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Unmanned Aerial Systems – for the Rest of Us

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ABSTRACT

Unmanned Aerial Systems (UAS) find their way into day-to-day commercial aerial mapping. Seven years of UAS-operations for service projects as well as for UAS-development projects and furthermore experiences with the related formal legislation in Germany and some other countries condense to some extent into this paper offering the reader a general overview. We introduce the UAS as such by identifying its major system components and try to help getting out of the acronym jungle of UAS, UAV, RPAS, VLOS, VTOL, and more. Model airplane versus UAS, what is the difference? An attempt of an answer is given here. Other typical questions frequently arising when discussing UAS-matters get summarized and discussed, from the point of view of a photogrammetric user and an UAS/model-airplane-user. Some projects complement this paper and give examples of UAS in geospatial mapping projects. What are relevant technical challenges given the legal operational frame within which one can operate UAS for mapping projects? We present our response to this in corpu of our different UAS-mapping-airplanes. Concluding remarks review the main messages of this paper and display the author's vision of how UAS-Mapping or UAV-Mapping might find a firm place in the technology toolbox of photogrammetry and remote sensing.

1. INTRODUCTION

When starting in 2006 to familiarize with the thought to basically transform standard procedures of aerial photogrammetric data processing onto tiny aerial imagery originating from a manually steered model airplane, a flying wing, made of coroplast and equipped with a Canon Ixus 50 in its right wing half and a Garmin handheld GPS in its left wing half, see Fig. 1, it was still part of the vision at that time that automatically flying small unmanned airplanes will collect aerial images for photogrammetric data processing.

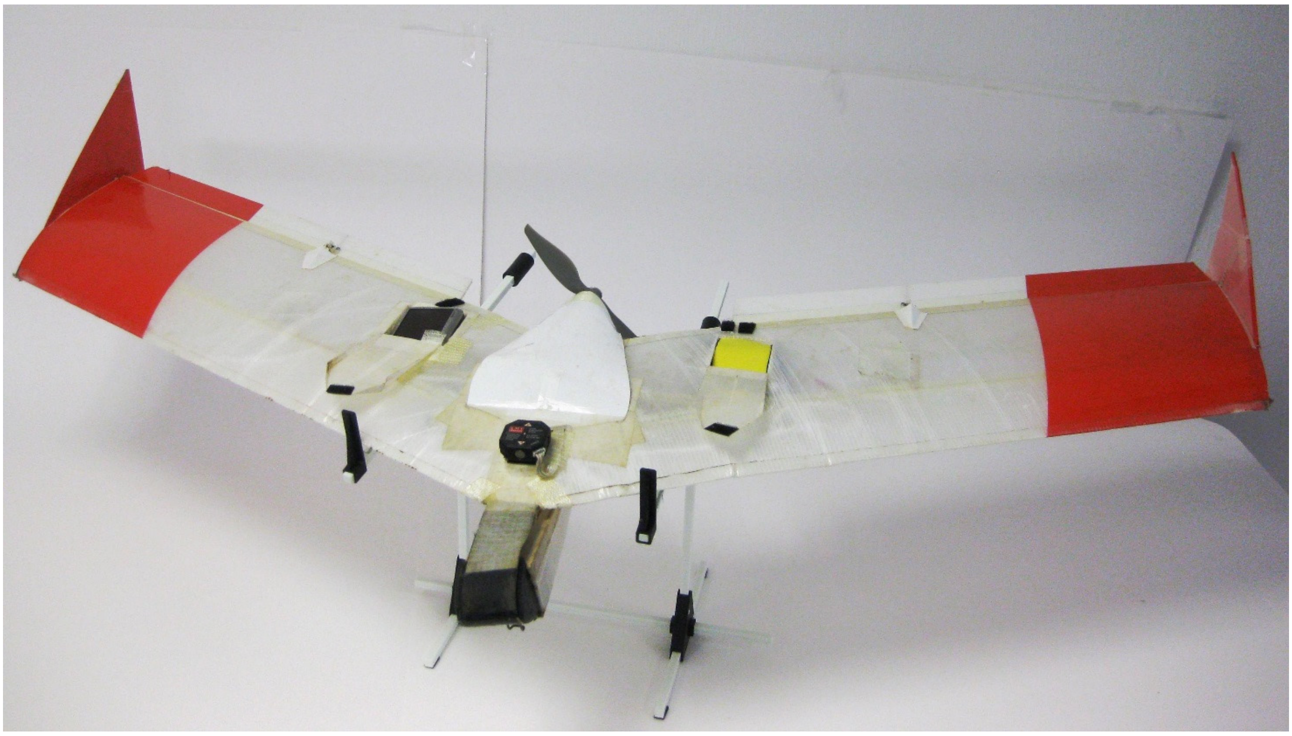


Figure 1: Flying Wing demonstrator 2006, with camera (right wing half) and GPS (left wing half).

