Autonomous Aerial Sensing – Fast Response and Personalized

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Key words: unmanned airborne systems, aerial survey, site documentation, surface modeling, disaster management

SUMMARY

Unmanned airborne systems (UAS) with a total weight of less than 1.1 kg are a new sensor platform. They offer a variety of applications as measuring systems and do not suffer the many administrative restrictions like various other, however, significantly heavier UAS. Different remote sensors like colour image cameras, colour infrared up to thermal cameras can be integrated.

The paper presents a concept of an autonomous airborne system. It is simple to handle, and its operation is easy to learn by everyone. It operates as a personal aerial mapping system. Data processing is part of the concept and can be done in the field to a certain extent or remotely via Internet for detailed analysis and higher accuracies. Accuracy magnitudes known and used in professional airborne systems are achievable and will be discussed. The paper describes the hardware and software system components. Its limitations due to technical restrictions are presented.

Applications in engineering surveys, fast documentation for disaster management and fast true orthophoto production are demonstrated in examples. An outlook on further developments completes the paper.

ZUSAMMENFASSUNG

Unbemannte Flugsysteme mit einem Gesamtgewicht von unter 1.1, kg stellen neuartige Sensorplattformen dar. Sie gestatten eine Vielzahl von Messmöglichkeiten und unterliegen in deutlich geringerem Umfang unterschiedlichsten administrativen Einschränkungen wie deutlich schwerere Systeme. Verschiedene Sensoren wie Kameras im Farb- und Farbinfrarotbereich oder gar Thermalkameras können eingesetzt werden.

Der Artikel stellt das Konzept eines unabhängigen, luftgestützten Systems vorgestellt. Es ist leicht zu handhaben, durch jedermann zu bedienen und ein individuelles luftgestütztes Messsystem. Bestandteil des Konzeptes ist auch die Datenverarbeitung, welche direkt im Feld oder mit einer höheren Präzision auch über Internetservices erfolgen kann. Es werden Genauigkeiten erreicht, wie sie von professionellen Systemen her bekannt sind. Hard- und Softwarekomponenten werden vorgestellt, gleichfalls die technischen Einschränkungen diskutiert.

Vermessungstechnische Anwendungen, schnelle Dokumentation von Schadensfällen, und schnelle „true orthophoto" Produktion werden an Beispielen aufgezeigt. Ein Ausblick auf kommende Entwicklungen schließen den Artikel ab.

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1. INTRODUCTION

Unmanned or robotic systems are in wide use for safety, economic and fast response reasons (see e.g. SCHROTH/MACIEJEWSKA 2008). Even at the 48th International Paris Air Show 2009 the unmanned aerial vehicles (UAV) took over a major role at the exhibition (see e.g. WILLIAMSON 2009). Unmanned aerial systems (UAS), also called automated drones, date back to the early 20th century. They are used as fixed wing planes or helicopters with weights between less than 1 kg and several hundreds of kilograms.

The paper will restrict itself to a specific category of UAV, the light weight UAV with less than 1.1kg weight, which are allowed to operate in the designated UAV corridor in civil airspace. The presented UAV is a flying wing, i.e. a fixed wing airplane without tail. This flying wing UAV is designed for outdoor operations covering up to $1km^2$ per flight mission. With its extreme low weight it can be operated with minimum restrictions.

But not only the fascinating technology of the UAV will presented, the total concept for operating the system, achieving and processing the remote sensing data will be introduced. Automation procedures assist the flight management and the data processing on ground in a fast and precise manner. Empirical tests and their results prove the functionality and the professional capacity of the concept. A demonstration of the wide range of possible applications will complete the paper.

2. THE CONCEPT – PAMS

Unmanned aerial systems not only fly unmanned but also register, store or transmit data. They are either operated remotely or operate autonomously. Thus, all UAS consist of a flying vehicle, often called an unmanned aerial vehicle, and some sort of data collection device. In this respect, UAS are one kind of remote sensing devices. UAV are in known use in the defense and intelligence domain since late 1940ies. Recently, their use in commercial projects becomes applicable and a multitude of manufacturers offer systems (EVERAERTS 2006; PETRIE 2008). From the remote sensing point of view, all UAS are platforms carrying some sort of sensor or sensors which in the aviation industry is generically called a “payload”. UAS might be categorized according to flying properties, i.e. Fixed Wing, Rotary Wing, Airships or Paraglide, according to weight and according to their application. Various instances of research and applications are known.

