RPAS – Sensors and Applications
Remarks from an User

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Abstract: RPAS – what is this? It's the acronym for Remotely Piloted Aircraft System. This new technical and internationally accepted Term, even more precisely its contents, is what will accompany us from now on and is the focus of this paper. By human pilots remotely controlled aircraft systems will increasingly accompany us in various surveying challenges as well as in inspections, image documentations, and other applications. They are in applied by surveying engineers, remote sensing scientists, archeologists, geologists, and many more. The author reports on experiences with RPAS in daily use for aerial mapping and remote sensing, on operational requirements in Germany and some other countries, and on some examples of sensors for an RPAS. Some remarks for categorizing RPAS and potential future developments and fields of applications conclude this paper.

Zusammenfassung: RPAS – was ist das? Es ist das Acronym für Remotely Piloted Aircraft System, ist die Antwort. Dieser neue, technisch und international verabschiedete Term, noch genauer: sein Inhalt, wird uns künftig in mancherlei Hinsicht begleiten und ist Gegenstand dieses Beitrags. Von Piloten ferngesteuerte Luftfahrzeug-Systeme werden in zunehmendem Maße für diverse vermessungstechnische Aufgaben aber auch für Inspektionen, Bilddokumentationen u.a. eingesetzt und haben Eingang ins Arsenal von Geräten und Systemen von Vermessungsingenieuren, Fernerkundern, Archäologen, Geologen und vielen anderen gefunden. Der Autor berichtet über Erfahrungen mit seinen RPAS im täglichen Einsatz für Luftbildvermessung und Fernerkundung, über Voraussetzungen, ein RPAS betreiben zu können bzw. dürfen im Vergleich Deutschland und ausgewählte Länder, und über Beispiele von Sensoren und Ausrüstungen eines RPAS. Ferner finden sich Anregungen zur möglichen Kategorisierung von RPAS sowie Ausblick auf mögliche technische Entwicklungen und neue Anwendungsfelder.

1 Introduction

A number of European companies apply or even focus on services with unmanned survey aircrafts. There is also a number of manufacturers of such systems. And quite many publications report on use and application examples of UAS respectively RPAS, e.g. Eisenbeiss (2011), Grenzdörfer (2011), Mayr (2009, 2011). The two major types of aircrafts for RPAS are rotary-wing-based aircrafts and fixed wing aircrafts. Latter ones we focus here. Kites, balloons, and airships are other examples of RPAS aircrafts in use. Another categorization of the aircraft vehicle refers to its “maximum take-off weight” (MTOW) which has impact not only on flight dynamics but rather on legal aspects as well. Nevertheless, RPAS increasingly gain in visibility and applicabilty. This paper will deal with some more general aspects and report on experiences of the author who operates fixed wing RPAS for several years.

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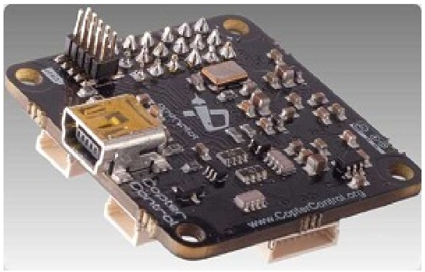
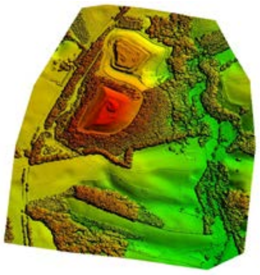
The acronym RPAS is used for Remotely Piloted Aircraft System. Its technology is one part of the story, but not all. Other parts are of operational and legal nature and are discussed below to some extent. Ultimately, when and after overcoming all obstacles one really can work with RPAS in aerial mapping applications, which we show in a few stimulating examples.

2 RPAS – Major Technology Components

A remotely piloted aircraft system consists of a particular aircraft equipped with an autopilot under the ultimate control of a human pilot. The type of aircraft is open. 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 pure manual flight control from remote. Table 1 lists the major components and properties of RPAS.