A few years later reality caught up with early vision, and there is a number of companies in Europe, focussing on services with unmanned survey aircrafts as well as a number of manufacturers of such systems. Quite a number of publications report on use and application examples of UAS, e.g. Eisenbeiss (2011), Grenzdörfer (2011), Mayr (2009, 2011). Several types of aircrafts are in use for this sort of remote sensing. The two major ones are rotary-wing-based aircrafts and fixed wing aircrafts. Kites, balloons, and airships are other examples of aircrafts in use. Another categorization of the aircraft vehicle refers to its “take-off weight” (TOW) or “maximum take-off weight” (MTOW) which has impact not only on flight dynamics but rather on legal aspects, see further below. The flying wing demonstrator as shown in Fig. 1 developed into SmartOneC of SmartPlanes, a “remotely piloted aircraft system” (RPAS), see Fig. 2.

Figure 2: SmartOneC, RPAS, 1.2 kg MTOW, 120 cm wingspan.

What is named in the paper title “unmanned aircraft system” should actually read “remotely piloted aircraft system or RPAS”. Thus, the acronym RPAS is subsequently used in this paper.

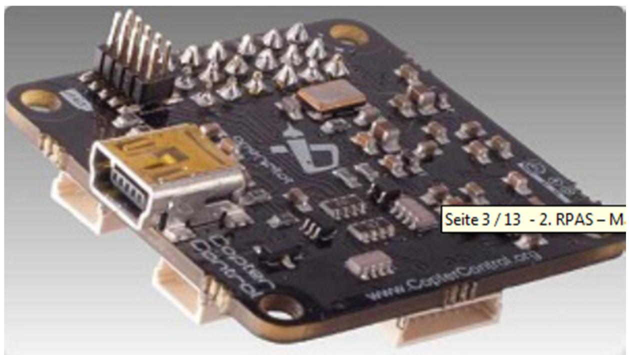
Technology is one part of the story, but not all, unfortunately. Other parts are of operational and legal nature. All parts are discussed below to some extent. Ultimately, when and after overcoming all obstacles one really can work with RPAS in aerial mapping applications, which we show in a few stimulating examples.

2. RPAS – MAJOR TECHNOLOGY COMPONENTS

A remotely piloted aircraft system, as the naming indicates, primarily is a system consisting of a particular aircraft equipped with an autopilot. The type of aircraft is not specified. While the autopilot can fly the aircraft on its own but according to an externally defined flight path, the human pilot is the ultimate decision maker who at any given time may take over manual flight control from remote. Table 1 lists the major components of RPAS.

<table>
<tr><td>System / Device
• fixed wing
• rotary wing
• others, e.g. airship, balloon, kite …
• groundstation</td><td> 
© www.sensefly.com © www.aibotix.de</td></tr>
<tr><td>Autopilot
Autopilot operates RPAS when in mission.

• Flightpath pre-loaded or interactively modified
• Bidirectional link with groundstation
• automatic flight, executed by autopilot
• supplementary sensors required
  ◦ GPS (always)
  ◦ stabilization (always), e.g. IMU, thermo-piles
  ◦ altitude, e.g. barometric, ultra sonic, laser sensor
• controls remote sensing & data collection

Human pilot can overrule autopilot at any time.</td><td>
© www.openpilot.org</td></tr>
<tr><td>Remote Sensing & Data Collection

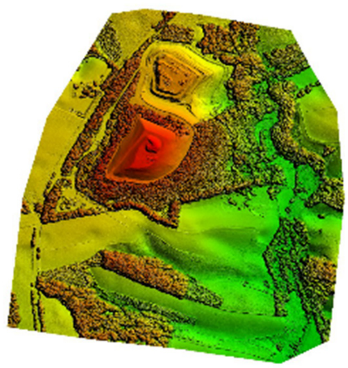
• camera: aerial mapping, location documentation, video
• collection of: temperature, air pressure, electric charge, radiation, pollution, …. many many more</td><td>
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Table 1: RPAS – major components.

The autopilot is a tiny, light electronics board. It is the core component of RPAS. There are autopilots on the market, e.g. from Micropilot, Canada, 3DRobotics, USA, or AeroSpy, Austria. Open source projects provide as well implementation solutions for autopilots, e.g. see www.openpilot.org or paparazzi.enac.fr/wiki/Main_Page. Its task is to fly the aircraft according to the rules of flight mechanics and flight control and according to a predefined mimic for the purpose of remote sensing. Such a method for obtaining remotely sensed data, e.g. aerial images, might be called "RPAS-Mapping". Below Fig. 3 depicts the data flow from generation resp. collection of remotely sensed data via RPAS, in this case aerial images, usually ground-based pre-processing of intermediate results, subsequent aerial image processing, and completing resulting deliverables.