In commercial use, a tendency or concentration on lower weight UAS with less than 10kg is visible (PETRIE 2008). Such systems are on one hand easier to transport and less restrictive to operate. On the other hand they are more limited in operational distance and endurance. Many UAS are applied for the generation of aerial images or airborne videos. Separate stitching software allows the composition of an image mosaic. This, however, usually lacks photogrammetric precision and geo-reference.

So a search for an UAS was necessary which is able to produce aerial images and to process them into orthomosaics in the photogrammetric sense, i.e. with high accuracy, known geometry and geo-reference. Such a system consists of hardware, the UAV, and software for photogrammetric data processing. Additional constraints were that the UAS shall be used for areas of up to 1km^2 per one flight mission, shall be operated by one person only, shall be easy to maintain and easy to transport in a regular car or as carry on luggage for air travel, shall be quickly to learn, shall be robust in flying and landing, shall be in operation as little dependent on regulations as possible and it shall be affordable, too.

Initially, known manufacturers were evaluated, see EVERAERTS 2006. However, this business area is highly dynamic and a 2006 published table is not any longer complete for evaluation in 2008/2009. Since the main goal was to fly photogrammetric blocks over smaller areas, rotary wing, airship, and paraglide types of UAV were excluded. Their properties fulfill other constraints respectively applications. The investigation pointed to a UAS named PAMS. Its manufacturer is SmartPlanes AB, Sweden, see www.smartplanes.se. PAMS ideally fits the requested needs, see Figure 1.

