Possible Applications of a Gyrocopter in the Field of Environmental Research

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Abstract

Anhalt University of Applied Sciences presented its innovative research gyrocopter at the Dessau Airfield in June 2014. It is a closed two-seater gyrocopter operated by the Institute of Geoinformation and Surveying. The gyrocopter is equipped with high quality sensors. Possible applications are in the field of remote sensing or 3D modelling. The gyrocopter can be used for environmental monitoring, mapping of inventory data, forest monitoring, precision farming, assessment of profits, derivation of water substances, 3D city and landscape models, atmospheric research and much more.

It is typically suitable for use in areas between 1 km² and 25 km² during one flight session. With its specific features, it can be classified within the operating range between modern drones and the traditional aircraft. In comparison to aircraft, it is a cost-effective alternative. Currently the gyrocopter is equipped with a RGB camera, a thermal camera and an imaging hyperspectral spectrometer. A flight management system and an inertial navigation system are integrated in the research platform for high-precision rectification and georeferencing.

1 Introduction

Anhalt University of Applied Sciences acquired a gyrocopter for research and teaching purposes in June 2014. The aircraft is equipped with very modern multi-sensory technology for research in the field of remote sensing. This involves, for example, the derivation of urban parameters such as the detection of aeration of cities, the generation of 3D city and landscape models but also the monitoring of waste dumps, the derivation of water or vegetation substances, or environmental monitoring. Another research focus is to support agricultural production. FRITSCH et. al. (2013) presented their first experience with an open gyrocopter for image data acquisition.

Gathered experiences show that commercial aerial image companies may be an unsuitable partner for scientific aerial surveys. This is often caused by the fact that companies have to carry out many projects simultaneously. They are therefore not able to meet scientific requirements sufficiently. Airborne research with hyperspectral sensors needs essentially an almost cloudless sky, which occurs statistically approx. 26 times in a year. Therefore, aerial surveys are often performed under adverse weather conditions. Furthermore, modifications to the aircraft are required for the fitting of the instruments. This often exceeds the tight
institute budgets. Operator errors from non-academic staff in handling the complex scientific measurement equipment lead to a need for repetitions of aerial surveys.

Due to the strong interest in evaluation and analysis of aerial image data, Anhalt University of Applied Sciences has acquired a gyrocopter. This light aircraft delivers much new inspiration for research and education. Research flights can be performed under optimum conditions because no commercial pressure exists.

Minimum requirements are defined before acquiring a light aircraft. It should be able to capture areas between 0.5 km² to about 25 km² in a time of 2-3 hours with the existing sensors. The airspeed should cover the range from slow (less than 50 km/h) to fast (up to 140 km/h) to achieve a high spatial resolution of the imaging sensors. In addition, various other sensors can be integrated. The payload of sensors should not exceed 60-70 kg.

Furthermore, the maintenance of the total system has to be acceptable in the long-term for a scientific institute. Taking these considerations into account, Anhalt University of Applied Sciences decided to purchase a closed side-by-side Gyrocopter of the type Cavalon from the company AutoGyro, Hildesheim. Since June 2014 the Institute of Geoinformation and Surveying in Dessau has been operating the gyrocopter.

2 Gyrocopter Cavalon D-MHSA from the Anhalt University of Applied Sciences

The Gyrocopter externally resembles a small helicopter. The difference is that the rotor (Fig. 1) of the gyrocopter is not driven directly by an engine but by the airstream generated by the propeller of the tail. Since the rotor is driven indirectly this is called autorotation. In order to keep the autorotation the gyrocopter requires a continuous airstrip. The aircraft cannot lift up vertically like a helicopter.

Fig. 1: Gyrocopter Cavalon D-MHSA from the Anhalt University of Applied Sciences
Depending on airspeed, the fuel consumption of 15-20 litres per flight hour is relatively low. The optimal flight speed for scientific measurements can be done between 80-130 km/h. However, the gyrocopter can be flown below 50 km/h. Then the flight behaviour becomes restless and image measurement flights can take place only conditionally. Depending on wind direction, wind speed and temperature, the gyrocopter requires a runway of 30 to 300 m. For landing the distance reduces to 0 to 50 m.