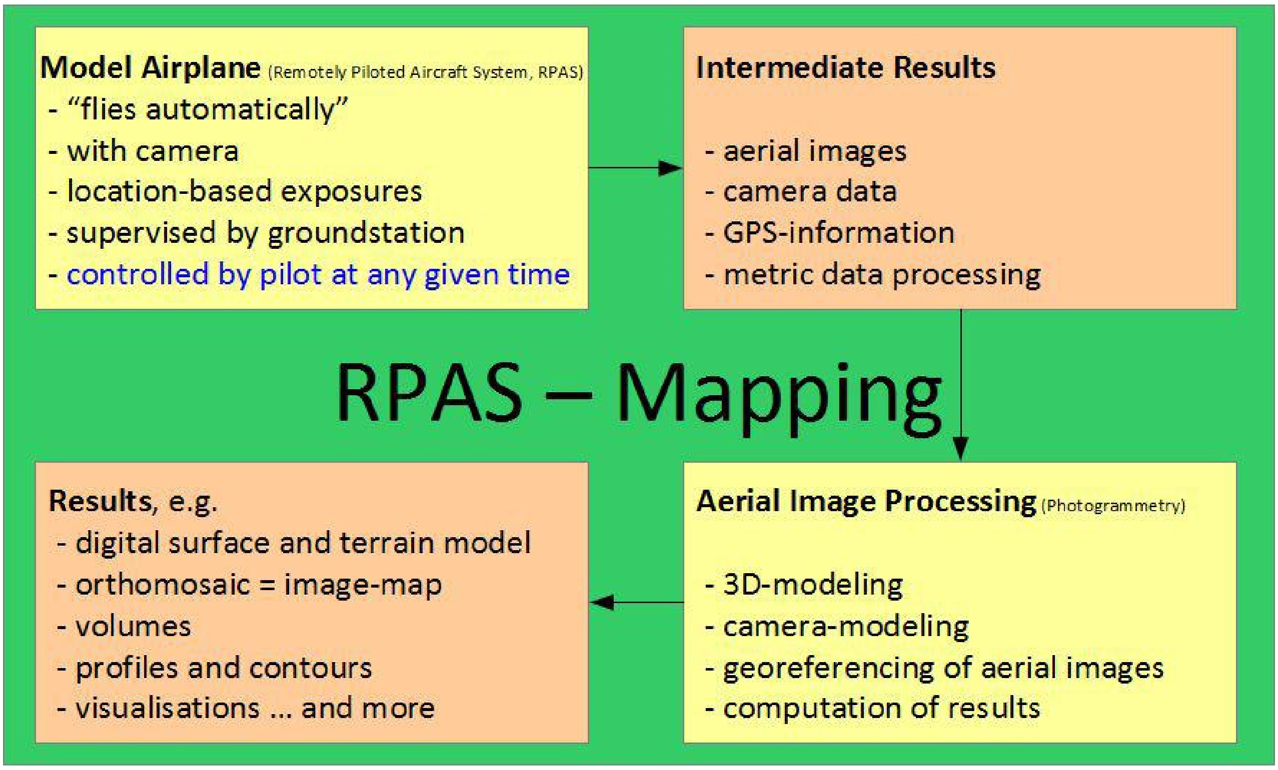

Figure 3: RPAS – Mapping.

It should be noted that above mentioned autopilots in RPAS represent the lower end of autopilot capabilities. The core functionality is flying the aircraft along a path defined either a priori or modified online via the groundstation. When flying in this auto-mode, one speaks of "automatic" flight. Higher level autopilots possess sense & avoid intelligence. Such autopilots are able to make their own decisions with respect to real-time modification of intended flight path due to detected obstacles. When flying in this category of auto-mode, one speaks of "autonomous" flight. All to the author known commercial RPAS for mapping purposes are flying in automatic mode. Autonomous flight requires autopilots with more sensors, more on-board compute power and thus result into significantly bigger weight.

Automatic or autonomous flight mode, common to all RPAS is the fact, that a human pilot is in charge of operation and has the ultimate degree of freedom and responsibility to take over 100% control of the flying aircraft at any given time. A system without this property is not a RPAS, and is unlikely to obtain a permit to fly in Europe.

3. PERMITS – NECESSARY FORMALISM

Flying with an autopilot equipped aircraft for recreational purposes over a model-club airfield is legally very different as to when you fly the same pattern over an e.g. land-fill site for commercial purposes with the same vehicle. This is the situation in Germany and presumably many other European countries. As long as the flying is for recreation one executes a hobby or sport, and the tool to do so is legally not considered an aircraft in a legal sense. Consequently (in legal thinking), air-traffic laws do not apply, but others. As soon, as the identical aircraft is used commercially, it morphs into an aircraft and thus is subject to air-traffic law. Its key property is that a human pilot ultimately is personally responsible and must be able to take over flight control at any given time.