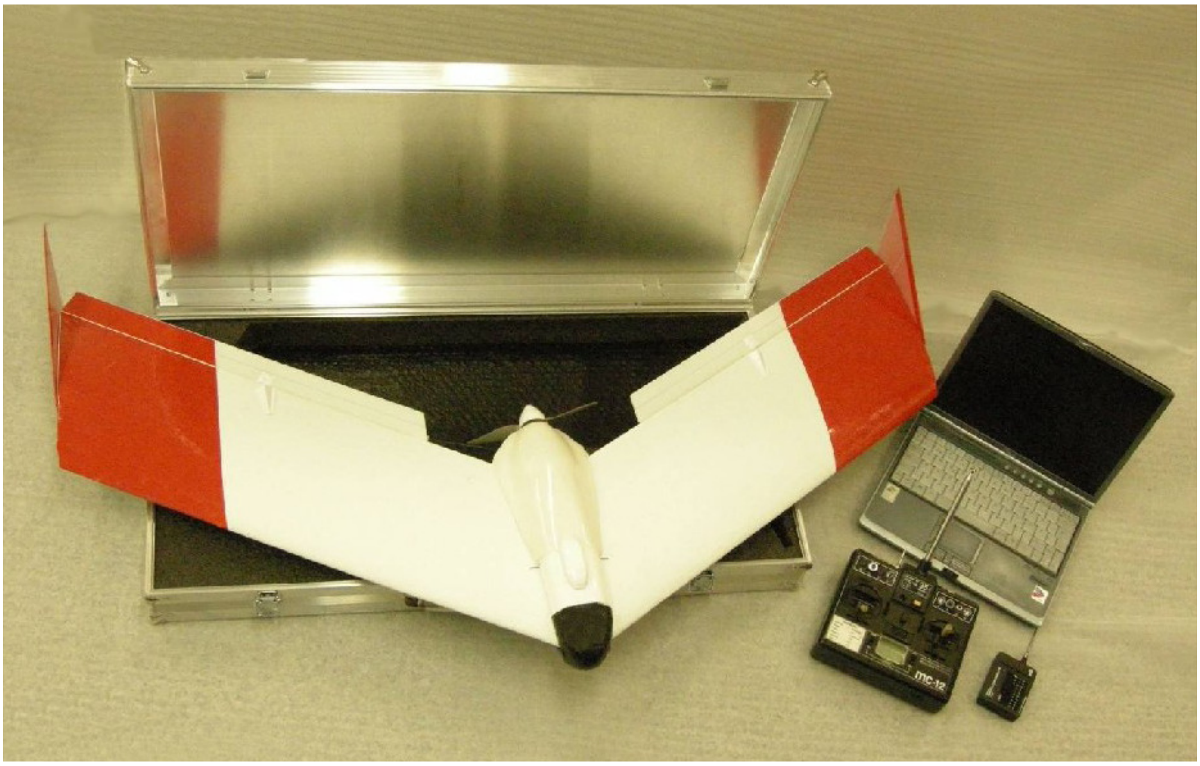


Figure 1: PAMS – SmartOneB UAV with ground station hardware and transport case

PAMS is the acronym for "personal aerial mapping system". It uses the SmartOneB UAV of SmartPlanes as payload carrier for a calibrated 7Mpixel camera and comes with a software package including ground station control and first level photogrammetric data processing. It further offers second level results via Internet services for higher demand data processing.

The concept of PAMS is intriguing. One person, the "pilot", can operate the system. The pilot defines in the ground station the size of the area which connects automatically to the SmartOneB UAV sitting on ground. From there the ground station obtains its initial GPS-signal defining the mission home-point. Finally, one sets the desired ground sampling distance (GSD) of the aerial images. Following, the pilot hand-starts the UAV in auto-mode. This brings it automatically up to operational height. When appropriate, the pilot commands in the ground station the start of the flight mission. This initiates the sequence climb to block height, fly to start of first strip, fly all strips while location-triggered exposing aerial images, come back home and park above mission home-point. Aforementioned sequence of actions is executed fully autonomously by PAMS. The pilot sees at all the time the track of the flight path and all footprints of exposed images in the graphics window of the ground station . For landing, the pilot initiates this phase of the flight mission and brings down the UAV in semi-auto mode, which automatically levels the UAV, but the pilot steers the UAV to avoid obstacles. Basically, the UAV glides down by its own and automatically leveled. Once landed, the pilot takes the SD-memory card off the camera and places it into the ground station notebook. There, first level data processing can take place immediately. The software produces two types of first level image-results, a so-called QuickMosaic and a so-called AirMosaic. Digital Surface Models (DSM) and OrthoMosaics are second level results and are accessible via an Internet service. With this concept every non-surveying related person can generate local geo-spatial image information and even derive high quality orthomosaics and DSMs.

2.1 System Components

The SmartOneB UAV of PAMS is a Flying Wing. With its GPS-connected autopilot it is capable of fully autonomous flight according to preprogrammed mission plans. Its battery power allows for flights up to ca. 35 min. SmartOneB carries a calibrated 7Mpixels camera. The autopilot triggers image exposures location controlled, i.e. image-exposure is speed-independent. Further, the autopilot transmits GPS data and other data such as voltage level of battery via the built-in bi-directional radio modem down to the ground station which in turn can send up control commands. The total weight of the UAV is little less than 1.1 kg. The wings are detachable which makes the UAV fit into a rugged yet compact transportation case measuring 85 x 40 x 15 cm^3, see Figure 1. The ground station consists of the aforementioned bi-directional telemetry hardware, a remote control device for manual flight mode and a powerful notebook with software for mission planning, mission control and automated image processing. The PAMS-software generates fully automatically geo-referenced imagery and mosaics. The image data of a flight mission can be second level processed using the PAMS Internet service to derive a high resolution OrthoMosaic and/or a high density Digital Surface Model per flown block. PAMS is commercially available and distributed e.g. by GERMATICS, see www.germatics.com, Germany, a Blom Group Subsidiary.

