

High-Detail Local Aerial Imaging Using Autonomous Drones

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ABSTRACT

Aerial Imaging is mainly done with small planes from several kilometres altitude. A small unmanned quadcopter (a type of helicopter with four rotors) is an alternative airborne platform, which allows fast aerial imaging of small areas with a higher level of detail and lower cost. It can be used for updates of GI-Systems after natural phenomena, e.g. update of the tree population of areas affected by windthrow from storms. Another possible application is the detection of tree diseases like rottenness or bug infections. We have developed and performed a prototypic workflow for the update of the “Virtual Forest”¹, a database and framework for efficient forest planning and wood mobilization, using aerial image data collected with the quadcopter AirRobot^{®2}. We have integrated a software component into VEROSIM[®], a software solution for virtual reality and GI-Systems, which allows the autonomous routing, flyover and imaging of a selected geographical unit, e.g. a land parcel, and the subsequent georeferenced display of the aerial images.

1. INTRODUCTION

In today's administration and business procedures, geographic information (GI) becomes more and more important: Architectural models are placed in three-dimensional mock-ups of the area, cadastral officers use aerial photographs to find differences between maps and reality, mobile networks are planned using a three dimensional representation of the ground and information about the buildings and natural cover. All these applications need GI on large areas. This information is often collected using airplanes equipped with lidar (light detection and ranging) and photographic sensors. The airplane is tracked with GPS, inertial measurement unit, barometric altimeter and differential GPS information.

But besides this long term GI, many applications need up-to-date information on a limited area: Insurance companies do not need an aerial photograph taken twelve month ago and available from the cadastral authorities when they have to estimate the claim after a forest fire, police needs up-to-date information on an accident site to collect evidences, archaeologists need accurate aerial photographs of the current situation when they have to judge a site. All this information is laborious or expensive to collect on the ground: Police often uses trucks with elevating platforms, insurance-companies and archaeologists spend money in local area sensing performed with remote-sensing technology including the costs that emerge from this technology.

The rest of this paper is organized as follows. Section 2 motivates the usage of quadcopters for aerial surveys. Section 3 describes the developed software component and workflow with an example application. Section 4 discusses the current status and future improvements concerning the georeferencing of aerial image data collected with drones. Section 5 shortly concludes the paper.

¹ <http://www.mmi.rwth-aachen.de/?virtuellerwald0>

² <http://www.airrobot.de>

2. THE IDEA

Today there are alternatives to remote-sensing with airplanes or helicopters. Small autonomous flying vehicles – so called drones – can monitor the environment. A light-weighted, affordable version of a drone is for example a quadcopter, a vehicle similar to a helicopter but equipped with four upright oriented rotors of equal size. Quadcopters offer the same flight capabilities as usual helicopters and are therefore capable of vertical take off and landing. At the same time, because all flight maneuvers are achieved just by individual controlling of the four rotor speeds, quadcopters don't need any mechanic components. Together with modern, brushless electric motors containing no wearing parts, quadcopters are nearly 100% maintenance-free.

Despite all these advantages, quadcopters were very hard to realize or at least very hard to control in the past. The quadcopter is inherently unstable; therefore simultaneous individual control of each of the four motors is necessary to achieve a stable flight attitude. This is a complex problem, which could only be solved using recent progresses in the fields of control engineering and microcontroller technologies. Thus today flying a quadcopter-platform even for non-professional users is as easy as controlling a remote control toy car. Furthermore even fully autonomous flying guided by waypoints becomes possible. Operators then will no longer worry about flight control, but instead define a route of interest, press a button and just watch the drone collecting sensing data of the predefined route and returning safely.

A typical quadcopter with an extent of no more than one meter has got a payload of 200g to 400g and flight duration of 20-30 minutes. To a certain extent, flight duration can be traded for payload and vice versa. No training or permission is required for a non professional operator to fly a platform of 1m size. This is enough to carry a photographic camera or even a stereoscopic sensor. Other sensors used in remote sensing are available in a light-weighted design or even are already integrated in a standard quadcopter. An inertial measurement unit is required by the quadcopter's control algorithm; often even a barometric device is included for flight-level-stabilization. Optional navigation equipment is an optical system for keeping the actual position or a GPS receiver. The GPS receiver with the respective navigation system is essential for the autonomous aerial survey.

3. EXAMPLE APPLICATION FOR SMALL-SCALE AERIAL IMAGING

The heart of the “Virtual Forest” (section 3.1) is a GI database of the forest stand in North Rhine-Westphalia (NRW), Germany. It can be accessed by VEROSIM[®], a software solution for virtual reality systems and GI-Systems (GIS). We have developed and performed a prototypic workflow for the update of GI databases like the “Virtual Forest”, using aerial image data collected with the quadcopter AirRobot[®]. We have integrated a software component into VEROSIM[®], which allows the autonomous routing of a selected geographical unit, e.g. a land parcel. The Airrobot[®] performs the aerial survey, taking pictures at the specified locations. The images are then imported into VEROSIM[®], combined via photo stitching algorithms and added to the database as an additional GIS layer.