Consequently, and here now technically justified and legally expressed, any operated RPAS is allowed to be flown in "visual line-of-sight operation" (VLOS) mode. "Operating within Visual Line of Sight means that the remote pilot is able to maintain direct, unaided (other than corrective lenses) visual contact with the unmanned aircraft (UA) which is sufficient to monitor its flight path in relation to other aircraft, persons, vessels, vehicles and structures for the purpose of avoiding collisions. Within the United Kingdom, VLOS operations are normally accepted out to a maximum distance of 500 m horizontally and 400 ft vertically from the remote pilot. Operations at a greater distance from the remote pilot may be permitted if an acceptable safety case is submitted. For example, if the aircraft is large it may be justifiable that its flight path can be monitored visually at a greater distance than 500 m. Conversely, for some small aircraft, operations out to a distance of 500 m may be impractical.", see RPAS Glossary 120812.

Opposite to this is operation Beyond Visual Line-of-Sight, BVLOS. Operation of a remotely piloted aircraft (RPA) beyond a distance where the remote pilot is able to respond to or avoid other airspace users by visual means is considered to be a BVLOS operation. RPA intended for BVLOS operation of the pilot will require an approved method of aerial separation and collision avoidance that ensures compliance with Rule 8 of the Rules of the Air Regulations 2007 (Rules for avoiding aerial collisions), or will be restricted to operations within segregated airspace (refer to Section 2, Chapters 1 and 2), see RPAS Glossary 120812.

Above are valid and more general definition and rule sets upon which national laws set up. In Germany, in order to operate a RPAS for commercial purposes one has to possess the appropriate permit. This is issued by the respective air traffic control entity of the state government. Air-traffic law is in Germany federal law. Nevertheless, German federal government delegated the implement-tation and surveillance of the air-traffic law onto the 16 states Germany consists of. Thus, one has to apply individually in 16 states for the same type of permit. As mentioned above, the categorization of aircraft is important when it comes to flight permits. Actually, we do not talk about a permit to fly, we talk about a permit to "take-off". The two main criterions for aircraft categorization are its take-off weight and its type of propulsion, electric or combustion. There are three categories, up to 5 kg MTOW, 5 kg to 25 kg, and up to 150 kg. For the smallest, or better lightest, category, i.e. up to 5 kg MTOW, one can apply for what is called a "general take-off permit for unmanned aircrafts up to 5 kg MTOW".

Table 2 summarizes the experiences which GerMAP gained when obtaining general take-off permits for its fleet of < 5 kg MTOW RPAS. Fees vary significantly. Some states honor the prior permit of other states and thus have a simplified procedure and reduced costs. Other states, it seems, do not care about the other states and define their own set of requirements. Common to all are a few requested documents and obligations to obey when flying. The required documents are trade register of the applicant, proof of liability insurance for the particular RPAS, technical specification of the aircraft/s going to be used. The common obligations (there are state specific obligations, too) for flying are:

- maximum flying height is 100 m above ground;
- pilot must be able to take over flight control at any time;
- VLOS operation only; in GerMAP's case it is a radius of 700 m; this might depend on the size of the aircraft;
- no operation over jails;
- no operation over human crowds;
- no operation over accident areas;
- no operation over military installations;
- no operation closer than 1.5 km to an airport.

Any deviation of these standard rules of the General Take-Off Permit requires a separate, special permit to be applied for from the respective state air traffic control entity. Validity of General Take-Off Permits is usually 2 years with exception of one state issuing the permit for one year only with option for one year extension. Time between application and receipt of permit varied between 1 to 4 weeks.

State	**Permit validity [years]**	**Accepts Permit of other State [Y/N]**	**Fee [€]**	**Remarks / specific application and operation requiremnents**
Baden Württemberg	2	N	250,00 €	Each pilot must be identified by name, home address, date and place of birth. Description of level of flying skills for each pilot required. Each pilot must sign that s/he follows the data privacy statement (law). Authorization for each pilot required, that s/he operates RPAS on behalf of GerMAP.
Bavaria	2	Y	120,00 €	No additional requirements
Berlin				Not yet applied for; city state; special rules
Brandenburg	2	Y	100,00 €	No additional requirements
Bremen				Not yet applied for; city state; special rules
Hamburg				Not yet applied for; city state; special rules
Hessen	2	Y	100,00 €	No additional requirements
Mecklenburg-Western Pomerania	2	Y	60,00 €	No additional requirements
Lower Saxony	1	N	150,00 €	Each pilot must be identified by name, home address, date and place of birth. Description of level of flying skills for each pilot required. Each pilot must sign that s/he follows the data privacy statement (law).

North Rhine Westphalia	2	Y	50,00 €	Requires a technical drawing of the RPAS used
Rhineland Palatinate	2	N	200,00 €	Each pilot must be identified by name, home address, date and place of birth. Each pilot must sign that s/he follows the data privacy statement (law). Authorization for each pilot required, that s/he operates RPAS on behalf of GerMAP. Each flight mission must be announced 1 day prior to flight mission to the state air control entity and the local police office.
Saarland	2		100,00 €	The managing director must sign that s/he and tasked pilots follow the data privacy statement (law). Each pilot must be identified by name, home address, date and place of birth. Each pilot must sign that s/he follows particularly the air-traffic the laws.
Saxony	2	Y	60,00 €	No additional requirements
Saxony-Anhalt	2	Y	70,00 €	No additional requirements
Schleswig-Holstein	2	N	150,00 €	Each pilot must be identified by name, home address, date and place of birth.
Thuringia	2	N	125,00 €	Each pilot must be identified by name, home address, date and place of birth. Each pilot must sign an eigen-declaration stating that s/he is experienced in flying a model airplane. Copies of pilot's personal ID-card are to be submitted. Each pilot must sign that s/he follows the data privacy statement (law).