2.2 System Operations

With a typical mission altitude of flying in a plane 200m above ground level (AGL) and with a 7 Mpix calibrated camera the resulting GSD in the derived AirMosaic or OrthoMosaic, also called ground sampling distance (GSD), is about 10 cm and from 100 m AGL the corresponding GSD is about 5 cm. The internal precision of the OrthoMosaic in planimetry, X and Y, is typically in sub-pixel size of GSD. The precision of computed heights is better than 2 pixels GSD (see chapter 3). With the addition of accurate ground control, sub-decimeter accuracy can be achieved in both position and altitude.

A flight mission consists of four phases: pre-flight planning and preparation, take-off, survey and landing. Although PAMS' SmartOneB UAV can execute the entire flight in full autonomous mode the pilot often takes over for take-off and precision landing.

For pre-flight planning one can load a background, geo-referenced image or map, which helps identifying the location of flight. Basically only flight area and GSD need to be set. One can scale, shift and rotate the rectangular flight mission area. The desired GSD determines the according flying height. Photo-overlap is per default set to be bigger than 60% in both directions, along and across flight direction. The ground station then flushes the set parameters onto the autopilot at its power-up using the wireless data link. After completion of pre-flight check-out and camera setup the UAV is ready for launch.

At hand-launch, see Figure 2, the on-board sensors detect the take-off situation, and the aircraft commences in auto mode a rapid climb to parking altitude, where it is then “parking”, i.e. flies circles. During parking the pilot checks out air space and UAV flight performance. An active command in the ground station starts the actual survey phase.

Figure 2: Hand-launch sequence of a PAMS – SmartOneB UAV

There it climbs in shape of a vertical spiral up to mission height and proceeds to the start of the first strip. Systematically and in fully autonomous manner SmartOneB UAV flies all parallel photo strips, see Figure 4. PAMS automatically senses and compensates for current wind conditions. This guarantees correct spacing between flight strips and imaging locations and the autopilot executes the exposures GPS-driven.

During all the time of a flight mission the pilot monitors the progress visually either by line-of-sight or on the real-time ground station display. One can temporarily suspend the mission or abort it at any time. There is also a direct manual control mode, e.g. for precision landing and take-off.

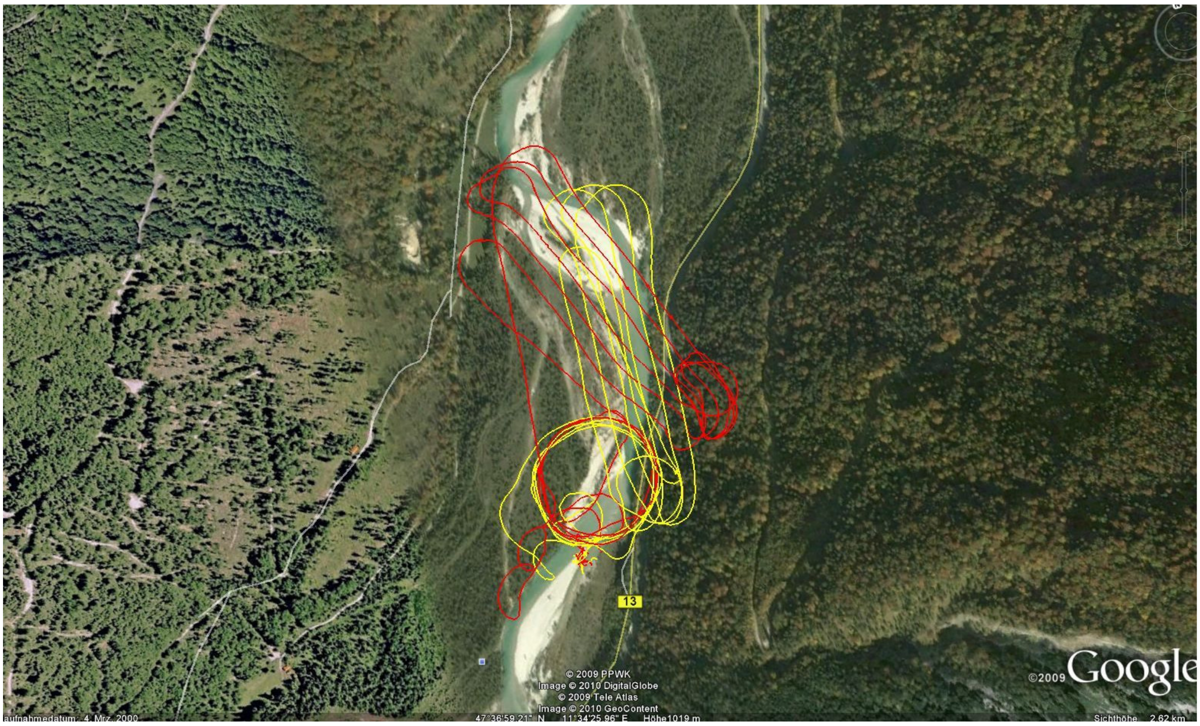
After completion of the survey-phase the UAV automatically returns, sinks down to parking height and circles above the take-off point until the pilot either commands an automatic landing or takes over to perform a precision landing, see Figure 3.