3.1 The “Virtual Forest”

In order to support competitiveness on the worldwide market - but also to overcome efficiency problems related to the forest owner structure in NRW - the "Virtual Forest" (Rossmann, 2007) is being developed as an intelligent planning and decision support tool for forest growth as well as for wood mobilization. In practice, the heart of the Virtual Forest consists of a database of approx. 240 million single trees in NRW, its major wood resource. In order to identify the trees, latest aerial survey and satellite technology is used and combined with virtual reality and robotics know how in order to efficiently gather and visualize the data. Thus, the Virtual Forest will serve as a reliable and

very up-to-date base and framework for new efficient forest planning, wood mobilization and machine logistics methods.

The “Virtual Forest” project is supported by the State of NRW, the forest administration of NRW and the European Union (Europäischer Fonds für regionale Entwicklung - EFRE).

3.2 State-of-the-art quadcopters

For the prototypic workflow presented in section 3.4, the commercial quadcopter Airrobot® AR100-B is used. The AR100-B is a flying platform with four brushless, gearless electric drives, position control, barometric height control and GPS-based position hold. A 10 mega pixel digital camera is installed as payload and can be rotated around one axis between vertical and horizontal orientation. With its total take-off weight of 1.3 kg the AR100-B can cope with a wind force of up to 7 m/s and perform flights of up to 30 minutes duration. Airrobot® recently developed a waypoint navigation software, that allows the AR100-B to approach GPS positions received online via digital short range radio. This feature will allow fully autonomous survey flights. Similar commercial flying platforms are the Microdrones® MD4-200, the Draganflyer™ X6 or the Hummingbird by AscTec.

3.3 VEROSIM® and the “Quadcopter GPS Survey” plugin

VEROSIM® is a software solution for virtual reality systems and GIS, developed at the Institute of Man-Machine-Interaction, RWTH Aachen University. Originally specialized on the simulation of robot cells for industrial applications, VEROSIM® now provides a wide variety of applications ranging from the simulation of the international space station or large agricultural machinery to a full forest inventory using its GIS and database features. It can easily be extended with additional plugins.

The “Quadcopter GPS Survey” plugin presented in this paper and used throughout the described workflow in section 3.4 provides the following functionality:

- Automatic generation, visualization and editing of flight paths for aerial surveys performed with drones.
- Interface to the Airrobot® software on the drone. Currently this covers only an XML export of the GPS route, but a direct online interface to the drone is under progress.
- Import of aerial images taken with drones. The images are automatically combined using integrated image processing tools and added to the GI database as additional layer.

3.4 Workflow

Before the aerial survey, the operator, e.g. a forest officer, chooses a target area for which a GPS route is automatically generated. In the field, he unpacks and starts the drone. After the route is transferred to the drone, this autonomously performs the aerial survey and returns to the starting position. The operator copies the images from the camera’s memory card to his laptop and imports the images into the GI database.

The following steps exemplify the usage of a quadcopter for local-area-sensing combined with the new “Quadcopter GPS Survey” plugin in VEROSIM® in more detail.

Step 1: Select Geographical Object

Access the Virtual Forest via VEROSIM® and select geographical objects. The selection can contain any combination of geometrical objects. In our example, we choose a land parcel.

Step 2: Generate Waypoints

At the push of a button, waypoints for the aerial imaging of the selection are generated. To simplify the combination of pictures taken within one flight and the subsequent combination of whole surveys, not only the selected object, but its axis aligned bounding rectangle (AABR), whereas axes are longitude and latitude, is covered. We assume that the top of the quadcopter camera is oriented northward, which is no restriction, since the quadcopter has no preferred orientation or flight direction. The route covers the AABR in a sinuous line, minimizing the flight distance, starting from and ending at a specified start position and depending on the following parameters:

- Altitude
- Camera opening angle
- Camera format
- Overlap picture to picture in longitude and latitude
- Overlap at selection border
- Starting position

Figure 1 shows a visualization of the route overlaid to a GIS layer containing RGB orthophotos obtained by remote sensing. The transparent green pyramids visualize the field of vision of the quadcopter camera at the waypoints where pictures should be taken. The red line connects these waypoints and the starting point in the lower left corner. Note the overlap around the selections bounding rectangle and between the pictures, where the green becomes more intense. The “Quadcopter GPS Survey” widget on the left hand side currently displays a list of waypoints generated from the selection. If the user is not satisfied, he can simply alter the above parameters and generate a new route.

