Co-operating Miniature UAVs for Surveillance and Reconnaissance

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Abstract. Some complex application scenarios for micro UAVs call for the formation of swarms of multiple drones. In this paper a platform for the creation of such swarms is presented. It consists of modified commercial quadrocopters and a self-made ground control station software architecture. Autonomy of individual drones is generated through a micro controller equipped video camera. Currently it is possible to fly basic maneuvers autonomously, such as take-off, fly to position, and landing. In the future the camera's image processing capabilities will be used to generate additional control information. Different co-operation strategies for teams of UAVs are currently evaluated with an agent based simulation tool. Finally complex application scenarios for multiple micro UAVs are presented.

1 Introduction

Groups of flying platforms are necessary to implement some complex monitoring and surveillance applications. While the control of single micro UAVs is already well understood and a wide range of commercial products is available the use of multiple platforms still needs investigation. This paper presents ongoing work on the development and simulation of devices and strategies for the formation of swarms of micro UAVs.

After a short survey of related work the apparatus used for this work is presented. It consists of a modified commercial flight platform and a self-made ground control station. Coordination and control of the micro UAVs is realized by a micro controller equipped "smart" video camera mounted on the drones. Different strategies for the coordination of individual UAVs are currently evaluated using agent-based simulation tools. This report closes with a presentation of different applications for groups of micro UAVs.

2 Related work

The cooperative control of groups or swarms of UAVs makes high demands on the flight platform and requires new control strategies. With an increasing number of team members manual control becomes more and more impractical. A general approach is to equip the UAVs with a certain amount of autonomy. This requires capabilities such communication between drones, autonomous real-time navigation, sensing, and collision avoidance. With recent advances in corresponding areas, those capabilities can be integrated into micro UAVs. The following section gives an overview of research efforts in building collaborative micro UAVs.

The projects Flying Gridswarms and UltraSwarm [1,2], both carried out at the University of Essex, investigated the flocking of a group of MAVs (Micro or Miniature Aerial Vehicles) for the purpose of solving tasks by making use of the unique advantages of swarms. While Flying Gridswarms used a fixed wing platform, UltraSwarm aimed at building an indoor flocking system using small co-axial rotor helicopters. The key idea is using biologically inspired rules of group behaviour (flocking) to enable a group of UAVs to control its own motion. The swarm members wirelessly network to form a single powerful computing resource.

The chosen aerial platform for the UltraSwarm project was an off-the-shelf model helicopter. Due to their low costs swarms can be built at reasonable costs. The platform was fitted with an onboard computer and a miniature wireless video camera. To compensate for the additional weight it was necessary to upgrade the motors and batteries.

The ongoing µDRONES (Micro Drone autonomous navigation for environment sensing) project [3], funded by the European Commission under the 6th Framework Programme, aims at developing a small size UAV designed for autonomous inspection and survey tasks in urban area. The core of the project is focused on the development of software and hardware modules providing autonomy to a small size drone in terms of navigation, localization and robustness to unexpected events. Key research areas are the development of a mission control system with an intuitive human-machine interface, the development of perception and command algorithms allowing the more efficient flight autonomy and development of a micro UAV prototype.

The focus of SUAAVE (Sensing, Unmanned, Autonomous Aerial VEhicles) [4] lies in the creation and control of swarms of helicopter UAVs that are individually autonomous but that collaboratively self-organise. The project investigates the principles underlying the control of clouds of networked resource-limited UAVs that are targeted towards achieving a global objective in an efficient manner.

While Flying Gridswarms and UltraSwarm suffer from the limitations of the chosen aerial platform, our approach is based on highly reliable and expandable UAVs. Whereas µDRONES focuses on the platform and autonomous navigation of a single UAV, we look at the operation and collaboration of a group of UAVs. SUAAVE follows an approach similar to ours. However, this project is still at an early stage.

3 Platform

The development for swarm UAVs is based on a modified commercial flight platform that can be controlled by a ground control station. In the following section these two elements of the platform are described.

3.1 Flight platform

A lot of effort has been put into the selection of the flight platform. A platform that already comes with a range of sensors, an advanced control system and autonomous flight features significantly reduces the effort necessary to realize a co-operative swarm of micro drones. Furthermore, when it comes to flying autonomously, the system has to be highly reliable and possess sophisticated safety features in case of malfunction or unexpected events.

