# Rapid Aerial Mapping with Multiple Heterogeneous Unmanned Vehicles

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## ABSTRACT

In this article, work in progress on a system for rapid aerial mapping is presented. We believe that a tool able to quickly generate an up-to-date high resolution aerial view, e.g. shortly after a natural disaster or a big incident occurs, can be a highly valuable asset to help first responders in the decision making. The presented work focuses on the path planning capabilities of the system, together with the area partitioning and workload distribution among a team of multi-rotor unmanned aircraft. Sensor footprint and range of the involved aircraft may differ. The presented approach is based on an approximate cellular decomposition of the area of interest. The results of this work will be integrated into an existing system which already provides a mobile ground control station able to supervise and control multiple sensor carriers.

### Keywords

Crisis management, aerial situation image, unmanned aerial vehicles, complete coverage path planning.

## INTRODUCTION

The security feeling of our society has significantly changed during the past years. Besides the risks arising from natural disasters, there are dangers concerning criminal or terrorist activities, and accidents in industrial environments. Especially in the civil domain, there is a big need for a better data basis to support the rescue forces in decision making.

Common characteristics of such events is that they cannot be foreseen in their temporal and local occurrence, also in situ security or supervision systems may not be present or they may have been rendered unusable. The data basis on which decisions can be made is rather thin and therefore the 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 specific suitable actions efficiently.

In recent years, technological advances have lead to the development of miniature unmanned aerial vehicles (UAV), which have become highly capable and affordable systems. In this paper, an aerial mapping tool is described which takes advantage of the capabilities of current unmanned aircraft to provide a valuable overview of the site of the incident in a very short time. Multiple single high resolution pictures taken by a team of UAVs are combined in order to provide a precise situational image of the area.

Our current research effort aims at further developing an existing tool which is already able to generate such images [1]. In the current implementation, the user can select an area to be inspected and the unmanned aircraft to be used in the mission. Afterwards, the area is partitioned into regions, taking into account the number of aerial vehicles, and a flight path is computed for each one of them. Then the aircraft are sent to autonomously acquire the images. Finally, the taken images are stitched together to provide a complete aerial view of the area.

The main enhancements resulting from the presented work, which the tool described in [1] benefits from, are an improved path planning algorithm, support for no-fly zones inside the area of interest, and an improved area partitioning mechanism which takes into account sensor footprint and range capabilities of the platforms involved in the mission.

The aerial mapping tool integrates into a mobile ground control station which enables its deployment in a very short time. The requirements for the take-off and landing of the aircraft are minimal. A user friendly interface simplifies its operation. Finally, by using multiple aircraft, the time to cover an area can be reduced or respectively a bigger area can be covered in the same time.

## RELATED WORK

There are several projects that propose data gathering solutions based on multiple unmanned aircraft for emergency situations.

In the SkyObserver project a geometric optimal placement algorithm is used to distribute the unmanned aircraft inside a given area. Advantages of the approach are that agents can be added or removed at any time and that the area can change during the mission. While these are important properties, it is not clear if fast complete coverage is guaranteed. Also, the approach doesn't consider the possibility of no-fly zones inside the area of interest [2].

In the AirShield and AVIGLE projects similar techniques are used. However, in this case, a more holistic approach which simultaneously considers spatial coverage optimization, the mobility strategy to explore the area and communication awareness is followed. [3, 4, 5]

In the context of the COMETS project, the area of interest is first decomposed into non-intersecting regions taking into account UAV's relative capabilities and initial locations. Afterwards, the resulting areas are assigned among the UAVs, who will cover them using a zigzag pattern. This solution, described in [6], is limited to convex polygons without obstacles.

Finally, the problem of rapidly creating an aerial image of a given area is also addressed in the cDrones project. Like in our case, the proposed solution is based on a grid approximation of the area of interest. Optionally, it's possible to optimize the positions where pictures should be taken by formulating the question as an ILP (integer linear programming) problem. A genetic algorithm is used to compute the flight path. While the system is able to use multiple aircraft, the method for distributing the workload is not described [7, 8].

Although the path planning methods differ, there are many similarities between the approach described in [7] and ours. Determination of the picture locations using ILP enables a more accurate mapping of the boundary zones; however this leads to more complex trajectories. In our case, the goal is to generate an efficient complete coverage path prioritizing long straight path segments. A more detailed study would be necessary to determine in what circumstances each method is more time and energy efficient.

Decentralized planning methods as in SkyObserver, AirShield and AVIGLE try to maintain connectivity between nodes. As a result, constraints imposed on the trajectories make complete coverage harder to achieve. We propose a practical approach where each aircraft executes a pre-assigned path. One aim of our approach is to allow the specification of no-fly zones inside the area of interest. With the exception of cDrones, the referenced projects don't provide support for no-fly zones. Finally, most approaches do not consider the possibility to perform the mission with heterogeneous platforms.