Based on a fictitious assumption that the pilot has a mass of 90 kg and the sensor weighs 60 kg, then 40 kg of fuel (equivalent to approximately 56 litres of fuel) can still be carried without exceeding the maximum take-off weight of 500 kg. In this case a flight time of approx. 3 hours is possible. Table 1 (AUTOGYRO 2015) shows some specifications of the university's aircraft.

**Table 1:** Specifications of the gyrocopter D-MHSA

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Width 1.8 m; length 4.7 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor</td>
<td>8.2 m</td>
</tr>
<tr>
<td>Motor</td>
<td>Rotax 914 UL, 115 PS turbo boxer engine</td>
</tr>
<tr>
<td>Consumption</td>
<td>15-20 l super unleaded fuel/h; 100 l tank</td>
</tr>
<tr>
<td>Climbing speed</td>
<td>85-100 km/h</td>
</tr>
<tr>
<td>Cruising time</td>
<td>30-160 km/h</td>
</tr>
<tr>
<td>Runway</td>
<td>30-300 m depending on wind and temperature</td>
</tr>
<tr>
<td>Landing strip</td>
<td>0-50 m depending on wind and temperature</td>
</tr>
<tr>
<td>Property</td>
<td>Stable flight attitude in turbulence</td>
</tr>
<tr>
<td>Tare</td>
<td>311 kg</td>
</tr>
<tr>
<td>Take-off weight</td>
<td>500 kg</td>
</tr>
</tbody>
</table>

The gyrocopter is a two-seater side-by-side aircraft. The seat on the left side (co-pilot) is removed to install the sensors. At the anchor points of the seat, the instrument rack is mounted and the sensors are integrated. For this purpose the bottom was reinforced and assigned with three recesses for the sensors. A motor-operated flap allows it to open or close them in flight and prevents the ingress of dust. During research flights the pilot has to simultaneously undertake the tasks of the operator and supervise the measuring systems in addition to the flight activity. This is a challenging task.

An additional alternator with a power of 1000 W is used exclusively for the energy supply of the sensors. In the operation of all currently installed sensors, the power output is a maximum of 400 W.

Because of its small size and mass, the gyrocopter can be transported to remote regions with a car and a trailer. This greatly increases the flexible use of the research platform at home and abroad, when bad weather conditions stop transportation flights.
3 Sensors

In the following sections, the integrated sensors in the gyrocopter are in focus. These include the hyperspectral imaging spectrometer, the thermal camera and the RGB camera.

3.1 Hyperspectral Imaging Spectrometer

The hyperspectral imaging spectrometer HySpex from the company NEO, Norway, is a measuring device for remote sensing. With a spectral sensitivity between 400 nm – 1000 nm, it is used for detection of environmental damages, forest monitoring, precision farming, derivation of water substances and much more.

By forward movement of the gyrocopter the imaging spectrometer captures line by line (1600 pixel) the reflected solar radiation from the earth. For each pixel a spectrum of 160 channels with a bandwidth of 3.7 nm (NEO 2015) is gathered. The opening angle is 34°. This results in a ground pixel size of 20 cm at an altitude of 600 m. Due to the technical development of hyperspectral spectrometer in recent years, weight and power consumption have been reduced drastically. The sensor head together with the data acquisition unit has a mass of 11 kg. The power consumption is 120 W. Parameters of the earth's surface derived with the help of spectral operations or by applying classification methods. Fig. 2 shows an example of a CIR image of Dessau with the associated spectrum of a tree.

