Instantaneous Autonomous Aerial Reconnaissance for Civil Applications

A UAV based approach to support security and rescue forces

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***Abstract* - The Fraunhofer Institute of Optronics, System Technologies and Image Exploitation (IOSB) deals with the interoperability of stationary and mobile sensors and the development of assistance systems, which optimize and simplify the operation of such systems. In particular one of the focuses is research on swarms with airborne miniature drones and their applications. The photo flight presented in this paper is one of the applications developed to bring the advantages of a swarm into a realistic scenario. With the aim to support rescue or security forces in action, the photo flight generates an immediate up-to-date situation picture by using an autonomous swarm of miniature drones.**

Keywords - aerial situation image, unmanned aerial vehicles, swarm, search and rescue

I. INTRODUCTION

This paper presents our most recent work on a software module called "photo flight", which was developed as part of the ground control station AMFIS [1]. AMFIS is a component-based modular construction kit currently under development as a research prototype. It already has served as the basis for developing specific products in the military and homeland security market. Applications have been demonstrated in exercises for the EU (PASR [1] program), German Armed Forces, and the defense industry. The surveillance system AMFIS is an adaptable modular system for managing mobile as well as stationary sensors. The main task of this ground control station is to work as an ergonomic user interface and a data integration hub between multiple sensors mounted on light UAVs (unmanned aerial vehicles) or UGVs (unmanned ground vehicles), stationary platforms (network cameras), ad hoc networked sensors, and a superordinated control center.

The photo flight is a special feature of the flight route planning in AMFIS that allows the user to generate a highly up-to-date aerial picture of a predefined area in a short time. The software module itself is designed to work as independent standalone software as well as a part of the complex control system AMFIS.

After a short survey of related work an overview of the application scenarios is presented, followed by a description of the airborne platform in section IV. Section V introduces the used algorithms followed by the description of the post processing, conclusions and future work.

[1] Preparatory Action for Security Research

II. RELATED WORK

As far as we know the photo flight is a quite unique project. However, there are some projects with a similar scope.

At the "Universität der Bundeswehr" in Munich Dr. P. Reidelstuerz is developing a UAV for precision farming [2]. It is used to analyze agricultural areas from the air to find the regions that need further manuring to optimize the growth of the crop. A commercial of the shelf fixed wing model is equipped with an autopilot and either a near infrared or a high quality camera. With this technique the biomass development and the intensity of the photosynthesis of the plants can be monitored.

The AirShield project (Airborne Remote Sensing for Hazard Inspection by Network Enabled Lightweight Drones) [3][4], which is part of the national security research program funded by the German Federal Ministry of Education and Research (BMBF), focuses on the development of an autonomous swarm of micro UAVs to support emergency units and improve the information basis in case of huge disasters. The aim is to detect potentially leaking CBRNE contaminants in their spatial extent and to carry out danger analysis with the help of these data without endangering human life. The swarm is supported by a highly flexible communication system, which allows communication between the swarm members and between the swarm and the ground station.

The precision farming project as well as the AirShield project are very promising and showed first results. However, the application aim of both projects differs from ours although we plan to extend the photo flight to scenarios similar to the ones of AirShield (see Extensions and Further Work).

III. APPLICATION SCENARIOS

The security feeling of our society has significantly changed during the past years. Besides the risks arising from natural disasters, there are dangers in connection with criminal or terroristic activities, traffic accidents or accidents in industrial environments. Especially in the civil domain in case of big incidents there is a need for a better data basis to

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support the rescue forces in decision making. The search for buried people after building collapses or the clarification of fires at big factories or chemical plants are possible scenarios addressed by our system.

Many of these events have very similar characteristics. They cannot be foreseen in their temporal and local occurrence so that situational in situ security or supervision systems are not present. The data basis on which decisions can be made is rather thin and therefore the present situation is very unclear to the rescue forces at the beginning of a mission. Exactly in such situations it is extremely important to understand the context as fast as possible to initiate the suitable measures specifically and efficiently.