Other essential prerequisites are the possibility to add new sensors and payloads and the ability to interface with the UAV's control system in order to allow autonomous flight. A platform that fulfils these requirements is the quadrocopter AR100-B by AirRobot (s. Fig. 1). It can be both controlled from the ground station through a command uplink and by its payload through a serial interface. The latter feature was used to realize autonomous navigation (s. Section 4).

Fig. 1: A quadrocopter serves as flight platform

3.2 Ground control station

The ground control station is an adaptable prototype system for managing sensor data acquisition with stationary sensors, mobile ad hoc networks, and mobile sensor platforms. The main tasks of the ground control station are to work as an ergonomic user interface and a data integration hub between multiple sensors possibly mounted on moving platforms such as micro UAVs (but also ground vehicles or underwater vessels) and a super-ordinated control centre. The system includes means to control different mobile platforms (among them the AirRobot quadrocopter) to direct them to potentially interesting locations in order to cope with large or not beforehand sensor equipped areas.

The actual prototype demonstrator (s. Fig. 2) is mobile and portable, allowing it to be taken to any location with relative ease and then put into operation there. The sensor carriers of this multi-sensor system can be combined in a number of different configurations to meet a variety of specific requirements. The functions of the ground control station include: task management, mission planning, control of mobile platform (without line of sight through a virtual cockpit), sensor control, dynamic situation display/situation awareness, fusion of sensor data, sensor data exploitation, reporting, generation of alarms, and archiving.

A GIS based landscape model is used as the basis for visualization and data integration. The software architecture is component oriented. It uses the .NET 3.0 framework. The system offers support for information perception and management. This is achieved by optimized information visualization and information fusion e.g. in the situation display.

Besides of this there are also active means of supporting the coordination tasks of the sensor data exploitation. Such a support system for the automatic combination and selection of sensor data sources in a surveillance task was implemented using a production system with the Drools rule engine. It repeatedly assesses the current situation and selects the most appropriate rules to execute. The Drools engine can be packaged as a .NET component.

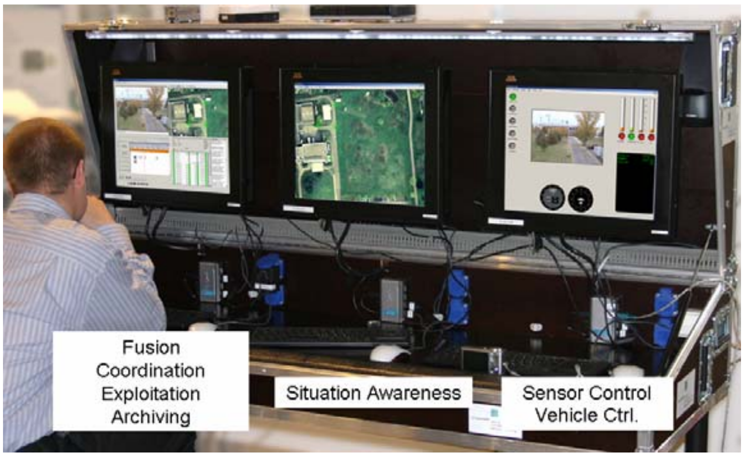

Fig. 2: Ground control station

The ground control station is realized as a modular framework allowing for adaptation to different operational needs. The platform has the function to integrate the data streams coming from a range of sensors. It is also used to control the different platforms. The underlying software architecture has a generic connector for interfacing the ground control station with different sensor types and other streaming data sources. This connector has to be adapted to the specific protocol used by any one sensor. It produces a unified data model from proprietary device specific formats (s. Fig. 3). The data model is built around a message which represents an event or single measurement. The message belongs to a certain sensor. The sensor is along with other sensors part of a sensor node which in turn is part of a sensor web. Sensor and message have a certain type that influences the interpretation of the associated message.