Table 2: Properties for General Take-Off Permits for RPAS < 5kg in German states.

A recommendation of what shall be requested for when someone applied for the General Take-Off Permit for RPAS < 5 kg is specified by the German Flight Safety Agency, DFS (Deutsche Flugsicherung), in its news letter NfL I 161/12 (Nachrichten für Luftfahrer). Not all states stick very closely to this recommendation yet.

As mentioned in above Table 3, it is required that one has to have a liability insurance for the unmanned aircraft. This is the law in Germany and in most all other European countries. It also is sometimes asked for in tenders as part of proof of professional performance.

Another important issue to remember is the fact that in all European Community countries every RPAS is considered to be of nature “dual use”. It thus is export regulated. Every export to another country requires minimum a carnet, if within European Community, and a permit issued by the German Export Authority (BAFA = Bundesamt für Wirtschaft und Ausfuhrkontrolle) elsewhere. The purpose of export can be anything, e.g. participation in an exhibition, service project, or sale into another country. This is an obstacle one has to life with. For service projects abroad this is particularly unlucky as weather does not wait for administration to be good enough for flying, and the grant of a permit might take 3-6 weeks.

4. APPLICATION EXAMPLES

From our experience, RPAS-Mapping is well applicable to areas too small for manned aircraft aerial mapping yet too big for terrestrial surveying. Certainly, there are overlaps in both directions. We've flown and processed several hundred projects, many of which we got as data sets for processing, and many we flew and processed ourselves. As we are at time applying fixed wing aircraft only, we prefer to fly projects in rural areas, e.g. landfill sites mainly for volume determination, golf courses, rural cadastral projects, environmental monitoring projects. Table 3 summarizes a few typical project representatives and displays the main objectives, i.e. deliverables.

Proj. ID	Application	Deliverables	# Blocks	# Aerial Images	Ortho-GSD [cm]	DSM-Spacing [cm]	Planim. Acc. ± [cm]	Height Acc. ± [cm]	MatchT	Area [ha]
1	Landfill	Volumes, Orthomosaic, DTM, DSM, 3D-Views	1	193	7,5	50	3	3,1	V5.5	33
2	Landfill	Volumes, Orthomosaic, DTM, DSM, 3D-Views	3	691	8	35	3,5	5,2	V5.5	113
3	Landfill	Volumes, Orthomosaic, DTM, DSM, 3D-Views	3	983	6	50	2,5	3,8	V5.5	117
4	Golf Course	Orthomosaic, DSM, 3D-Views	4	1126	8	50	3	3,8	V5.5	170
5	Golf Course	Orthomosaic, DSM, 3D-Views	2	332	7,5	50	3	7,2	V5.4	70
6	Golf Course	Orthomosaic, DTM, DSM, 3D-Views	2	346	7,5	50	3,5	6,4	V5.4	88
7	Quarry	Volumes, Orthomosaic, DSM	3	707	10	30	2,5	6	V5.5	117
8	Cadastre	Orthomosaic, 3D-Views	2	445	6	40	2	1,5	V5.5	64
9	New Housing Area	Orthomosaic, DTM	3	557	6	40	3	6,8	V5.4	104

Table 3: Examples for applications and their major parameters.

As one can see from above Table 3, the planimetric accuracy is in the order of half of the ground sampling distance of the orthomosaic and in height between 0.25 to 1.2 times the ortho GSD. Also, progress in software brings better modelling and thus more accurate results, see project number 8. All of above image processing was accomplished using standard professional photogrammetric software, in this case Trimble-Inpho's line of software applications. All of above projects were imaged using Canon S95 or Canon S100 cameras. They deliver great images, but have a rather simple optics in terms of distortion. It seems to be crucial that the modelling of parameters of the interior orientation at time of imaging can be accomplished by the image processing software used for the generation of the deliverables.

The following examples of landfills, see Fig. 4 to Fig. 7, exhibit typical application projects executed by GerMAP. The client may order several deliverables, e.g. several volumes, an orthomosaic in digital and analog form, a digital surface model (DSM), perspective views, and different 3D-modelings. For volume determinations clients provide construction plans of their landfill sites, i.e. for the existing and planned basins and the planned different sections of fill-in areas. A definition of the covering recultivation mass usually is given as well as the planned final shape of the top cover of the landfill. With this information we deduct as per project the current absolute volume of the landfill, the volume of recultivation mass on top of the landfill, the absolute final volume and the remaining volume as the difference volume, final minus current volumes. The DSM raster-spacing varies between 35 cm to 50 cm and height accuracy between ±3 cm to ±6 cm, see Table 3. The extent of the land fill might be about 1.200 m x 600 m. Mostly, between 1 to 3 flight missions are required to cover all of the landfill. 3 blocks take approximately 3 hours to fly including aircraft setup, flight mission, dismantling, and re-location to next starting point. Typically, 250 to 1.000 aerial 12MB images might be collected. In an example of 3 blocks and big extent 15 ground control points were used. Data processing from aerial triangulation to volume computations of a 900 image flight mission might take some 2-3 days of office engineering work to generate all deliverables, e.g. project ID 3 in Table 3. Fig. 4 to Fig. 7 give some impressions.