Table 1: RPAS – major components

System / Device • fixed wing • rotary wing • others, e.g. airship, balloon, kite … • groundstation	 © www.sensefly.com  © www.aibotix.de
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 • controls remote sensing & data collection **Human pilot overrules autopilot at any time.**	 © www.openpilot.org
Remote Sensing & Data Collection • visible range: cameras for: aerial mapping, location documentation, thermal, hyperspectral, video • invisible ranges: sensors for e.g.: temperature, air pressure, electric charge, radiation, pollution, … many many more • supplementary sensors & components, e.g.: ultra sonic, barometric heighting, suspension mounts,	 © www.germap.com

The autopilot is a tiny, light electronics board and the core component of RPAS. Its task is to actively fly the aircraft according to the rules of flight mechanics, which are put into its firmware, and according to a predefined mimic for the purpose of the intended application e.g. aerial mapping, which the author briefly calls "RPAS-Mapping", MAYR 2013.

3 Some Formal Aspects

There is a difference in terminology for the terms „automatic flight“ and „autonomous flight“. Current RPAS, we talk about here, are capable of automatic flight. In automatic flight mode the autopilot mandatorily follows its a priori uploaded flight path. Far more capable is autonomous flight mode in which the autopilot possesses a higher degree of „intelligence“ being capable of „sense and avoid“ execution enabling it to decide itself temporarily and how to modify its predefined, intended flight path thus bypassing obstacles and then returning back to its preplanned flight path. No matter which flight mode, automatic or autonomous, the human pilot is in charge of RPAS operation and has the ultimate degree of freedom and responsibility to take over 100% control of the flying aircraft at any given time.

For commercial flight missions, no matter if manned aircraft or unmanned aircraft, one requires a take-off permit in Germany and most European countries. Common to all European RPAS flying permits amongst other constraints is the VLOS-constraint, fly within Visual Line Of Sight. The pilot must be capable to see the aircraft without spectacles and to maneuver it manually at all the times. In Germany, issuing take-off permits is delegated to state-level aviation authorities. Due to this one has to apply in 16 states, and to pay fees. For details see MAYR 2013. Usually, these permits are valid for 2 years. The „General Take-Off“ permit is for RPAS ≤ 5 kg MTOW (maximum take-off weight). Non-for-profit organizations such as UAV-DACH on a national level or UVS-International on an international level thankfully are very actively engaged to harmonize European regulations for commercial RPAS operations.

Another formal aspect of RPAS is the circumstance that RPAS are considered to be goods of dual use. They thus are export controlled, be it for exhibitions or service contracts or final destination in another country. Each border crossing requires a certain a priori effort to obtain official documents such as a carnet issued by an IHK, a chamber of commerce (German: Industrie- und Handelskammer) or an export permit issued by BAFA, the Federal Office of Economics and Export Control (German: Bundesamt für Wirtschaft und Ausfuhrkontrolle).

4 Application Examples

In our company environment we operate up to now fixed wing RPAS of type SmartOneC (S1C) of the Swedish manufacturer SmartPlanes and apply RPAS-Mapping to areas of landfills, golf courses, quarries, cadastre, or new housing built-up areas, and other local instances of environmental interest. Often orthomosaics, terrain models or surface models but as well volumes or profiles are requested. Table 2 gives an overview over a few of our projects with typical parameters and results and all flown with S1C RPAS. Generally, we deal with a block of images as a unit. Several of those might cover an area and constitute the project area. Typically, one block including setup, assembling, checking equipment and airspace takes about 45 to 60 min to fly. Actual flying time for one block usually is between 15 and 30 minutes depending on size of area and strength of wind. Accounting for light conditions during the day and travel time between different take-off points we count between 4 to 8 blocks per day per RPAS.