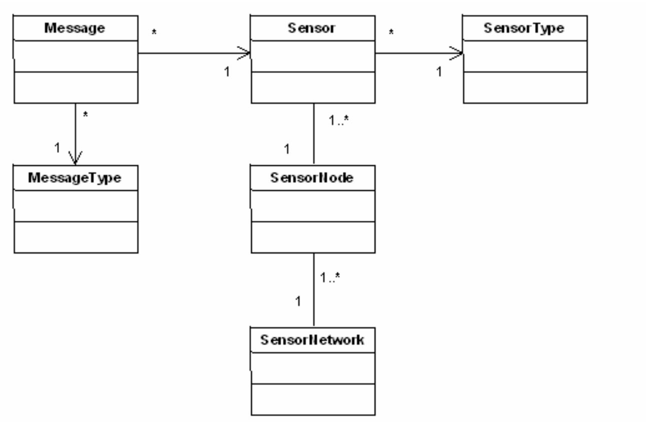

Fig. 3: Unified data model within ground control station

4 Towards autonomy

To allow the highest degree of autonomy possible, the quadrocopter should be controlled by a micro computer that it carries as a payload. Due to space, weight and power constraints of the payload, this computer module has to be small, lightweight and energy-efficient. On the other hand, a camera as sensor system should not be left out. A perfect solution is the use of a “smart” camera, i.e. a camera that not only captures images but also processes them. Processing power and functionalities of modern smart cameras are comparable to PCs. Even though smart cameras became more compact in recent years, they usually still are too heavy to be carried by a quadrocopter. In most applications, smart cameras are used stationary where their weight is of minor importance. However, a few models are available as board cameras, i.e. without casing and the usual plugs and sockets (s. Fig. 4, left). Thus, their size and weight is reduced to a minimum. The camera we chose has a freely programmable DSP (400MHz, 3200MIPS), a Linux-based real-time operating system and several interfaces (Ethernet, I²C, RS232). With its weight of only 60g (without lens), its compact size and a power consumption of 2.4W it is suitable to replace the standard video camera payload.

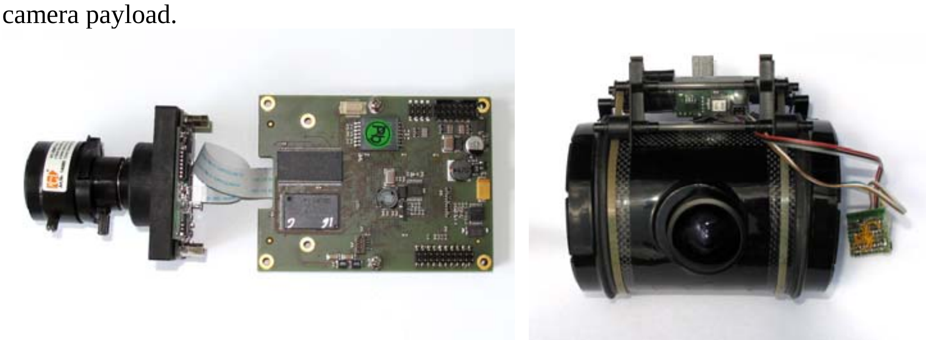

Fig. 4: A “smart” board-camera (left) controls the UAV and is carried as a payload (right)

The camera can directly communicate with the drone's controller though a serial interface. The camera receives and processes status information from the UAV such as position, altitude or battery power, and is able to control it by sending basic control commands or GPS-based waypoints.

A drawback of the board camera is its lack of an analogue video output thus rendering the quadrocopter's built-in video downlink useless. Image data is only available through the camera's Ethernet interface. Communication between the smart camera and the ground control station was enabled by integrating a tiny WiFi module into the payload. The WiFi communication link is used to stream live video images and status information from the UAV to the ground control station. Furthermore, new programs can be uploaded to the camera on the fly.

Currently, we are able to perform basic maneuvers autonomously, such as take-off, fly to position, and landing. In the future we will also use the camera's image processing capabilities to generate control information. As a safety feature, it is always possible to override the autonomous control and take over control manually.

5 Simulation and evaluation

In order to assess different co-operation strategies for teams of UAVs, a simulation tool has been realized. Modeling and visualization of scenarios is done using a computer game engine with corresponding editing tools. An interface to the engine has been implemented. It allows full control of the implemented entities as well as feedback from the virtual world.

