Fast Aerial Image Acquisition and Mosaicking for Emergency Response Operations by Collaborative UAVs

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ABSTRACT

Small-scale unmanned aerial vehicles (UAVs) have recently gained a lot of interest for various applications such as surveillance, environmental monitoring and emergency response operations. These battery-powered and easy-to-steer aerial robots are equipped with cameras and can promptly acquire aerial images.

In this paper we describe our system of multiple UAVs that are able to fly autonomously over an area of interest and generate an overview image of that area. Intuitive and easy user interaction is a key property of our system: The user specifies the area of interest on an electronic map. The flight routes for the UAVs are automatically computed from this specification and the generated overview is presented in a Google-Earth like user interface.

We have tested and demonstrated our multi-UAV system on a large fire service drill. Our system provided a high-resolution overview image of the 5.5 ha large test site with regular updates, proved that it is easy to handle, fast to deploy, and useful for the firefighters.

Keywords

Aerial imaging, overview images, collaborative microdrones, multiple UAVs, emergency response, firefighters.

INTRODUCTION

Unmanned aerial vehicles (UAVs) have gained great interest over the last couple of years. While initially only available in the military domain, small-scale UAVs became also available and affordable for the civilian market recently. Here, the main use of UAVs is remote sensing: UAVs are equipped with cameras or other sensors and steered manually to the desired locations. Typical applications include aerial photography of buildings, surveillance of crowds, and support of first responders in large-scale emergency situations. For instance, firefighters can get a detailed, accurate, and up-to-date picture of an affected area without exposing people's life.

Our research focuses on a UAV system that operates as autonomously as possible, requiring only minimal user interaction. Our multi-UAV system is based on small-scale networked UAVs that are able to fly autonomously to a specific waypoint. The UAVs can be equipped with different visual sensors, e.g., monochrome or color cameras for generating overview pictures or infrared cameras to detect people or fire. The UAVs further have to be equipped with reasonable on-board computing and communication infrastructure that allows for coordination among the UAVs and collaboration on certain tasks, which leads to an inherently distributed architecture. The ultimate goal, thus, is that a single person can easily operate a fleet of UAVs.

In this paper we present the design of *FAMUOS* (*Fully Autonomous Multi-UAV Operation System*), our multi-UAV system that supports first responders in disaster scenarios. Based on a high-level task description, the UAVs fly autonomously over a defined area and provide a high-resolution and up-to-date overview image of the area. We show first results of a fully autonomous execution chain, starting from the user's input to the planning and finally the generated overview image. Moreover, we demonstrate the value of our system during a fire service drill.

The contribution of this paper is threefold: it introduces the system architecture and an operational prototype of an autonomous multi-UAV system; it points out that such a multi-UAV system can deliver high-quality overview images, mosaicked from individual pictures, of a non-trivial area of interest with a reasonable update

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frequency; and it demonstrates the use of the system in a real-world, large-scale fire service drill.

RELATED WORK

While early research on UAVs focused on flight stability, the attention now shifts towards multi-UAV systems, e.g., (Gancet, Hattenberger, Alami, and Lacroix, 2005; Bertuccelli, Choi, Cho, and How, 2009; Daniel, Dusza, Lewandowski, and Wietfeld, 2009). Prominent research questions are coordination, task allocation, and collaboration of multiple UAVs, among others. The reasons for using multiple UAVs are to overcome the limitations of small-scale UAVs, namely limited resources (most importantly flight time), limited payload, and limited operating range, among others.

In the civilian domain single- and multi-UAV systems are heavily used for remote sensing in different applications, e.g., vegetation and environment monitoring (Berni, Zarco-Tejada, Suárez, and Fereres, 2009; Jensen, et al., 2009), air pollution monitoring (White, Tsourdos, Ashokaraj, Subchan, and Zbikowski, 2008), reconnaissance after disasters (Murphy, Steimle, Griffin, Cullins, Hall, and Pratt, 2008), or support in fighting forest-fires (Ollero, Martínez-de-Dios, and Merino, 2006; Casbeer, Beard, Li, McLain, and Mehra, 2005).

COMETS (Ollero, et al., 2005) is probably the first and most prominent research project on collaboration among multiple UAVs, using fixed wing aircrafts, helicopters, and blimps. The focus was on autonomous UAVs, coordination, and mission planning and scheduling. While some of the UAVs were able to fly autonomously, others still required manual steering. The intended use case is remote sensing, e.g., to detect forest fire.