An up-to-date aerial image can be a valuable additional piece of information to support the briefing and decision making process of the applied forces. However, helicopters or supervision airplanes that can supply this information are very expensive or even unavailable. Up-to-date high-resolution pictures from an earth observation satellite would provide the best solution in most cases. But under normal circumstances these systems will not be available. Nevertheless, it would usually take too long till a satellite reaches the desired position to provide this information. A small, transportable and above all fast and easily deployable system that is able to produce similar results is proposed to close this gap.

The AMFIS tool “photo flight” can provide the lacking information by creating an overview of the site of the incident in a very short time. The application can be used by first rescuers for example directly on site with relative ease. The results provide a huge enhancement to already available information.

Applications include support of fire-fighting work with a conflagration, clarification the debris and the surroundings after building collapses, and search for buried or injured people. Additionally the system can be used to support the documentation and perpetuation of evidence during the cleaning out of the scene at regular intervals.

Non-security related application scenarios are also conceivable, as for example the use of infrared cameras to search large cornfields for fawns before mowing or to document huge cultivated areas or protective areas and biotopes.

The photo flight tool, which was developed from a former research project, shows excellent results in the production of up-to-date aerial situation pictures in ad hoc scenarios. The intuitive and ergonomic graphic user interface allows the operator to define an area of interest and start the photo flight. The results are a number of images depending on the size of the area of interest. They are merged and geo-referenced by suitable tools.

Since AMFIS is capable of controlling and coordinating multiple drones simultaneously [5] the photo flight tool was designed to make use of the advantages and benefits of a UAV swarm. By using more than one single UAV, the same search area can be covered in less time or respectively a bigger area can be searched in the same time.

The biggest problem when working with multiple UAVs is the dwindling clarity for the operator, especially when there are different types of UAVs and payloads. The more drones used in an application the more complicated the control of the single systems gets. That is why it is most essential to reduce the working load on the user as much as possible. Therefore the idea of a self-organizing swarm is transferred to the photo flight application in order to reduce the efforts for controlling this tool to a minimum. The user only has to define the area of interest and decide, which drones he would like to use.

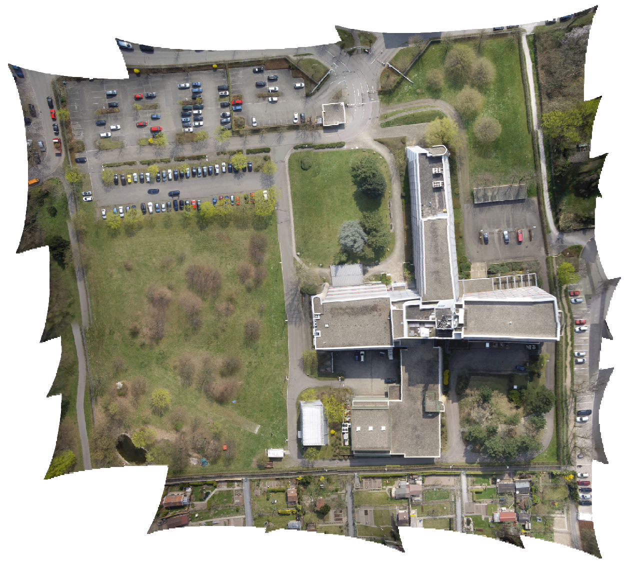

Figure 1. Situation picture from photo flight (ca. 9500 x 9000 pixel)

All additional work as for example the composition of the respective flight routes or the control of the single UAVs including the observation of the aerial security to avoid collisions up to setting the return flight is done by the application.

IV. Platform Description

The primary aim of the photo flight is the clarification of certain areas. The used drones do not necessarily have to be identical. They also can differ in their technical configurations. Nevertheless, in this first research attempt to build a swarm, UAVs of the same type were used.

A lot of effort has been put into the selection of this 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 cooperative 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 (see Figure. 2). It can be both, controlled from the ground control station through a

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command uplink and by its payload through a serial interface.

