

AERIAL 3D RECONSTRUCTION OF ANTIQUE BUILDINGS VIA LTA UAV

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Abstract

Due to new technological developments in the field of photogrammetry, camera technology, electronics and informatics, the reconstruction of solid bodies with the help of high resolution photography from different positions is common sense, latest after the appearance of Google Earth. The reconstructed bodies can vary in size, if the bodies to be reconstructed are buildings, aerial photography is applied. Depending on the site and the object different methods can be chosen for the aerial data collection with different efforts and risks. The options can be manned carriers like a helicopter or today in coming, unmanned aerial systems (UAS). Manned flights are expensive and a common multicopter with an adequate resolution camera system is for some building types too heavy and a crash would be too risky because of the caused possible damage on the building, carrier and camera system. These cases can be e.g. antique buildings in cities. For antique buildings we propose a lighter than air carrier system with a lenticular shape and an elastic body. The advantages are lower costs, longer endurance, low risks and higher payload capacity. One has to take the weather more in attention. In the following the description and discussion of the carrier, different data collection modes and the results takes place shown on a reference antique building.

Keywords: LTA, UAV, Photogrammetry, Autonomy, Inspection, Surveillance, Earth Observation, Hybrid

1. INTRODUCTION

The biggest challenge of current aircraft, actually most significant for multicopters and air taxis, is the increase of their flight time. Other problems are related to sustainability and security issues, like the usage of kerosene in combination with climate change aspects or safety regulations like line of sight flight and not allowed missions over gatherings if one focuses on UAVs. Facing these issues economically friendly UAVs are needed, which fulfil those long endurance missions, which today have to be done by manned aerial carriers, like helicopters or planes. For the analysis of large areas e.g. agriculture, resource exploration surveys, forestry and many other lighter than air flight (LTA) concepts and hybrids experience a renaissance.^{1,2}

The development of a new flight concept is risky in terms of finance and technological challenges, therefore our group decided to develop small carrier systems in the 1kg to 3kg payload range first. The reason for this was to lower the risk financially and technically but to increase the learning curve in terms of regulations (RPAS SORA), handling, autonomy, adaptive structures and LTA commercialization. First this paper defines a methodology to be able to assess quickly, if an LTA carrier system is suitable for any given mission. Later an example will be given, how such a LTA UAV was used to solve the problem of an indoor 3D scan of an antique church built in the 14th century. Subsequently the results will be discussed. The paper closes with the acknowledgments.



Image 1 h-aero® indoor scann system



Image 2 Indoor 3D-Modell

¹ Singer, Cs.: "Ultralight Solar Powered Hybrid Research Drone", The Smithsonian, NASA Astrophysics Data System, June 2012,

² Schultze Ch. et al.: "Ballon, Hubschrauber oder Flugzeug?", Luft- & Raumfahrt, DGLR, ISSN 0173-6264 B 13716, 2019

2. METHODOLOGY

On the one hand for any aerial mission within the atmosphere of a planet LTA systems can generally be taken in account. On the other hand LTA carriers are sensitive to weather conditions and used to have increased dimensions compared to flight concepts that don't apply a buoyant gas to generate static lift.³ If we see it generally and how we saw it in the past, LTA carrier systems could not break through to spread commercial use. A differentiated view related to the classification of abilities of LTA combined with the therefore defined classification methodology of aerial missions, helps to find those missions, where LTA systems bear huge efficiency and resource reduction potentials.⁴ If we look at aerial missions, where a system is not connected to the ground or stays despite of a mass and gravitational forces over ground (kite), for a differentiated mission profile we define:

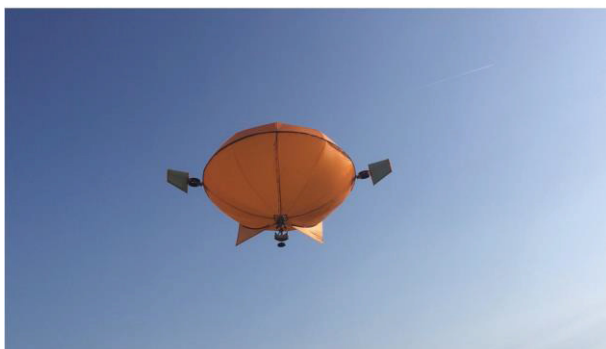


Image 3 h-aero® Flight Systems (zero, zero+, one)

³ Khoury G.A., Gillet J.D., „Airship Technology“, Cambridge University Press, ISBN-13: 9780521607537, 1999

⁴ R. Haude: „Fliegen mit Solar-Luftschiffen“, Solarenergie-Förderverein Deutschland e.V., Aachen, Germany, 28.05.2015

- a. Indoor Missions with Payload
- b. Outdoor Missions with Payload

Furthermore:

- I Weather Dependent Missions
- II Weather Independent Missions

While a. and b. differentiate the condition, if the control volume of the desired mission is surrounded by walls or not, I and II need a deeper explanation.