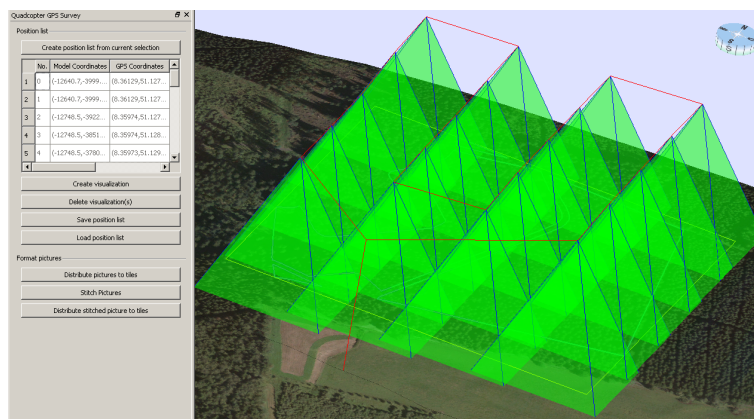


Figure 1: GPS route visualization.

Step 3: Send GPS Route to Quadcopter

The generated list of GPS waypoints should then be sent to the quadcopter. Since the autonomous waypoint navigation software of Airrobot[®] was completed only recently, the list is currently stored as XML file but will be adapted to the interface of the new Airrobot[®] software as soon as possible. This data exchange can of course be extended to other software or hardware requirements.

Step 4: Aerial Survey

The quadcopter performs the aerial survey. At the specified waypoints, pictures of the subjacent ground are taken and saved to a memory card. As already mentioned, the autonomous waypoint navigation software of Airrobot[®] was completed only recently. It was already tested thoroughly by Airrobot[®] and we can probably start testing in March 2009. In the meantime test flights had to be performed manually by remote control.

Step 5: Import Images to GIS

The pictures from the aerial survey can then be imported into VEROSIM[®] and combined using photo-stitching algorithms. The combined picture is then tiled to an additional GIS layer and can be stored in the Virtual Forest database. The photo stitching is currently performed using the following integrated tools:

- autopano (Jenny, 2009) – Generates control points for a set of overlapping pictures.
- ptoptimizer (Dersch, 2001) – Optimizes positions and sizes of images using control point data.
- ptmender (Dersch, 2001) – Remaps, adjusts and combines images.
- enblend (Mihal, 2008) – Smooth, seamless combination of aligned images

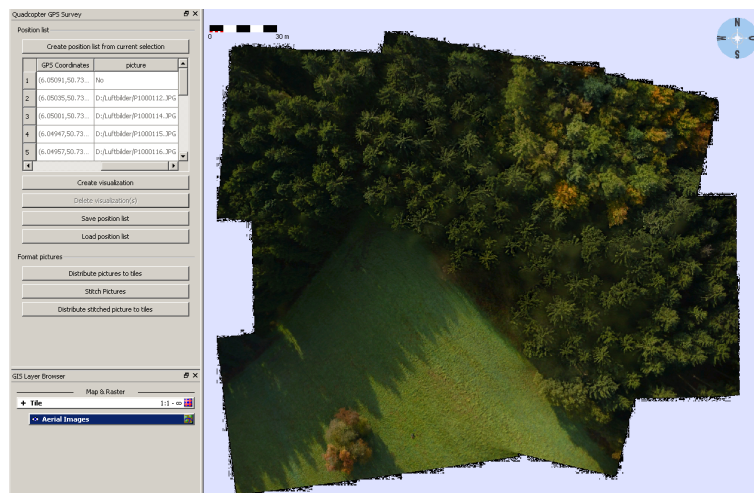


Figure 2: GIS layer containing a stitched combination of images taken during a quadcopter flight over the forest of Aachen, Germany.

Figure 2 shows the stitched combination of a set of images taken during a quadcopter flight over the forest of Aachen, Germany. Note that this flight was performed manually due to the mentioned reasons. Although a non-professional operator can easily handle the quadcopter, approaching an exact position and orientation with a 1m-drone 150m above one's head while not exceeding flight time is difficult. Therefore the original images are not aligned and the covered region is relatively small. The misalignment can easily be compensated by the stitching algorithms. The utilization of the flight time for larger areas and the alignment should improve dramatically with the GPS waypoint navigation software.

4. GEOREFERENCING

The final goal of the described workflow is the update of an existing GI database, in this case the "Virtual Forest". To this end, the combined picture from the aerial survey has to be overlaid to the existing GI. This requires georeferencing of the combined picture with respect to position, orientation and size (or scale).

4.1 Current Status

The georeferencing of a stitched picture is currently done in the following way. The width of the area represented by an image can simply be derived from the camera opening angle and the flight height:

$$\text{width} = 2 \cdot \text{altitude} \cdot \tan\left(\frac{\alpha_{\text{opening}}}{2}\right)$$

If the exact camera opening angle at a certain setting is not known, one can simply take a picture of a large object of known size at known distance and turn around the formula.