To form a heterogeneous swarm from different UAVs, new systems were gradually integrated. Currently, beside the AR100-B there is also a Microdrones MD-400 as well as a MikroKopter with eight rotors (MK Okto). The user can identify the system by its call sign – the operation of the drone, however, remains identical, rendering the complexity of the heterogeneity transparent.

Figure 2. Sensor platform AirRobot 100-B

V. ALGORITHMS

To be able to clarify an area of interest by multiple drones the polygon defining that area must be divided into several subareas, which can then be assigned to the individual UAVs. It is important that each of the branches is economically optimized for its appropriate drone. UAVs with longer endurance or higher sensor payload can clear up vaster areas and should therefore receive longer flight plans than systems with a lower performance.

Besides, the flight routes must consider the behavior of the drones at the single photo points and their flight characteristics. Tests with the multicopter systems have shown that an optimum picture result can be achieved if the system stops at each photo point for two to four seconds to stabilize. Proceeding precisely in such a way, no special flight behavior must be considered, because the drones show identical flight characteristics in every flight direction due to their construction. Indeed, this behavior also decisively affects the operation range, because such stops reduce the efficiency of the drones. To solve this problem, a stabilized camera platform, which compensates the roll, pitch and yaw angles, was developed at Fraunhofer IOSB. Nevertheless, if the photo points are flown by without a stop, an enlargement of the flight radii must be considered at turning points. Since in future versions also fixed-wing aircrafts may be used, further attention must be paid to the fact that the calculated flight paths can also be optimized for systems with different flight characteristics.

The algorithm developed from these demands consists of two main steps. The first part is to break down the given polygon of the search area in suitable partial polygons *(A)*. Then, the optimum flight route per partial polygon is searched for each individual drone *(B)*.

A. *Calculation of the partial polygons*

Different attempts for decomposing the whole polygon into single sub cells were investigated.

A nice and elegant method to divide an area into subareas is the so-called “Delaunay-Triangulation” [6]. Unfortunately it proved to be very difficult to divide a polygon in such a way that the resulting partial polygons correspond to a certain percentage of the whole area.

In addition to the basic triangulation the single polygon needed to be checked for their neighborhood relations in order to compose them accordingly again. The originating branches would hardly correspond to the targeted area size so that additional procedures would have to be used.

As an alternative the possibility to divide a polygon by using an approximation procedure and surface balance calculation to get partial polygons was investigated. With this variation the polygon is disassembled first into two incomparably large parts by using predefined angles through the surface balance point. Besides it is irrelevant whether the balance point lies outside or within the body. According to the desired size the algorithm can select the bigger or the smaller partial polygon as a source area for any further decomposition. Afterwards the calculated partial polygon is divided again by the surface balance point. This process continues recursive until the requested area size is reached. On this occasion an approximation procedure could be used to calculate a solution as quickly as possible. However, this segmentation method only works with convex polygons. For concave polygons it is necessary to prevent that the area is divided into more than only two parts.

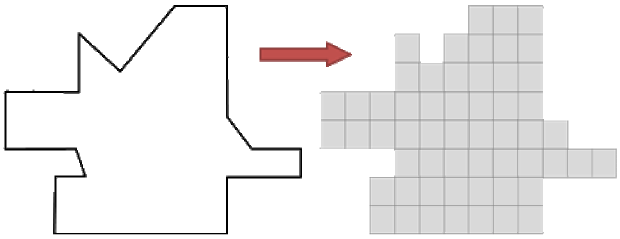
Figure 3. Scanning procedure

A quicker and mathematically less complicated variation to split a polygon is the scanning procedure (see Figure 3). The method is equal to what is called rendering or scan conversion in 2D computer graphics and converts the polygon into a grid of cells. That implies that a higher resolution (i.e. a smaller cell size) will result in a more accurate match of the grid with the originally defined area. To be able to divide the grid afterwards the number of required cells is calculated from the desired area size. With this information and by using a suitable growth algorithm, which extends from any start cell within the grid as long as enough cells have melted, one single continuous area of the desired size can be calculated. This technique resembles the flood-fill algorithm [7] also known from computer graphics. Likewise in this case it is very urgent to know the neighborhood relationship of the cells. Nevertheless, this is quite simple because in contrast to the same problems with

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the triangulation each of these cells is commensurate and is therefore easy to assign to the co-ordinate system.