An example scenario that simulates an intrusion has been implemented (s. Fig. 5). Besides the UAVs and the actors in the scenario, also sensors have been modeled. Different kinds of sensors such as motion detectors, cameras, ultra sonic or LIDAR (light detection and ranging) sensors can be modeled with their specific characteristics. The simulation tool can decide if an object lies within the range of a sensor. This helps evaluate and optimize the use of different sensing techniques.

Fig. 5: Simulation of an intrusion scenario

The intelligence of team members is implemented in software agents. They interface with the simulation engine using the same syntax as the actual quadrocopters. That way, the simulation can be transferred to the real world without changes to the agents.

6 Application scenarios

In a recent Frost & Sulivan report [5] application scenarios for general UAV platforms are divided into military and civil applications. According to this report micro UAVs are already used in vast and diverse civil applications. Some of the tasks that can be supported with UAVs in general are in agriculture, police surveillance, pollution control, environment monitoring, fighting fires, inspecting dams, pipelines or electric lines, video surveillance, motion picture film work, cross border and harbor patrol, light cargo transportation, natural disaster inspection, search and rescue, and mine detection. Obviously some of these tasks cannot be supported by micro UAVs due to their limited operating range and payload. But many surveillance and monitoring scenarios can be implemented using micro UAVs. With groups or swarms of micro UAVs it is even possible to monitor larger areas and with more diverse sensory than with a single drone.

Military users such as tactical units on patrol missions can apply micro UAVs for intelligence, surveillance and reconnaissance tasks. Swarms would additionally bring the capability of coordinated area surveillance. Also the application of micro UAVs in “military operations in urban terrain” (MOUT) is publically discussed. Especially the capability to safely look into buildings is something that is asked for today. Such a feature is not yet ready available but is actively investigated e.g. in the DARPA program VisiBuilding. The use of micro UAVs acting as relay node into buildings is also discussed.

Many needed features of micro UAV swarms can be investigated using the scenario of protecting a safety critical infrastructure site such as a military camp or a large industrial installation. In such an application the perimeter or outer fence could be monitored by movement detection sensors (e.g. visual or passive infrared). In case of a perimeter violation a quadrocopter could be directed to the place of the event in order to follow and monitor a potential intruder. Several cases could rise the demand for a swarm of quadrocopters in such a situation.

- The distance is too far for transmission of signals to a ground control station. A relay station is needed. A line of quadrocopters can act as network. All start together. If the swarm reaches a predefined distance from the ground control station one drone from the group is “parked” and takes over relay function between the rest of the swarm and the ground control station.
- A group of intruders enters the site, later divides, and individual intruders take different directions. Then every single intruder has to be followed by its own. This can be achieved by smart functionality of tracking targets and following them. But initially a swarm of drones has to go to the group of intruders in order to build up stocks of later needed single UAVs.
- The duration of surveillance is too long for one battery charge. Single quadrocopters have to call for substitution. When the replacement quadrocopter is arriv-

ing on site it has to take over and the first one can go back to the base for recharge.
- A thread has to be monitored with different sensor types. For example an intruder who is best visually controlled suddenly places an object. Besides the visual sensor some CBRNE (chemical, biological, radiological, nuclear, and explosive) detection devices are needed. Since the payload of every one quadrocopter is limited a swarm could carry different sensors.
- Multi-sensor capability could also be needed to visually control the action of different drones. For example an infrared sensor equipped quadrocopter could be used by the operator located in the ground control station to navigate a chemical sensor equipped micro UAV through a dark building.

These cases illustrate that there is a need of different swarm and coordination based capabilities for micro UAVs.

7 Conclusions

Forming teams of micro UAVs opens new application fields. However, the coordination of teams requires advanced control strategies and an extended degree of autonomy of the individual drones. Our approach is to equip commercial micro drones with “smart” cameras that control the UAVs. The drones are integrated into a modular sensor network whose central part is an adaptable ground control station.

Currently, we use a simulation tool to test and evaluate different team collaboration strategies, sensor techniques, as well as collision avoidance and path planning algorithms. In the future, we will raise the level of autonomy by implementing vision algorithms on the camera. Possible capabilities range from tracking of objects to the detection of suspicious behavior.

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