Under the assumption that the images are aligned (top oriented northward), position and size of the stitched picture are given by the following simple combination scheme of positions and sizes of the input pictures (Figure 3, left).

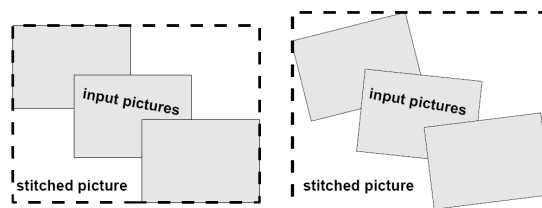


Figure 3: Size and position of stitched picture (left: ideal, right: with orientation deviations).

This basic approach has the following problems and restrictions:

1. The alignment will not be perfect in practice (Figure 3, right). The stitching algorithm produces a picture representing a bounding rectangle of the real areas exposed to the camera, whereas the accuracy depends on the conditions (overlap, quality of control points, distortions). If this picture is then fitted into the assumed size (Figure 3, left), scale and consequently positions are distorted.

2. The centre of a picture will not be exactly below the quadcopter GPS position at the time the picture was taken, since the quadcopter will always have a little declination depending on the wind strength. The stitching algorithm will correct for this and again, the stitched picture has a different size than assumed.
3. The input pictures are perspectively distorted and not orthogonal. In contrast to a map, the scale of a photograph is not uniform. Thus, also in the georeferenced stitched picture, object positions will not be accurate.

4.2 Future Improvements

The following ideas should overcome the problems mentioned above.

1. The georeference should be integrated in the stitching process. If the centers of the input pictures are tracked throughout the stitching process, just like the generated control points, their output configuration can be used to optimize size, position and orientation of the stitched picture with respect to the “true” GPS waypoint configuration (Figure 4).

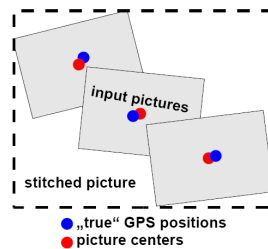


Figure 4: The georeference of the stitched picture can be improved by minimizing the distances between the “true” GPS positions and the picture centers.

2. There are two possibilities to improve the uncertainty on the GPS position of the input picture centers due to the declination of the quadcopter. Either the camera has to be tilted with respect to the quadcopter to compensate its declination or the declination has to be stored together with the pictures and GPS positions to calculate the picture centre from Quadcopter position, altitude and declination. The first solution additionally reduces the perspective distortion, but makes higher demands on the camera mounting.
3. One can trade efficiency or level of detail for lower perspective distortion. Higher altitude results in lower resolution and lower distortion. Larger overlap regions allow the cropping of heavier distorted image borders, but reduce the area per survey. The complete orthorectification of the images requires a digital elevation model of the ground (McGlone, 2004). This will in most cases not be available with the necessary accuracy. But already a simple orthorectification using only the slope of the ground in longitude and latitude (which is probably known approximately) will surely be an improvement.

5. CONCLUSION AND OUTLOOK

We have shown that quadcopters can in principle be used for the aerial imaging of small areas. The outlined workflow covers all necessary steps between the selection of an area of interest and the display of the aerial images in GIS Software. The outcome of the performed prototypic tests (Figure 2 & Figure 5) are promising. The introduction of a GPS waypoint navigation software for autonomous flights and the intended improvements on the georeferencing will lead to higher efficiency and quality and bring practical applications within reach.

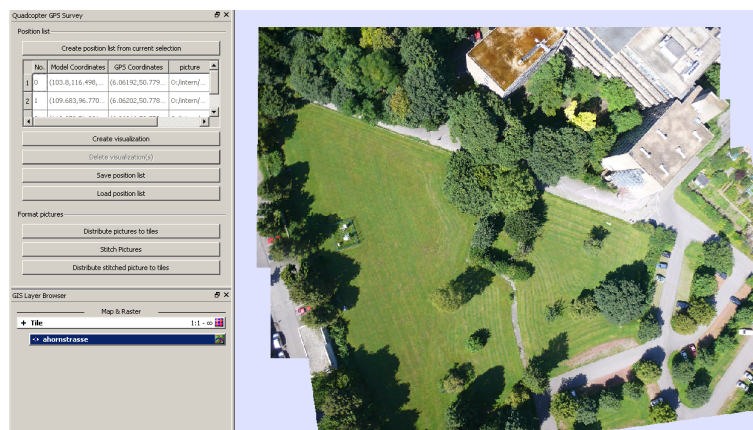


Figure 5: Screenshot of VEROSIM[®] displaying a GIS layer that contains a stitched combination of images taken during a quadcopter flight over a green area in Aachen, Germany.

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