![Fig. 2: Representation of a CIR image of Dessau (left) with the spectral curve of the radiance of a tree (right)](image)

3.2 Thermal Camera VarioCAM hr 600

Thermal cameras and thermal imaging are (Fig. 3) are used in remote sensing for detection of energy losses of cities, the inspection of supply lines, landfill monitoring, the moisture penetration of agricultural land, border protection and much more.
The installed thermal camera is a VarioCAM hr (Fig. 4) developed by the company InfraTec. It has a micro bolometer chip with a resolution of $640 \times 480$ pixels. The spectral sensitivity is between 7.5-14 µm wavelength. The measuring range of $-40$ to $+1200$ °C is digitized with 16-bit (INFRA TEC 2015). The camera is equipped with a pre-selected chip, so that a temperature resolution of 30 mK is ensured. At the standard flying altitude of 600 m above ground and a given camera opening angle of 30°, the spatial resolution is 50 cm. The triggering of the thermal camera is performed automatically during the flight. Release points are set in advance in the context of the flight planning. The triggering will take place as soon as the distance between the planned and actual release point is a minimum.

In flight planning, it is important to consider the “Non Uniform Correction” (NUC) which is adjustable but can also be operated manually. A NUC correction takes about two seconds. If the correction is carried out shortly before reaching the trigger point, a thermal image capture is not possible. If a NUC is done in large time intervals (e.g. after each flight line), this leads to temperature drifts. A minimum temperature drift is achieved by a NUC interval of 2 minutes.

The camera works on the principle of a rolling shutter. A theoretically straight road is curved as a result of this effect. In other words, the exterior orientation changes during image acquisition. This error was estimated and regarded as negligible. The infrared images are constantly recorded with 60 Hz. Depending on the trigger interval an image is selected from the frame grabber and stored together with the attitude and position data.

The required facilities for all the necessary corrections such as radiometric and geometric calibration are available at the Institute of Geoinformation and Surveying. For many applications, a radiometric correction is not strictly necessary because relative temperature differences are usually of interest and not absolute values. In any case, the geometric calibration must be carried out, so that the image data can be sufficiently accurately georeferenced.

### 3.3 RGB Camera AC-8

The AC-8 RGB camera system is essentially a Nikon D800e full-frame digital camera (NIKON 2015) that was modified for use in the gyrocopter. Some specifications are presented in Tab. 2. It is equipped with a vertical focal-plane shutter, which moves from top to
bottom. In contrast to the cameras with central shutter, the exterior orientation of focal-plane shutter cameras changes while taking images. This is disadvantageous. Therefore, aerial photo companies mostly preferred systems with central shutters. Lately, due acceptable distortions, more and more focal-plane shutter cameras are being operated to capture aerial images. These cameras are cheaper by a factor of 15-20, and of sufficient quality for many applications.

Table 2: Specifications of the AC-8 RGB Camera system

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera type</td>
<td>digital camera</td>
</tr>
<tr>
<td>Resolution</td>
<td>36.3 Mpix</td>
</tr>
<tr>
<td>Image format</td>
<td>24 mm × 36 mm</td>
</tr>
<tr>
<td>Shutter type</td>
<td>focal-plane shutter</td>
</tr>
<tr>
<td>Shutter speed</td>
<td>30 s – 1/8000 s</td>
</tr>
<tr>
<td>Focal length</td>
<td>50 mm (46.8°)</td>
</tr>
<tr>
<td>Remote control</td>
<td>USB 2.0</td>
</tr>
<tr>
<td>Frame rate</td>
<td>ca. 0.43 Hz</td>
</tr>
<tr>
<td>Weight</td>
<td>3 kg</td>
</tr>
<tr>
<td>Power</td>
<td>4.5 watt (max.)</td>
</tr>
</tbody>
</table>

The camera system (Fig. 5) is not equipped with a Forward Motion Compensation (FMC). Therefore, distortions occur where oval objects from circular objects arise. The image motion depends on the flight speed \( v \), the exposure time \( t \) and the image scale \( m \). It is calculated according to the formula:

\[
ds' = \frac{v \cdot t}{m}
\]

In this case, a flight speed of 100 km/h, an exposure time of 1/250 (0.04 s) and an image scale of 12000 are assumed (altitude 600 m, focal length 50 mm). Computationally there is an image motion of 0.00926 mm. This corresponds to 1.89 pixels or 11 cm GSD.