Different types of UAVs—fixed wing, vertical takeoff and landing (VTOL)—have been reviewed for their use and applicability for forest-fire fighting. (Ollero, et al., 2006) have investigated the capabilities of different types of UAVs (e.g., high altitude long endurance, VTOL). The paper proposes to use medium to high altitude fixed wing UAVs equipped with cameras for generating image mosaics of the affected area. VTOL UAVs, on the other hand, are—according to the authors—more adequate for monitoring tasks.

SYSTEM OVERVIEW

From the user's point of view, the interface to a multi-UAV system must be intuitive and efficient, the goal being that a single individual can operate a fleet of UAVs. Hence, the operator no longer steers the individual UAVs but defines certain high-level tasks such as the area that has to be observed. This is done by simply sketching the areas of interest as well as the forbidden areas (i.e., areas where the UAVs are not allowed to fly) on a digital map. Certain quality parameters and an update frequency (e.g., provide image data updates every 20 min.) can be assigned to each observation area. The UAVs then fly fully autonomously over the defined area, capture images and send the data to the ground station. Here, the individual images are mosaicked to a single orthographic overview image that is presented to the user.

Fully Autonomous Multi-UAV Operation System (FAMUOS)

FAMUOS' system architecture, our presented multi-UAV system, is depicted in Figure 1. The system design considers the inherently distributed nature where the individual modules can run on different machines and on-board the UAVs. Figure 1 also depicts the individual subsystems, namely the UAVs with their on-board processing, the ground station, comprising mission planning and sensor data analysis, and the user interface. The arrow in the background denotes the dataflow. The user's high-level tasks are broken down into plans for the individual UAVs by the *Mission Planning* component. The UAVs execute the mission and send the captured images to the ground station where an overview image is computed and presented to the user.

Mission planning and mission control are the core components of our multi-UAV system. On the one hand, the planning component takes the user's input and derives plans for the individual UAVS. On the other hand, the ground station monitors the execution of the mission and triggers plan adaptation and re-planning in case the execution deviates from the computed plans.

We explore different methods and strategies for planning and executing a mission. This ranges from centralized, fully deterministic planning to decentralized and self-organized planning, either done on the ground station or distributed on the UAVs. Hence, the planning module is located on both, the ground station and the UAVs. *Mission planning* on the ground station has a global view of the whole system and therefore is supposed to compute plans for all entities. The UAV's *on-board planning* module, on the other hand, only considers the local view of a single UAV and probably UAVs in near vicinity for collaborative planning. *On-board planning*, therefore, is typically responsible for plan refinement and plan adaptation.

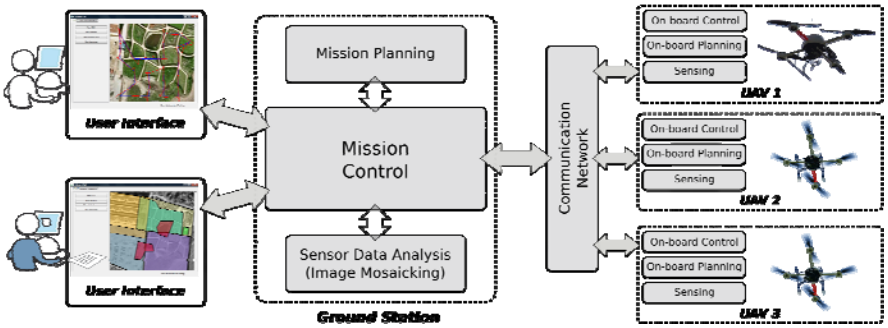

Figure 1. FAMUOS' system architecture. The arrow in the background indicates the dataflow.

In the case of fully decentralized and self-organizing planning, the whole computation is done on-board the UAVs and the *mission planning* module on the ground station degrades to generate a dummy plan. In both cases (central planning and collaborative planning), it is not required to plan the whole mission in advance.

In (Quaritsch, Kruggl, Wischounig-Strucl, Bhattacharya, Shah, and Rinner, 2010), we present a deterministic planning approach where in a first step the area is partitioned into rectangles of the size of a single picture and in a second step the routes for a number of UAVs are computed. In (Yanmaz and Bettstetter, 2010), a random, belief-based approach is presented where the UAVs share their knowledge when they are in close proximity.

We use an incremental hybrid approach for mosaicking the overview image using the individual pictures (Yahyanejad, Wischounig-Strucl, Quaritsch, and Rinner, 2010). Image meta-data is used for a rough and immediate placement and then refined by taking into account the image data.

DEMONSTRATION AND RESULTS

In this section, we present the effectiveness and capabilities of FAMUOS. We demonstrated our multi-UAV system in a real-world county fire service drill with more than 300 fire fighters, which took place on September 11th, 2010 in Wietersdorf, Austria. In this fire service drill, one exercise involved an accident with (simulated) dangerous goods. Our task was twofold. First, we were to build an up-to-date overview image of the affected area, which allowed the officers in charge to better assess the situation. Second, the overview image of the area should be frequently updated to keep track of the ongoing activities and the environmental changes.