Figure 3: PAMS SmartOneB UAV in landing phase

Figure 4 depicts the flight tracks of two overlapping blocks used to form one bigger orthomosaic consisting of ca. 360 aerial images. In this example a river in the Bavarian Alps, Germany, had to be monitored for example. For this, two overlapping blocks with each 8 strips and ca. 180 images had to be flown. The mission height was 150 m AGL using 8 parallel strips and two cross-strips. The total flight time per block was about 12 minutes.

After landing aerial image data are transferred to the ground station computer. Quickly an overview mosaic, QuickMosaic, is compiled in order to verify that full image coverage was achieved. At this stage the individual images are available for direct analysis and field work.

In a second step the image data is processed using advanced image processing and photogrammetric techniques to produce a geo-referenced AirMosaic ready for use in geographic information systems (GIS). In an advanced application mode one flies several adjacent blocks and combines them into one large orthomosaic.



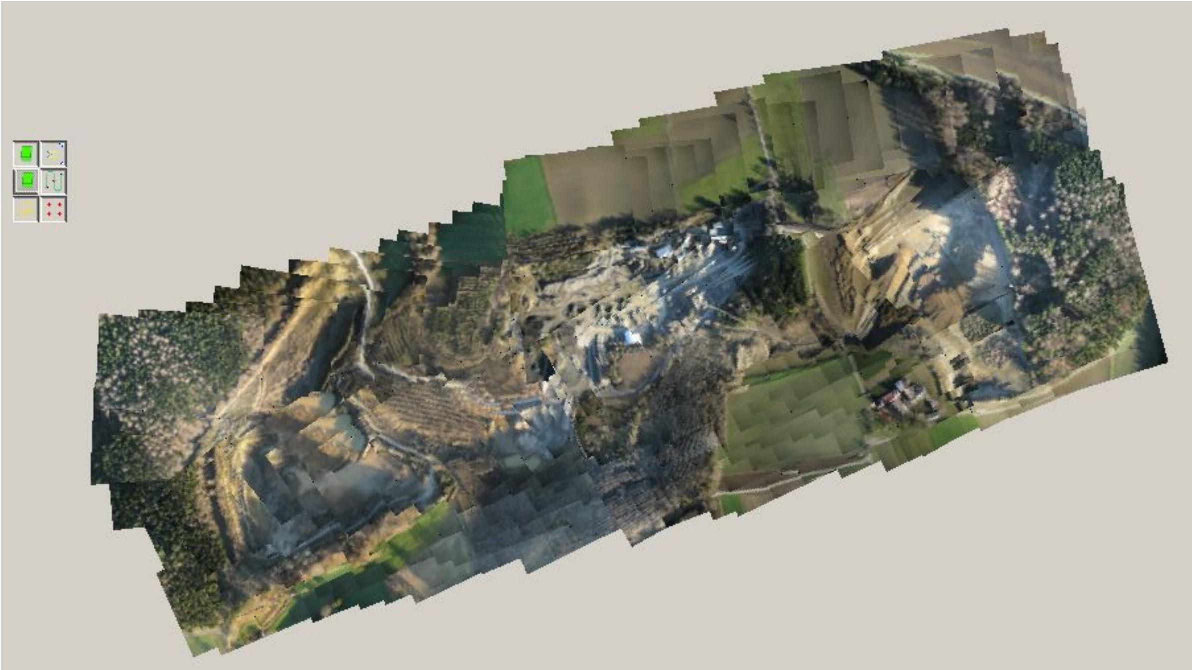
<u>Figure 4:</u> Flight tracks of two overlapping blocks (yellow and red) with parking circles