## CURRENT STATUS OF THE RESEARCH

Our recent work has already led to the development of a path planning algorithm for the fast generation of an efficient path for complete coverage of an area. The area of interest is divided into cells with a size proportional to the footprint of the sensor. A cell size smaller than the actual footprint provides the necessary overlap to enable stitching the pictures together. Different rotations are applied to the target area in order to minimize the number of edges found in the contour of the resulting grid.

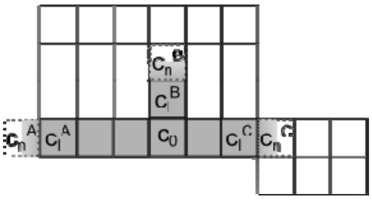

**Figure 1. Example cell sequences starting at $c_0$.**

Finding a path that visits each cell on the grid only once is similar to the Travelling Salesman Problem, thus trying to find an optimal solution could be time consuming and not appropriate for an emergency response situation. After researching the state of the art, a new method has been proposed which prioritizes the selection of the longest sequence of consecutive adjacent cells without turns. In Figure 1 an example is provided to illustrate how the formation of these sequences takes place. Being $c_0$ the starting cell, three possible directions are considered. One possibility is to advance to the left until an area limit is encountered. This option results in a sequence of length four (including $c_0$). Another option would be to move upwards. In this case we would advance through open space, which would eventually lead to the partition of the area into two different subareas. To avoid this situation, the upwards sequence only contains two cells, which means that after moving from $c_0$ to the next cell, the system would stop and consider in what direction to advance next. Finally, the third option is to move rightwards. The sequence ends at the point where we stop following the lower boundary of the area. The general idea is that the formation of these sequences stops when an area limit is reached or when a point is reached where there is a change related to the boundaries of the cells. At that point, a decision concerning the next move is required.

In the example of Figure 1, the sequence to the left direction is the longest one among the three possibilities, and therefore is the one that gets selected. The general algorithm for generating the complete coverage path works as follows:

1. Set the current cell to the initial cell.
2. Find all unvisited neighbor cells of the current cell (between 0 and 4 cells are returned).
3. Generate the longest possible sequence in the direction of each unvisited neighbor cell.
4. Select the longest sequence.
5. Add all cells of the sequence to the path and mark them as visited.
6. Set the current cell to the last cell of the sequence.
7. Repeat starting at point 2 until all cells have been visited.

Additional details about the proposed algorithm can be found in [9]. In Figure 2, some example paths generated using the proposed algorithm are shown.

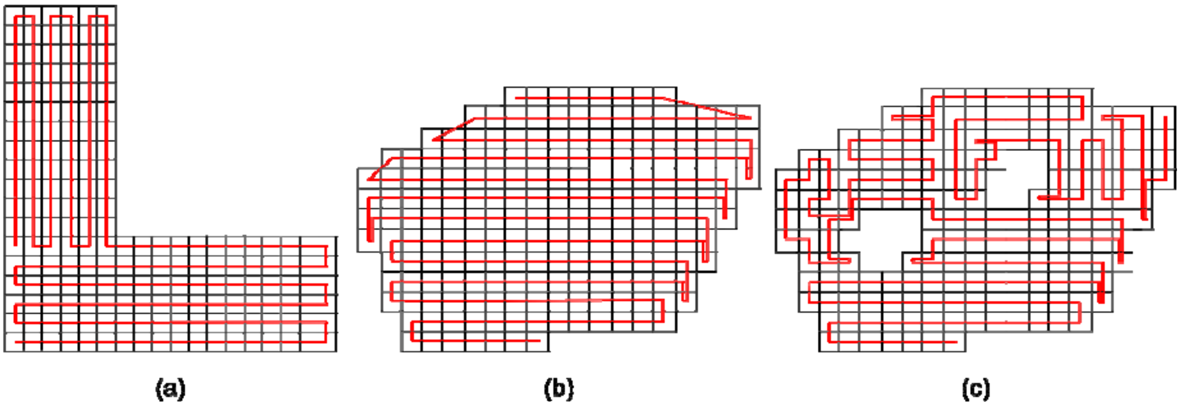

**Figure 2. Example paths generated with the proposed algorithm.**

Since the algorithm is able to compute a complete coverage path in a short time, it is possible to apply it choosing different points for starting the mission. Afterwards, a cost function can be used to choose the solution which yields best results.

## ON-GOING WORK

In the previous section our method to compute an efficient flight path that completely covers an area of interest is described. However, when the aerial pictures are to be taken by more than one aircraft, the area of interest must be first divided into several parts. The process of dividing the area taking into account aircraft capabilities is the focus of our current work.