Table 2: Application examples

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

As a rule of thumb, one can expect to obtain a planimetric accuracy in the order of half of the ground sampling distance (GSD) of the resolution of aerial image respectively orthomosaic and in height between 0.25 to 1.2 times the GSD for GSDs not smaller than 4 cm. All of above results were obtained using Trimble-Inpho's line of photogrammetric software applications. Canon S95 or Canon S100 were used in all of above projects with 80% along track overlap and 70% to 80% across track overlap. Note the big across track overlap which directly influences flying time in terms of number of strips to fly! Newer, bigger cameras might improve image quality and to a minor extent geometric quality. They help reducing flying time per block and thus increase throughput in terms of blocks per day. A comparison of 2 cameras, Canon S100 vs. RicoGR, shows this, see Table 3. To our experience it is mandatory to model the parameters of the interior orientation at time of imaging, i.e. for each block. For a more detailed discussion of application examples, please see MAYR 2013.

Table 3: Comparison of 2 cameras

Parameters	**Canon S100**		**RicoGR**	
Rows / cols	3000	4000	3264	4928
Mpix	12		16,2	
Sensor type	CMOS		CMOS	
Pixel pitch [µm]	1,8		4,8	
Focal length [mm]	5,8		18,3	
Block size L [m] x W [m]	800	500	800	500
Flying height above ground level [m]	100		100	
Ground sampling distance [cm]	3,1		2,7	
Overlap along / across [%]	80	80	80	80
Number of strips / images	20	860	20	920
Flying height above ground level [m]	100		117	
Ground sampling distance [cm]	3,1		3,1	
Overlap along / across	80	80	80	80
Number of strips / images	20	860	17	680
Flying height above ground level [m]	100		100	
Ground sampling distance [cm]	3,1		2,7	
Overlap along / across	80	40	80	40
Number of strips / images	7	301	7	322

A first view onto Table 3 shows no big differences. A second view opens some details. A flying height of 100 m above ground level (AGL) as permitted in the General Take-Off permit results into fine grain ground sampling distance (GSD). It is an open question how often this is needed. GSD from same AGL is slightly better for RicoGR. The real difference would materialize in bigger flying heights, where one could cover bigger areas with RicohGR in same flying time. A big, general difference, however, exists, if one can fly with significantly less overlap as shown in in Table 3 for 40% across track overlap as compared to 80%.

5 New Developments

From a practical point of view the daily throughput is the most sensitive parameter. In order to influence this on a per RPAS basis one can optimize in various locations. The most effective one appears to be the reduction from e.g. 80% across track overlap down to e.g. 40% as shown in Table 3. This is why GerMAP integrates into its G212 RPAS a 2-axis dual-camera gimbal. i.e. camera suspension mount, as shown in Image 1.