To receive a very simple and steady grid polygon, different growth algorithms were compared to each other. A straight growing algorithm turned out to be the most efficient because the results showed more straight edges than other algorithms. In direct conclusion this means a significant reduction of the required rotary and turn maneuvers of the UAV, which leads to a better cost-value ratio in case of using UAVs with a limited turning rate. The generated grid polygons are recalculated into partial polygons just to disassemble them once more into a grid. This time the grid size corresponds to the calculated dimension of the footprint, which depends on the camera specification (focal length and picture sensor) in combination with the desired flight altitude of the drone.

B. *Calculating the flightpath*

To receive an efficient and economically reasonable flight route it is important to find the shortest path that includes all way points and that in addition contains the smallest possible number in turn maneuvers.

The best flight path solution can only be calculated by using a highly complex algorithm and even than an optimal result cannot be achieved in limited time (see the problem of the travelling salesman [8]).

To get acceptable results under the constraint to keep the expenditure as low as possible, different variations were checked mutually.

Because as mentioned earlier a very steady flight route with as few as possible direction changes offers big economic advantages, a method was developed, which processes the polygon according to its expansion in columns or line-by-line similar to a type writer. The so calculated flight route shows a clearer construction in particular with bigger areas.

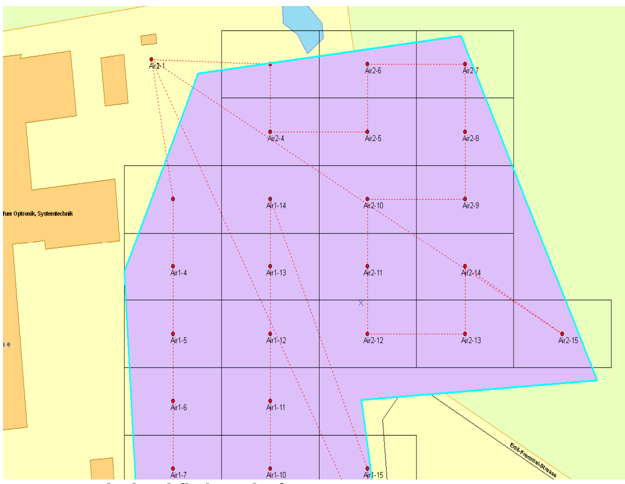

Figure 4. Calculated flight paths for two UAVs

Afterwards the calculated flight route is complemented with safe approach and departure air corridors to avoid collisions between the team members.

VI. POST PROCESSING

The data accumulated by the drones are post processed after the flight to generate an overall result from the single images. Two steps of post processing are done: transferring the images *(A)* and the mosaiking and geo-referencing *(B).*

A. *Transferring the images*

To receive high-quality pictures, high-resolution cameras (10-15 megapixels) are used as payloads for the UAVs. In order to transmit the originating images to the ground station a transport medium must be used that has enough data capacity available. The most elegant method to transfer the images is to use the downlink of the drone. This assumes that the UAV provides an interface, which can be used to feed the data into the downlink of the system. If such an interface is not available other procedures have to be found. During the development of the photo flight, different technologies were tested and evaluated.