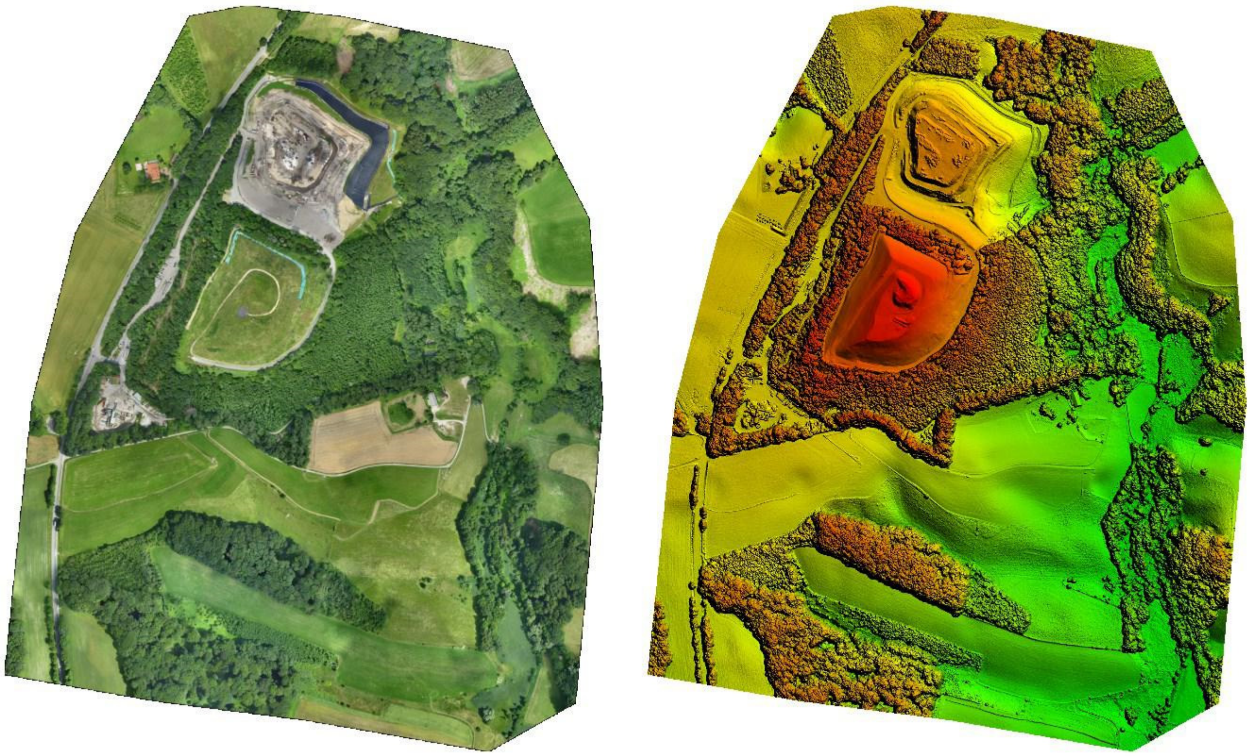

Figure 4: Orthomosaic (left) and DSM (right) of a landfill; 3 RPAS-blocks, 983 aerial images.

Fig. 5 displays a project flown for a development project of a village. In this example 4 cm GSD was required in the orthomosaic. It shows the applicability of RPAS-Mapping in such applications.

Figure 5: Orthomosaic, 4 cm GSD, village, cut-out of a block 600m x 800m.

Past and future, both status quo need to be modelled, as seen in Fig. 6. The reference surface, Fig. 6 left, is mostly extracted from construction plans, which are often only in scanned form available. The planned top cover defines the maximum volume.