2.3 Data Processing

Data processing with PAMS is truly easy. Everyone can execute it, either by himself or by uploading and using an Internet service. First level data processing generates QuickMosaics and AirMosaics. Both can be computed on site. Second level data processing delivers DSM and OrthoMosaic and is accessible as PAMS–Internet–Service.

2.3.1 <u>QuickMosaic</u>

For QuickMosaic the software uses the recorded GPS data and some additional sensor data for direct geo-referencing and combines all aerial images into sort of an image-mosaic. This takes less than 20sec for about 250 images covering an area on ground of about 700m x 700m extent. The QuickMosaic (see Figure 5) is intended to quickly visualize, if the areas is fully covered or not. Due to the high image overlap of more than 60% in along and across flight direction, full coverage never was a problem. The QuickMosaic can be stored and thus gives first evidence of job-completion.



<u>Figure 5:</u> QuickMosaic, one clearly can see the full coverage but geometric displacements

<u>Figure 6:</u> AirMosaic, one clearly can see that it is not yet a perfect orthomosaic

2.3.2 AirMosaic

The AirMosaic is based on the evaluation of the GPS-recording of the autopilot. A specialized automated aerial triangulation ties the aerial images together, derives attitude values and refines the input GPS data. This process performs without human interaction. Its results are used to form a composite overall image of the area covered. Since it applies no digital terrain information, the resulting composite image, called an AirMosaic (see Figure 6), is on one hand a rectified and geo-referenced image, but on the other hand not a perfect orthomosaic. In many instances and due to the fact that the covered areas are small and thus mostly flat to moderately undulating, the resulting AirMosaic turns out to be very close to a rigid orthomosaic. Important, however, is that due to its fully automatic process this operation can be conducted by everyone and it does not require any specific surveying pre-knowledge.

2.3.3 Digital Surface Model

For higher level applications one can extract from the aerial images a digital surface model (DSM). This requires specific photogrammetric knowledge paired with particular modeling know-how of the UAS technology. Since this is beyond the expertise of a standard PAMS user, the PAMS–Internet–Service offers this capability. One uploads the aerial images and some more information to a website and receives download information after completion of the DSM computation. For some visualized DSMs see Figure 7. Usually, the DSM raster spacing of an e.g. 10cm GSD OrthoMosaic is at 20cm, i.e. 2 orthopixels. This produces lots of modeled details in the surface model which is subsequently advantageous for draping orthomosaics or computing volumes.