To keep the system as simple as possible, the best solution would be to select a communication device that has a great acceptance and is widely used. Therefore the first drafts where done by Wi-Fi. To build such an additional communication line between the UAVs and the ground station a small secure digital memory card was used. This SD card fits perfectly well into the payloads and is able to establish a Wi-Fi connection and to transmit the captured images automatically. The problem with this solution is that in most cases the frequencies for the digital video downlink of the drones is in the 2.4 GHz band which is also used by Wi-Fi for broadcasting. For this reason it can be assumed that at least the Wi-Fi transmission will be disturbed heavily. The best solution for this problem is to move either the digital video downlink or the Wi-Fi to the 5 GHz band. Unfortunately in the current system stage the video downlink is fixed and the used Wi-Fi SD card is not capable of using the 5 GHz band.

For now, the images have to be transferred manually to the ground station.

B. *Mosaiking and geo-referencing*

To benefit from the advantages of the photo flight in full extent, the images taken must be merged to an overall situation picture according to the demand and can be brought into the correct geographical position.

For this purpose different tools were compared to each other. The application of different freeware products showed completely good results but the integration into the overall system proved to be difficult. The software ABUL, (Automated image exploitation at the example of the UAV LUNA), which was also developed at Fraunhofer IOSB would be a possible candidate. However, it is on account of its application aim a too mighty software, which would need, in addition, immense hardware capacities.

Due to the fact that the geo information system used in the photo flight application is based on the software by ESRI [9], which also provides different methods for mosaiking and geo referencing, this variation was also examined. The first results did not show the same quality as previous experiments but they are promising.

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The main problem, which leads to disturbances in the final mosaic is, on this occasion, the divergence or inaccuracy of the calculated footprints of the sensor payload. These calculations are based on the GPS position of the drone and the aperture angle of the optic or the size of the used sensor.

To reach more exact values a way must be found to bring the calculated positions of the UAVs in consistency with their real positions. Because these problems are not trivially solvable, another approach could be more promising. Thus it is examined at the moment to what extent the calculation of the corner co-ordinates of the single images can be improved by taking into account certain a priori knowledge and the use of various filters.

VII. Conclusions

The described algorithms were implemented as a software library and are integrated into a geographic information system based on ESRI software specially provided for test purposes. The photo flight tool is an independent software module whereas the logic behind it is interchangeable and thus can be used in other software modules like the situation representation module of AMFIS mentioned above. The results of the algorithm and its ability to adapt to new flight systems with other flight characteristics are currently evaluated. The software was integrated into a three-dimensional simulation tool and the first real test attempts with homogeneous and also with small heterogeneous swarms have taken place.

This research project resulted in a complex prototype system, which is able to form a fully autonomous swarm of UAVs on the basis of several drones and a standard PC or mobile computer at almost any place in very short time that allows acquiring a highly up-to-date aerial image. The sustained data can also make it possible to understand complex blind scenarios quicker. It permits a more exact planning and simplifies the contact with the situation. The deployment of a swarm with a theoretical unlimited number of UAVs means thereby a huge advancement in the field of local just-in-time reconnaissance.

VIII. Extensions and Further Work

In parallel to the work on the photo flight algorithms a small gas sensor, which can also be carried as a payload by an UAV was developed in cooperation with an industrial partner (see Figure 5).

The gas sensor is designed as a very light and compact payload and has been built as a prototype. It can be equipped with up to five different gas sensors and contains, in addition, a sensor to detect universal inflammable gases and a photoionisation detection sensor. Future versions will also be able to detect temperature and humidity. The selection of the five gas sensors can be changed to fit different applications at any time. A supplementation or a further development of the photo flight, in which at least one UAV is equipped with a gas sensor, is planned. Because the aim of this application differs from the original task - visual reconnaissance - above all the geometry of the flight routes must be adapted. This can be assumed from the fact that either the propagation of the gases or the concentration at certain places is of interest. That means that a meandering flight path over a relatively small area makes no sense.

Figure 5. Gas sensor to detect inflammable gases, Ammonia, Nitrogen Dioxide, Sulphur Dioxide, Carbon Monoxide and Chlorine

To recognize the propagation of gases certain a priori knowledge like origin, wind force and direction is necessary. With the help of these data a propagation model can be provided as a basis for the calculation of optimum flight routes to validate the estimated results.

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