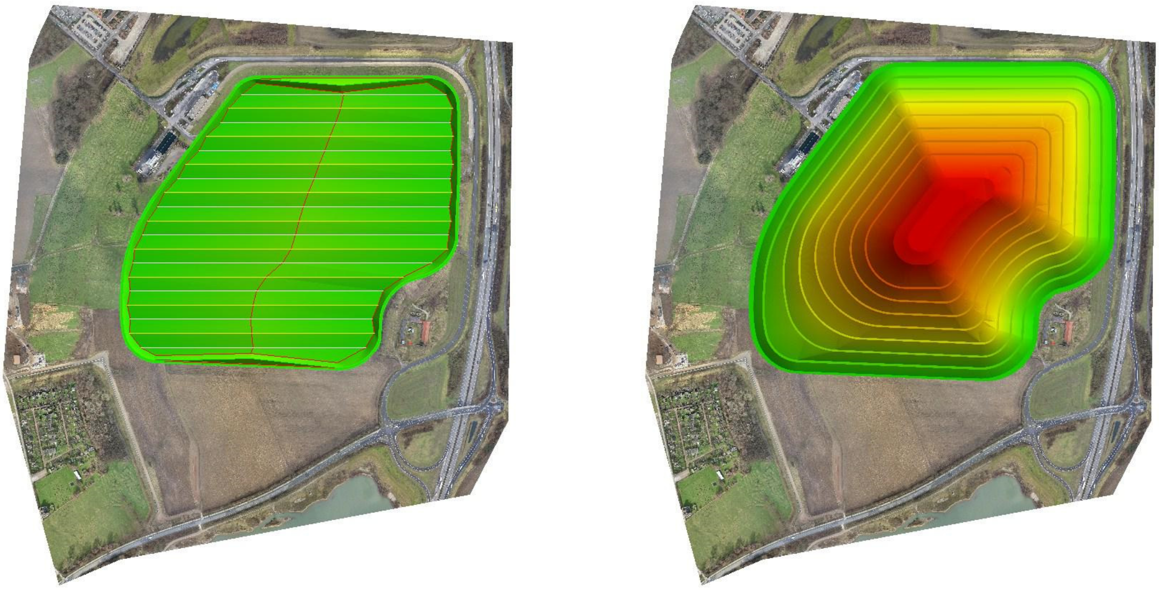

Figure 6: Basin modelling of a landfill (left), planned top cover (right).

Due to the fine grain surface model of a few centimeters DSM-raster-spacings, as seen in Fig. 7 right, the RPAS-Mapping approach delivers a degree of detail which the traditional survey approach usually does not deliver in an economic way. Furthermore, the landfill operator can localize areas where already too much waste is dumped versus the planned top cover.

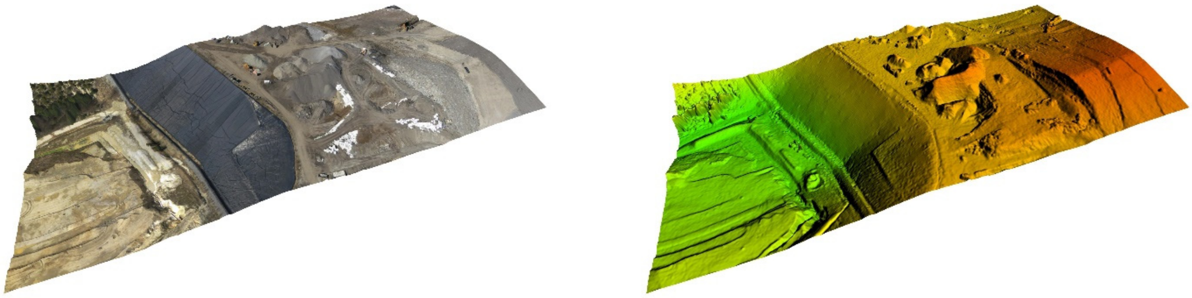

Figure 7: Perspective view of part of a landfill, draped with orthomosaic (left, DSM (right).

An important aspect to many landfill operators is the fact that the RPAS-Mapping approach requires a minimum of on-site presence, which is a safety-concern having all the coming and going trucks and other moving machinery in mind. The list of examples could be extended for a long time. RPAS-Mapping is truly very much applicable to many geospatial tasks.

5. EXTENDING RPAS CAPABILITIES

At GerMAP we work on some RPAS development projects, too. Goal is to even better exploit RPAS' great potential. Different aircrafts get e.g. equipped with different autopilots in order to see performance properties. We test-flew in September 2012 our G180 demonstrator with 2 cameras, one looking 30 degrees off-nadir to the left and the other one to the right, see Fig. 8 and Fig. 9. Now, our G220 has also 2 cameras integrated, however with the option to either have 2 cameras look parallel in nadir direction, e.g. for one RGB and one NIR camera, or to some degrees to the left and right almost doubling the swath width from e.g. 4000 pixels per camera to 7800 pixels across track per dual-camera configuration. We thus greatly reduce flying time and are prepared to fly larger areas if BVLOS operation becomes possible. Image processing is accomplished with standard professional photogrammetric software delivering DSM and orthomosaic. At time we have three aircraft types, G180, G220, and G240, where the 3-digit number indicates the wingspan in centimeters. They consist of different material, e.g. EPP, EPO, or fibre-glass, have different airfoils and flight dynamics triggering speed and flight performance, and carry one or two cameras and are able to do more. The larger wingspans aircraft are also intended for long endurance flights. All of our aircrafts have a MTOW smaller than 5 kg. We like to stay with light weight aircraft. This opens easier access to flight permits. It enables us to land in rough terrain and thus make use of the airframe for a long time. Our SmartOneC for example has a cruise speed of approximately 12 m/s or 43.2 km/h and a MTOW of 1.2 kg. Other aircrafts on the market have to fly twice as fast due to airfoil geometry and weigh up to 2 times as much. This produces an impact energy approximately 8-times as high. A small stone in the landing flight path then might have a significant destructive effect on the integrity of the aircraft body or its components. This and similar considerations make us sensitive to the overall design, applicability, and durability of an unmanned aircraft vehicle and motivates us to improvements.