Our partitioning method also relies on a grid approximation of the area. In past efforts, a flood-fill like algorithm was adopted in order to perform this partitioning step. After an initial calculation of the number of cells that will be allocated to each aircraft, the algorithm takes a starting cell and grows the area by selecting neighbor cells until the desired percentage is reached. It then proceeds in the same manner for the remaining aircraft. This approach can lead to the situation depicted in Figure 3, where some unallocated cells are left isolated (see top right of the first grid). The current algorithm is able to redistribute cells between areas in order to solve this problem.

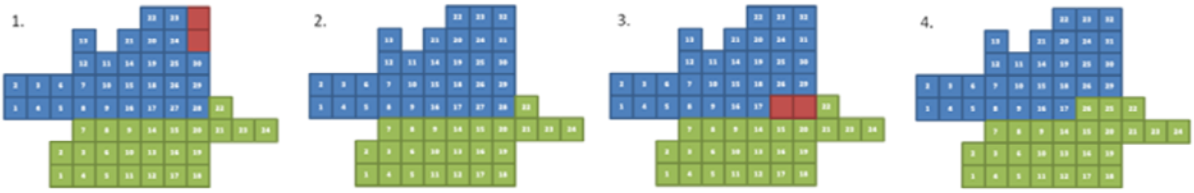

**Figure 3. Partitioning to equally distribute workload between two unmanned aircraft.**

In our current work, we are adapting this approach to handle aircraft with different range and footprint. This leads to new problems that need to be addressed:

- First, one needs to compute which percentage of the given area should be allocated to each aircraft. These percentages depend on the length of the flight path, that is computed later and which, in turn, depends both on the sensor footprint and the aircraft range. For these reasons the actual percentages are based on estimated values.
- Once the percentages are known, the corresponding number of cells must be allocated to each aircraft. However, we need to take into account that sensor footprint may differ. An initial approach currently under development uses as many grids as aircraft. The cell size of each grid depends on the aircraft's sensor footprint. Figure 4 illustrates this process. The partitioning algorithm is applied to the first grid using the previously computed percentages. Once the partition has been done, the part that belongs to the current aircraft (number 1 in Figure 4) is projected onto the rest of grids and marked. Afterwards, the process is repeated with the next grid with a smaller area and one less aircraft to assign cells to.

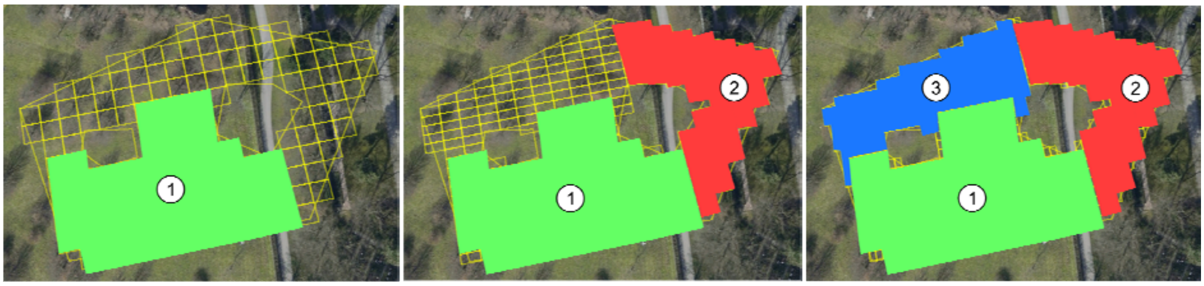

**Figure 4. Partitioning to proportionally distribute workload between three unmanned aircraft.**

## FUTURE WORK

After the work on the partitioning method is completed, the resulting algorithms will be integrated into the existing path planning tool. The current mission planning code will be replaced with the new implementation and the GUI will be adapted to enable the users to specify non-flying zones inside the area of interest.

One of the aspects that need further development is ensuring collision free operation during a multiple aircraft mission scenario. Allocation of different areas to different vehicles already reduces such risk. However, when the aircraft operate at the boundaries of the subareas or when they need to cross other subareas to reach their own, collision risks cannot be neglected.

Another aspect that also needs to be addressed relates to the actual footprint of the sensor with different camera orientations or in the presence of irregular terrain. In our current solution vehicles are equipped with a down facing camera. A configurable overlap between pictures facilitates stitching and provides room to cope with GPS imprecision.

Finally, the generated path plans are suitable for maneuverable systems such as multi-rotor aircraft. Future work should address the adaptation of the flight planning algorithm to enable the utilization of fixed wing aircraft, which are not able to execute sharp turns, in a mixed team of unmanned vehicles.

## CONCLUSION

In this article work-in-progress on a solution for rapid aerial mapping of an area has been presented. The two main problems being researched are the partition of the area into pieces proportional to the capabilities of the aircraft and the generation of a flight plan for each one of the systems assigned to the task.

The results of this work will allow an existing tool to be improved with more efficient algorithms, support for holes in the area of interest, and the ability to deal with aircraft with different range and sensor footprints.

We believe that the high definition up-to-date aerial images produced by the system will be a key tool for first responders that will enable better decision making and task prioritization.

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