T. Gleason. *Introduction to UAV Systems*. 4th edition, Wiley, 2012.

[5] J. R. Kok, N. Vlassis. *Collaborative Multiagent Reinforcement Learning by Payoff Propagation.* Journal of Machine Learning Research 7:1789–1828, 2006.

[6] N. K. Ure, G. Chowdhary, J. P. How, J. Vian. *Multi-Agent Planning for Persistent Surveillance.* In: Planning Under Uncertainty, M. J. Kochenderfer (ed), MIT Press, 2013.

[7] N. K. Ure, T. Toksoz, G. Chowdhary, J. Redding, J. P. How, M. Vavrina, J. Vian. *Experimental Demonstration of Multi-Agent Learning and Planning under Uncertainty for Persistent Missions with Automated Battery Management.* In: Conference on Guidance Navigation and Control, Minneapolis, USA, 2012.

[8] C. Renton, T. Perez. *Energy-based Positioning Control of Underactuated Vehicles using Manifold Regulation*. IFAC Intelligent Autonomous Vehicles Symposium, June 26-28, 2013, Gold Coast, Australia. The Federation of Automatic Control, pp.9-16, 2013.

[9] C. Watkins, P. Dayan. *Technical Note: Q-Learning*. Machine Learning 8(3):279-292, 1992.

[10] S. Whiteson, M. E. Taylor, P. Stone. *Critical factors in the empirical performance of temporal difference and evolutionary methods for reinforcement learning.* Journal of Autonomous Agents and Multi-Agent Systems, 21(1):1–27, 2010.

[11] Z. Chen, H.-T. Zhang. *No-beacon collective circular motion of jointly connected multi-agents.* Automatica, 47:1929–1937, 2011.

[12] H.-T. Zhang, Z. Chen, L. Yan, W. Yu. *Applications of collective circular motion control to multi-robot systems*. IEEE Transactions on Control System Technology, 21:1416–1422, 2013.