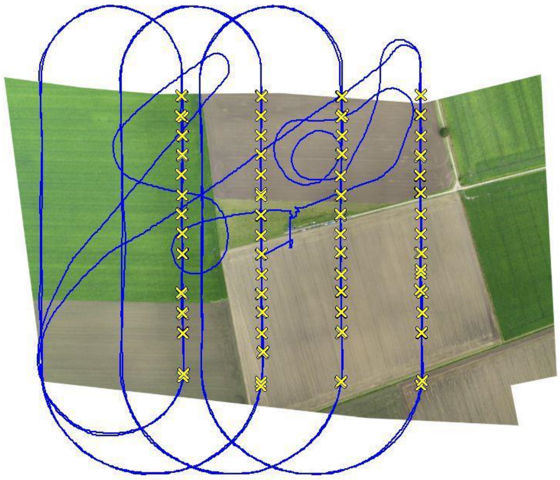

Figure 8: Demonstrator of G180 – DualCam (left); its flight path and exposure locations (right).

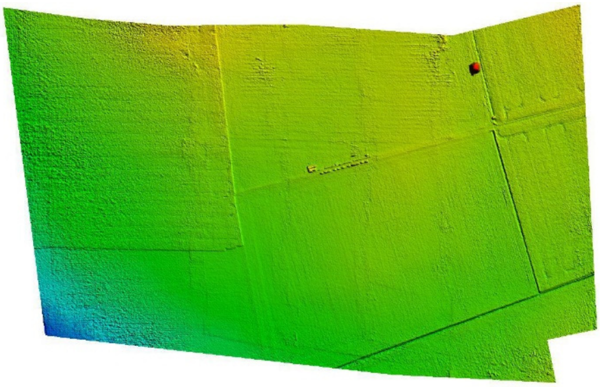
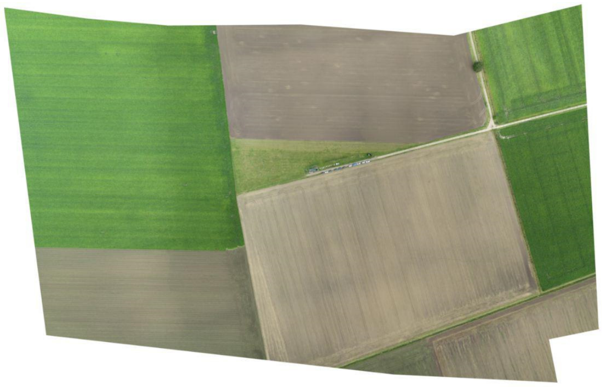

Figure 9: DSM (left) and orthomosaic (right) derived from dual-camera configuration, see Fig. 8.

6. CONCLUSIONS AND OUTLOOK

RPAS is a working technology and integrated into geospatial methods of data processing. There is a multitude of commercial applications. Entering RPAS technology requires not only financing projects but also the understanding that one enters a new dimension in terms of operating a flying vehicle. Aerial mapping companies are familiar with this, all others are, usually, not. Learning to fly a RPAS might be as short as a few days. One brings it up and down safely if and only if the autopilot stabilizes the aircraft. Do not mix up this ability with becoming a model airplane pilot in a few days. Piano players need some time too, before one calls them piano players. It is a good idea to seek support from some enthusiastic model airplane pilots teaching you resp. your staff or even acting as your pilot for RPAS. The aerial images originating from RPAS-Mapping can be handled with professional photogrammetric software. Though, it needs some experience and tricks to play the photogrammetric software piano so that one obtains high quality results in a decent amount of working hours. There are some blackbox packages on the market performing quite well for a number of cases. When, however, it comes to complex situations such packages do not offer handy interactive operations to safeguard the project, and one looses efficiency and thus money.

Policies for RPAS operations are treated on a European level, e.g. Kämpfe 2013. The RPAS regulatory roadmap is getting laid out, EUROCAE 2013. Large official bodies are giving a very serious attempt to bring use of RPAS to a high level of visibility and are preparing according regulations of use. RPAS will be part of the geospatial toolbox, it actually is already in a few instances. Not only aerial imaging is of interest but collecting all sorts of remotely sensible data are of interest. RPAS will push remote sensing to a new level of local geospatial awareness and to new applications. Responsibility when operating RPAS will certainly help increasing the partly suspicious general public. To all RPAS operators: have always happy landings!

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