4 Aerial Survey in Dessau

The first flight with the Gyrocopter and the RGB camera system took place over Dessau-Roßlau on the 28th of August 2014. The aim was the creation of orthophotos and a digital surface model (DSM).

4.1 Flight Planning and Data Collection

A flight management system and an inertial navigation system are integrated in the research platform for high-precision rectification and georeferencing.

In addition to the described sensors, the gyrocopter is equipped with the flight management system AeroTopol and the flight software FlyMap. This makes it possible to fly to the research area and to trigger the sensors automatically and position-controlled. For the record of the attitude and position of the gyrocopter, the inertial navigation system iMAR IMU
FSAS in combination with the AeroDiDOS direct orientation system and DGPS is used. The IMU is a fibreoptic gyro with a measuring rate of 200 Hz. With this system position accuracy of 0.02 m RMS and height accuracy of 0.05 m, RMS can be achieved by the postprocessing. The triggering of the camera together with acquisition and storage of the GPS and IMU data is done with the AeroDiDOS system.

The flight planning was performed using a longitudinal overlap of 80 % and also as a test transversal overlap of 80 %. The flight over the study area was in the southwest-northeast-direction. With an 80 % overlap and a ground pixel resolution of 8.5 cm, the area was covered by 8 flight legs with a maximum of 32 frames per flight line. A total of 256 images were collected. The flight duration was 30 minutes (100 km/h) without approach and departure. It was started from the Dessau Airfield. Fig. 6 shows the flown trajectory with the real trigger points and the number of image overlaps at the area of interest. The red-colored areas have a small overlap (1-7) and are only conditionally suitable for the creation of a 3D model. In contrast, the green areas have a high overlap number (25-31). The triggered points not lying on a line can be attributed to stronger turbulences, which makes it difficult for the pilot to fly the exact line (red).

![Fig. 6: Trigger points and areas of overlap from flight on 28th of August 2014, Dessau-Roßlau](image)

### 4.2 Generation of a Surface Model from RGB Data

The digital surface model (DSM) in Fig. 7 was generated from the acquired RGB data with the software Agisoft PhotoScan. The first step consists of the orientation and calibration of the images per image triangulation. For the orientation of the images, the extraction of image correspondences by the SIFT algorithm is used.

The software provides various setting options. These include, for example, the maximum of corresponding points that were involved in the evaluation and the accuracy of the orientation of the images. The computing time various widely associated with these parameter settings. After input, all parameters 3D reconstruction are computed via correspondences. The generation of the point cloud is done using spatial intersection, followed by the meshing with texture. In the selection of parameter settings a high quality was generally chosen. Ultimately, this depends on individual requirements and circumstances such as the size of the considered area, the quality requirements and the available computational resources. The software provides a largely automated workflow which enables the generation of attractive surface models, also from non-specialists.

Since the implemented algorithm is not published, the program largely represents a black box. An accuracy and error assessment are limited. In these initial studies it was also estab-
lished that Agisoft PhotoScan reads all position angles in the program, but this is not used in the processing. Only the east and north values are integrated in its own process chain. The problems shown are the starting point for further studies at the Institute of Geo-information and Surveying to apply a suitable method for creating DSM with the data from the sensors of the gyrocopter.

5 Summary

The research gyrocopter from Anhalt University of Applied Sciences with its multisensoral technology was shown to fly budget-friendly over areas of 0.5 km² – 20 km². It is an aircraft between traditional measuring aircrafts and drones. The RGB camera, thermal camera and the hyperspectral sensor can be operated simultaneously in the gyrocopter. Its applications are for example in environmental monitoring. Further efficiency increases in the analyses of image data can be obtained with the overall system by exploiting synergies of the different working sensors in the future. The created DSM shows one of many possible fields of application.

References

AUTOGYRO (2015), Flug- und Betriebshandbücher.  


INFRAtec (2015), Wärmebildkamera Serie VarioCAM® hr head 600.  


NIKON (2015), D800E.  