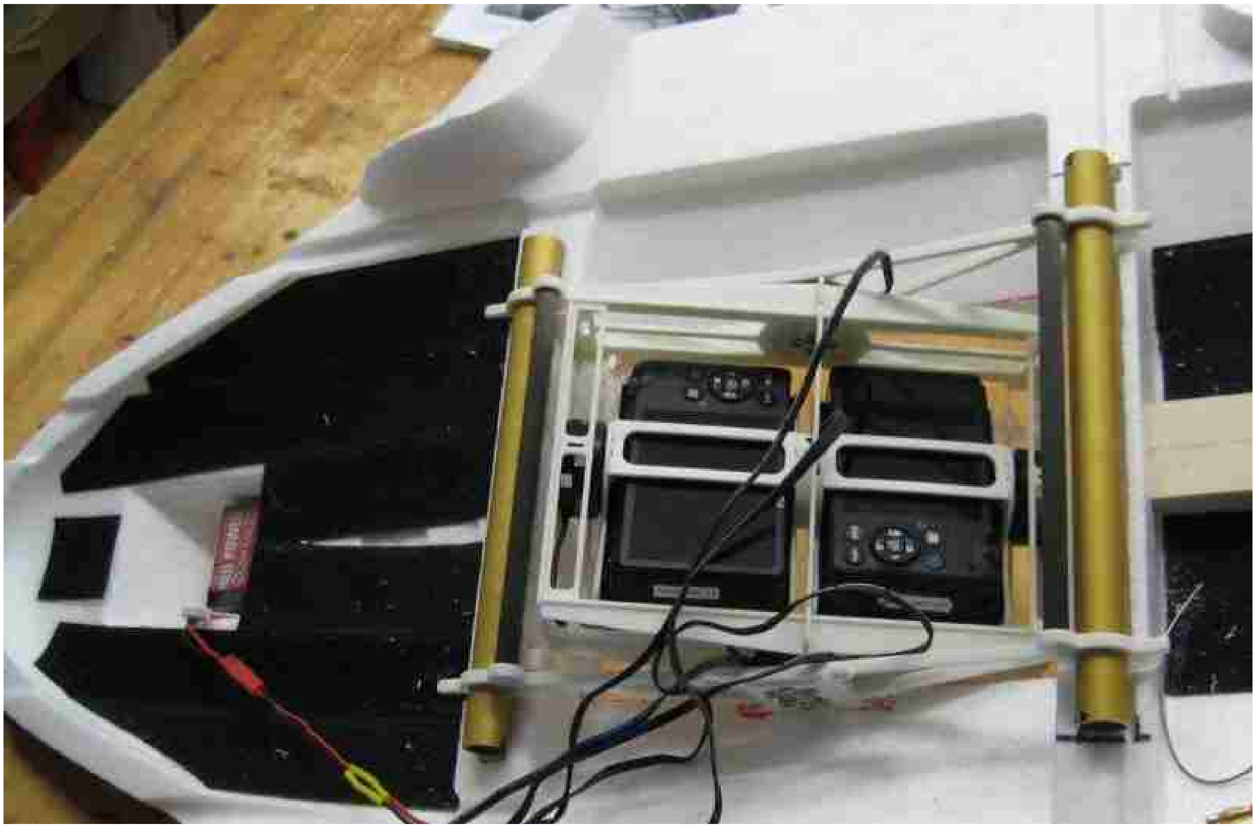


Image 1 2-axis dual-camera gimbal in a roll and pitch inclined fixed wing airplane body

This gimbal compensates for ± 30° in pitch, comparable to φ, and ± 40° in roll, comparable to ω, for 2 cameras which may be mounted in either parallel planes, e.g. 2x nadir looking, or opposite looking, e.g. ± 25°. In the parallel looking case one can operate simultaneously a RGB camera and a NIR camera thus enabling 4 bands, RGBI, while reducing the required overlap down to e.g. 40% or even less. When placed in opposite looking directions, still stabilized, one can even double the swath width which reduced the flying time for the same area even further, or almost double the area for the same amount of flying time in single camera mode.

Integrating gimbal solutions to copters is, mechanically seeing it, more an attaching a gimbal than integrating it. Usually, copter-gimbals sort of hang below the (multi-)copter which is a different task to resolve as literally integrating a gimbal inside the body of a fixed wing airplane.

6 Conclusions and Outlook

RPAS works fine. Traditional photogrammetric flight mimic is realized and data processing in place. It is applicable for local tasks. The application dictates the most appropriate tool. Vertical inspection tasks are the domain of copters. „Larger“ small areas are the domain of fixed wing airplanes. The technology suffers reputation from a certain non-commercial but governmental use of similar systems. Commercial use will have to proof the technological readiness and commercial applicability of RPAS-Mapping in various fields. This is also strongly influenced by the ethics of its users. Effect pushing marketing portraying extreme, singular applications of RPAS might be misguiding the general public and the community just approaching to this technology. Its great potential is in commercial, civil applications. Legislations will have the major impact of applicable technology. And it remains to be seen how swift and progressive European legislation will enable European RPAS technology and RPAS services. Policies for RPAS operations are treated on a European level, e.g. Kämpfe 2013.

Specialists from other domains, e.g. forestry, civil engineering, insurances, and others, might approach RPAS as a “simple tool” for collecting their specific data. All of them will need to georeference their data, the domain of surveyors or should one state geomatics-engineers? Integration of more versatile sensors, miniaturization, and simplification of user-interfaces will further push the applicability of RPAS. Nevertheless, all users of RPAS always may have safe and happy landings!

7 Literature

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