During this fire service drill, we used the system as outlined in the previous section to define the tasks, plan and execute the mission, and compute the overview image. In the next subsections, we describe the user's interaction with the system and the process of generating the overview image in more detail.

Specification of the Observation Area

First of all, the operator had to specify the scenario. Figure 2 illustrates the scenario of the firefighter service drill in Wietersdorf. We specified the whole area of the exercise as the observation area, so that the officers in charge could monitor the movements of the firefighters. The buildings in the area were marked as obstacles because those were not of interest in this case. Specifying the scenario with the observation area, forbidden areas, allowed altitudes, and available resources took less than 2 minutes.

Figure 2. Observation area, forbidden areas, and planned route

Figure 3. Overview image computed from a set of 40 pictures

Planning of the Picture Points and UAV Routes

We used the deterministic approach outlined in (Quaritsch et al., 2010) to compute the mission plans. Our UAVs were equipped with a camera with a focal length of 32mm (35mm film equivalent), which resulted in a ground-coverage of about 32 m by 24 m per picture. An overlap of approximately 12.5% gives enough margin for image mosaicking. The picture point planner computed a solution with 187 pictures to cover the whole area. The route planner split the picture points in three groups with a route length between 950 m and 1350 m, which resulted in a flight time between 11 and 14 min per route. The results of the planning step, i.e., the picture points and routes, are shown in Figure 2. Computing the picture points for the observation area took 25 seconds and solving the traveling salesman problem for generating the routes required 26 seconds.

UAV Flight and Picture Retrieval

The next step was to execute the mission. When the user started the mission, the UAVs took off fully autonomously, flew the specified routes, and sent the pictures to the ground station. Figure 3 shows a part of the acquired overview image from this fire service drill, overlaid with the actual flight route of a UAV (red trajectory). The lower right corner of the figure shows a close-up of a group of firefighters to illustrate the high resolution of this overview image.

Summary

During the fire service drill, we did in total five flights over a period of about 3 hours. The first flight was covered first. Hence, although the whole flight took approximately 14 min, the affected area was covered after a few minutes. For the first two updates of the overview image, we chose an update interval of approximately 20 min because most activity was going on in the beginning. After the primary danger had been averted, we did two more flights with an update interval of approximately 40 min.

The quantitative characteristics of the scenario for this fire service drill are summarized in Table 1. The size of the scenario we sketched in Figure 2 is in the range of a real-world case for a disaster, it covers the whole area of a company in Wietersdorf, in total about 5.5 ha. Table 2 summarizes the quantitative characteristics of the computed plans. In order to cover the whole area the planner came up with 3 routes (cf. Figure 2) with a length between 950 m and 1350 m. With four UAVs the whole area can be covered in about 14 min. In each flight 187 pictures were taken. Table 3 summarizes the preparation time of the individual steps. The whole system is operational in less than 5 min in total while the planning takes less than 1 min.

CONCLUSION

In this paper we presented our system of networked, collaborative UAVs. This system is easy to operate and achieves a high autonomy by integrating mission planning and image analysis in the UAV operation framework. Our demonstration on a large fire service drill achieved promising results. First, our intuitive user interface enabled a setup of the whole system within five minutes. Second, only a single operator is necessary to control the UAV system even under realistic conditions. Finally, we received very positive feedback from the fire fighters. The provided aerial images were intensively used for assessing the situation and planning next steps.

Our UAV system is not only helpful for emergency response operations but can also be used in many other applications where up-to-date aerial images are required. Examples include environmental monitoring and industrial surveillance. We are currently testing our system on documenting the progress of construction sites.

Future work includes improving the geo-referencing of the computed overview image and improving the performance of the image mosaicking process. Moreover we aim to integrate further image analysis methods to automatically detect certain objects (e.g., detected persons, cars) and highlight their positions in the images.

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Observation area (total)	55038 m^2
Obstacle area (buildings)	7524 m^2
Number of UAVs	3

Table 1. Summary of scenario characteristics

Definition of the scenario	< 2 min
Mission planning	51 s
Picture point computation	25 s
Route computation	26 s
UAVs ready for takeoff	~ 5 min

Table 3. Summary of preparation time

Length of routes (total)	3518 m
Route 1	1355 m
Route 2	948 m
Route 3	1214 m
Flight time	14 min
Number of pictures / flight	187

Table 2. Summary of computed flight routes

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