Definition of Weather Dependent Aerial Missions:

A Weather Dependent Aerial Mission in the context of this paper is an aerial mission, whereas the meteorological conditions of the mission's control volume are not known when the mission is planned. This applies mainly when the mission has to take place at a certain time point in the future. In this case the missions cannot be guaranteed.

Definition of Weather Independent Aerial Missions:

A Weather Independent Aerial Mission in the context of this paper is an aerial mission, whereas the meteorological conditions of the mission's control volume can be shifted as the task can be carried out in a time interval.

Summing this up, one can exemplary conclude that all indoor missions LTA UAV is an option, if one likes to lift any payload moving freely around in the given space in a secure way. Despite of a negligible amount of missions that are indoor and weather dependent (a.I) almost all missions under a. are weather independent aerial missions (a.II).

Furthermore one can exemplary conclude that at the current state of the art LTA UAV is not well suitable for weather dependent outdoor missions (b.I).

Furthermore one can exemplary conclude that at the current state of the art LTA UAV are well suitable for weather independent outdoor missions (b.II).

Examples:

a.I Aerial Building Inspection Indoor, when the building is not isolated from the surrounding atmosphere (e.g. Power Plant Chimney) and the inspection needs to take place at a certain day to a certain time point in the future (e.g. Event). Note: Only a negligible amount of indoor missions show this profile.
LTA UAV not suitable

a.II Aerial Building Inspection Indoor,
Tunnel Inspection,
Power Plants Inspection (e.g. Chimney)
Pump Storage Power Plants Inspection
Tanker Inspection
Antique Buildings
Indoor Events
LTA UAV is suitable

- b.I Festival Observation Outdoor, when the mission needs to take place at a certain day to a certain time point in the future (e.g. Opening).
LTA UAV currently not suitable
- b.II Agricultural Inspection,
Forestry Inspection,
Power Line Inspection,
Low Altitude Pseudo Satellite⁵ (LAPS),
High Altitude Earth Observation⁶
LTA UAV is suitable

Related to the low risk commercialization of a new flight concept on a low-budget basis, we selected different industrial inspection missions to start to harvest the technically “low hanging fruits” of our innovation via photogrammetric 3D-Modelling and Reconstruction.

The first project in 2017 related to the development of a new and innovative method of conducting airborne Geological, Geophysical and Environmental Surveys. The ‘Proof of Concept’ program encompasses research and development in the design, construction and first operational field trials of a radically new and innovative technique of conducting a more cost effective geophysical survey.



Image 4 LTA UAV Geophysical Surveys (b.II)

The technique employed a helium assist UAV (Unmanned Aerial Vehicle) to fly a geophysical data collecting sensor pod adapted for low level aerial flight. Field trials were conducted on an active mineral exploration site in Northern Ireland. The results were then compared over the same exploration site against both ground and standard airborne geophysical results both in terms of cost effectiveness and resolution of survey data.

Then we carried out indoor flights in a tunnel segment (4 km) of the Deutsche Bahn bei Rastatt in 2019. Photographs are shown in Image 5 and Image 6. The Payloads were a GoPro Hero 4 with Gimbal and a 2400 mAh LiPo Battery.