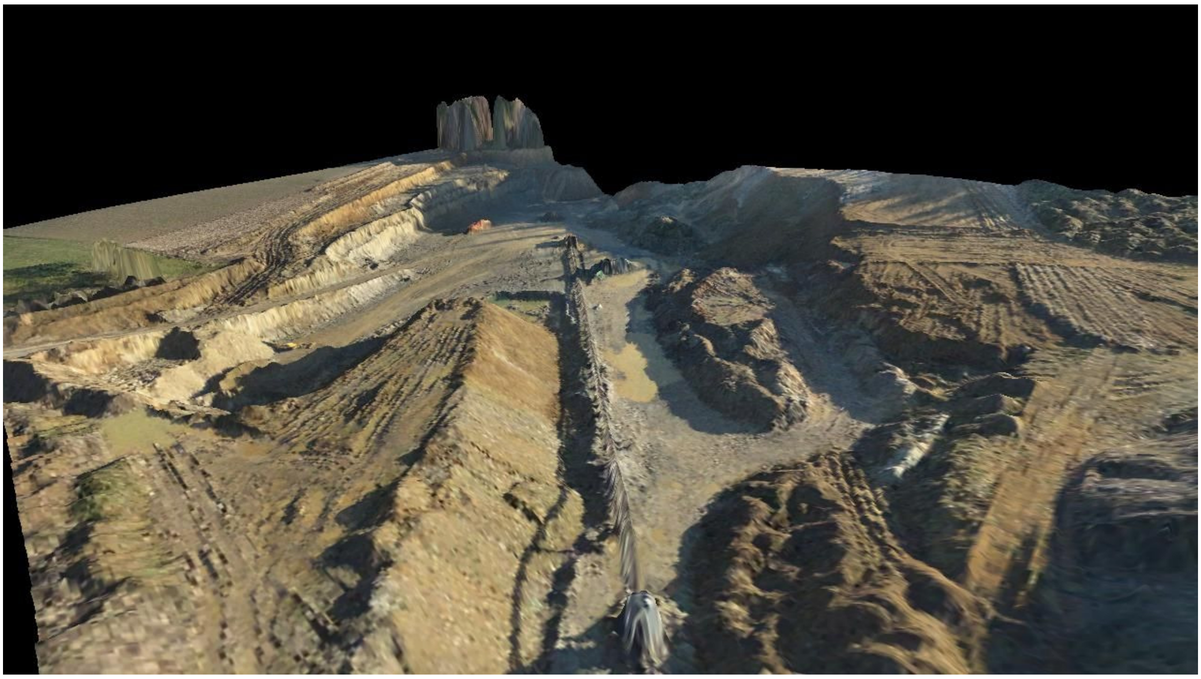


Figure 7: **Perspective view of the DSM resulting from flight mission of Figure 6**

2.3.4 “True” OrthoImage

In the same manner like the DSM one obtains an OrthoMosaic of the flown area. Due to the facts that the PAMS–Internet–Service possesses technology for generating a DSM and due to the high overlap, often 80% / 80% along and across flight direction, one even can produce a True OrthoImage (TOI, see MAYR 2002), see Figure 8.

Figure 8: OrthoMosaic of flight mission depicted in Figures 4 and 9

3. ACCURACIES

As the PAMS UAS is used for some months only, the observations regarding accuracies are preliminary. So far, it seems appropriate to differentiate between internal and external, or better: relative and absolute accuracies. Which one to apply and to consider is completely application driven. For pure volume data, relative accuracy mostly is sufficient to consider. For cadastral GIS overlays absolute accuracy is vital to be high.

Up to now PAMS is operated in direct geo-referencing mode. It’s experienced an inner planimetric accuracy is of less than half the GSD of the orthomosaic. In height, determined in derived DSM, an inner accuracy between 1 to 2 pixels GSD of the related orthomosaic was found.

For determination of absolute accuracy two modes were used. In mode A a priori signalized ground control points were available. In mode B a posteriori some common natural ground control points were measured. A block with GSD 7cm was available for mode A consideration and a block with GSD 10cm for mode B consideration. Table 1 summarizes the results.

Mode	GSD [cm]	Planimetry [cm]	Height [cm]	Planimetry [pixel]	Height [pixel]
A	7	3	5	0,5	0,7
B	10	7	12	0,7	1,2

<u>Table 1:</u> Absolute accuracies of orthomosaics and DSM derived from PAMS imagery