⁵ Miriam McNabb: “From the Floor at InterGeo: The H-Aero Aircraft, This You’ve Got to See”, dronelife, September 19, 2019 <https://dronelife.com/2019/09/19/from-the-floor-at-intergeo-the-h-aero-aircraft-this-youve-got-to-see/> visited 23.09.2019

⁶ University of León et al.: “High Altitude Pseudo-Satellites: Proposal of Initiatives to Enhance Satellite Telecommunications (HAPPIEST)”. Final Report. General Studies Programme (GSP) contract No. 4000-117605/16/NL/GLC.
<https://esabox.esa.int/owncloud/index.php/s/vZFvdGfe7KrrGn>

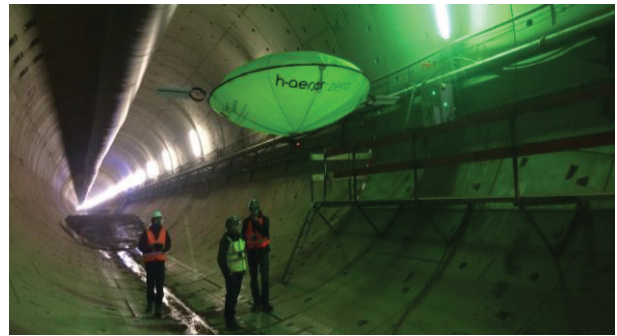


Image 5 Indoor Tunnel Inspection (a.II)



Image 6 Outdoor Tunnel Inspection (a.I)

Subsequently in fall 2018 we carried out basic industrial inspection experiments (a.II and b.II) with the Fraunhofer Institute for Nondestructive Testing IZFP. A related publication is work in progress.



Image 7 Outdoor LTA UAV for industrial inspection needs with payload (b.II)

Another a.II indoor inspection came up early 2019, whereas a gothic church from the 14th century had to be 3D scanned and digitally conserved for further restoration reasons. This happened three months before the Notre Dame fire in April 2019. Due to the relevance we decided to describe this aerial mission deeper.



Image 8 Indoor 3D Scan in Puck, Poland (a.II)

h-aero's unique design means that it is safe to use inside of priceless heritage buildings, where it cannot damage the structure by accidentally brushing against a surface.

The purpose was to collect as many optical datasets from the churches inventory and walls as possible in one flight and to use the collected pixel matrices to stitch the optical information in a way that a virtual 3D Model can be displayed on a screen of a personal computer.

The used LTA UAV was a h-aero® zero+ with a DJI X5 Camera System incl. Gimbal and Gimbal Remote Control. The used LTA UAV is published elsewhere^{7,8,9}. The DJI X5 Camera System can also be mounted under a DJI Phantom 4 multicopter for comparison.

For the modelling different tools were benchmarked. We selected then Capture Reality as the 3D Modelling software. The authors assume that the modelling theory of 3D reconstruction is known and state of the art. Further info can be found all over the internet¹⁰ and scientific literature¹¹.

The modelling hardware was a Fujitsu Celsius W550 Workstation (i7 6700 3.4GHz, 32GB, 256GB SSD, DVD-RW, Quadro K1200) + Win 10.

3. RESULTS

This section summarizes the resulted performance.

Collected Data:

24 GB | Resolution 4K | Video 4000x3000

Flight Endurance per flight:

2.4 hr

Number of Flights:

3

Processing Time:

10 h

Model Information:

Please see Image 10

Modelling Theory and Used Parameters for Calculation

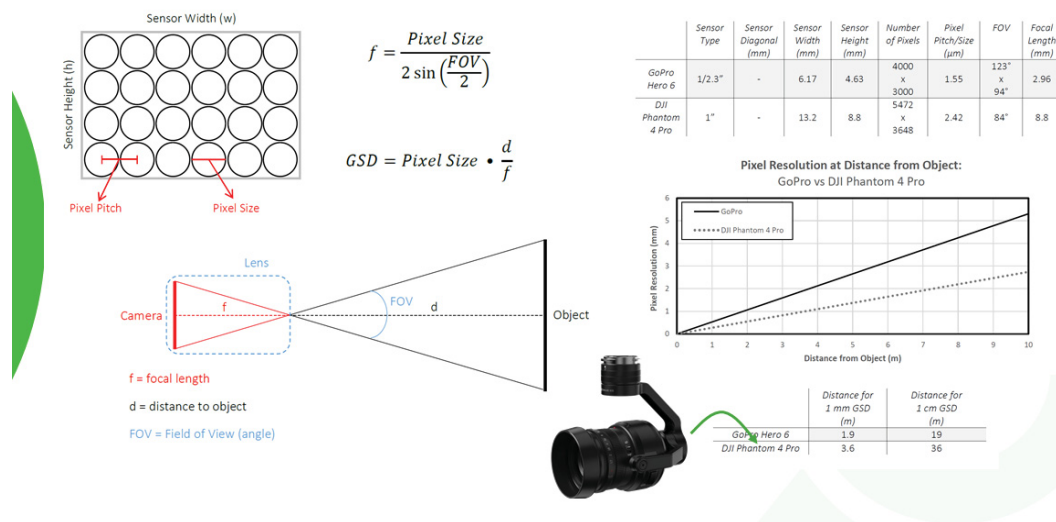


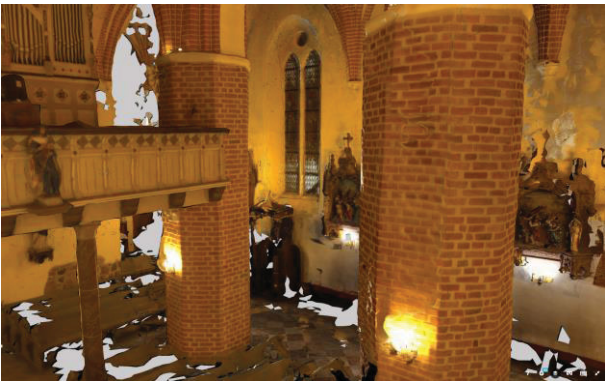
Image 9 Modelling Theory and Used Parameters for Calculation

⁷ Ch. Schultze, Cs. Singer: "Prototyping of a long endurance UAV applying a solar LTA concept", Proc. 1st Int. Aerospace Supply Fair AIRTEC 2016, Munich, Oct. 2016
⁸ Deutsches Patent- und Markenamt, DEPATISnet – Senkrechtstartendes Hybridflugzeug (Dokument DE102006028885A1), 2006
⁹ WIPO IP Portal: PCT/EP2017/063221, 31.05.2017

¹⁰ ACM Digital Library <https://dl.acm.org/citation.cfm?id=1754449&preflayout=tabs> visited 23.09.2019
¹¹ Soltani, A. A. et al.: "Synthesizing 3D Shapes via Modeling Multi-View Depth Maps and Silhouettes With Deep Generative Networks." In Proc. of the IEEE Conference on Computer Vision and Pattern Recognition (pp. 1511-1519)", 2017

Model Information ✕

Geometry	Triangles 600k
Vertices	309.4k
PBR	No
Textures	1
Materials	1
UV Layers	Yes

Image 10 Relevant Model Information**Image 11 Overview Whole Model****Image 12 Perspective Model View of Columns, Organ and Statues****Image 13 Model Detail****Image 14 Close View**

The model can be observed [online](#)¹².

4. DISCUSSION

Comparable datasets for churches indoor can be found online in [sketchfab](#)^{13,14}. The church models with low ceiling heights have finely resolved structures and serve as benchmarks. Church models with high ceiling heights are rare. With finely resolved structures in the ceiling area we could not find any specimens. This could be explained assuming that the optical data for those models were scanned from the floor and that the higher located structures could not be caught with the required resolution to gain an overall clean model. Fine models from high churches and cathedrals with e.g. three ships and other high priceless heritages are fully missing.

Due to the size of the h-aero® zero+ carrier systems (2.6m x 2.6m x 1m) the handling requires little effort in comparison to scaffolding to reach the same results. Due to the flight abilities of the system and the controllability of the camera orientation each target position can be filmed at high resolution. The pluggable maneuver flaps of the system help to keep a distance of the motor and propeller from statues and the paintings in the church.

It is clearly visible that the gained models of this work have very fine parts up to the ceiling located in 25m above ground level. The system promises an estimated cost reduction potential compared to scaffolding of up to 80%. The cost reduction potentials can apply many times, once while the scan of priceless heritages and many times, when a renovation or a reconstruction is necessary and the models can be used for architectural and structural planning needs directly in CAD and CAE. This can be the case after earthquakes, tornados, hurricanes or other reasons requiring a reconstruction of the scanned object.

5. ACKNOLEGEEMENT

We thank the Cathedral Provost of the St. Peter and Paul Church in Puck, Poland, Thilo and Dr. Ken Varner, who helped us with the location and the models. Furthermore we thank all partners, who helped to reach this milestone.

¹² <https://sketchfab.com/3d-models/a2e00bcf27344267a7ab913da4c0a5a2>

¹³ <https://skfb.ly/6JDFq>

¹⁴ <https://skfb.ly/6lopE>