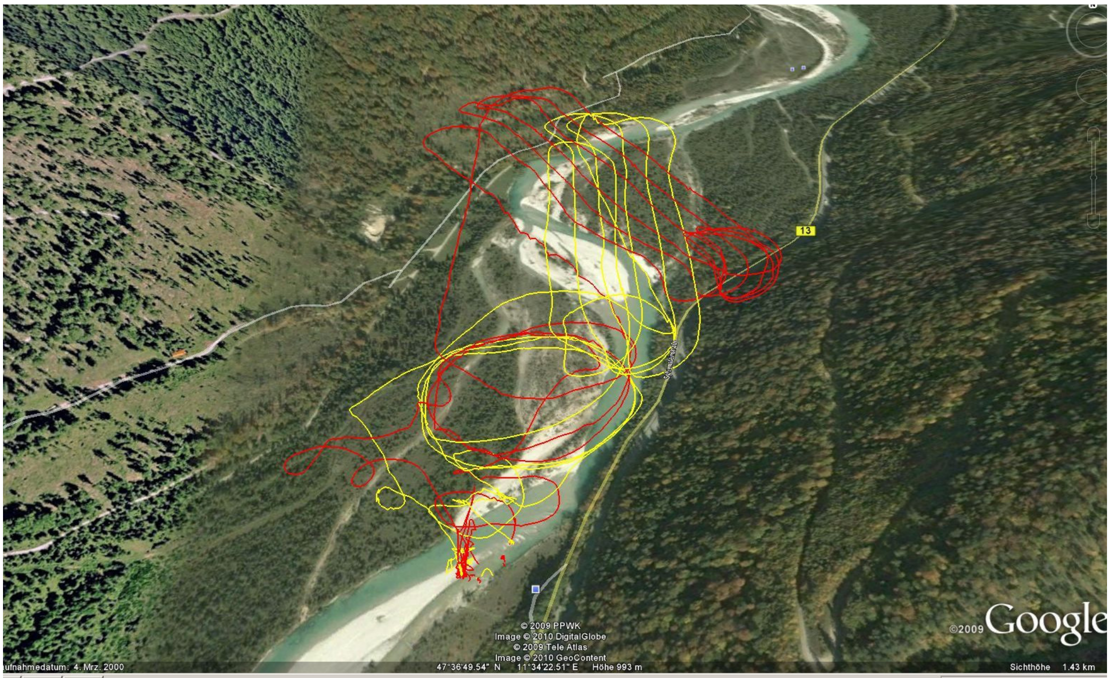
4. APPLICATIONS

The PAMS UAS successfully executed about 90 projects, all in non-urban areas. By far not all were flown by the authors. Overall, the SmartOneB UAV completed about 110 h of flying time in missions and test flights without causing operational problems. Application opportunities are manifold. They can be found in e.g. monitoring agriculture, forest, construction places, environmental sites, golf courses or wind mill location planning.

In below example an orthomosaic of a river bed in a natural preserve had to be produced, see Figure 8, where the environmental agency injects 6.000m^3 of new gravel into the river for purposes of re-naturalization. The agency wants to monitor periodically the appearance of the gravel pile and measure its take-away and distribution volume at a given time. For this area one needed to fly two slightly overlapping blocks. Challenging in this application were the steep hills to the left and right of the river bed which is depicted in Figure 9. Both flights including setup and dismantling the equipment took place in about 2 hours.

In another project a golf course in northern Sweden was UAV-mapped in 7 blocks. A total number of 1.939 aerial images was collected and transformed into one single OrthoMosaic with a GSD of 7.5cm , see Figure 10, and an according DSM with a raster spacing of 20cm. The execution of all 7 flight missions took 1 day. Processing all images to aforementioned deliverables took several days. This is a standard photogrammetric product with its typical ins and outs. Processing many images takes some time, even if they are small. Most difficulties arise in pure forest areas. The lesson learned is: dense forest is hard to triangulate, with large format images as well as with tiny format images.

The until now largest flown such super-block consists of 31 consecutively overlapping single-blocks with a total of 7.306 used aerial images. Two pilots were flying simultaneously for 1 week these 31 blocks over mostly forested area which extended about 6km north-south and 2.5km east-west. The derivation of its overall OrthoMosaic took 3 weeks including aerial triangulation, DSM derivation, final OrthoMosaic generation and quality control. Only due to flying below cloud coverage the execution of this project was possible (see Figure 11).



<u>Figure 9:</u> Flight paths of 2 blocks in a narrow Alpine valley

<u>Figure 10:</u> PAMS OrthoMosaic composed of 7 PAMS flight missions, 1.939 aerial images

Figure 11: **PAMS OrthoMosaic composed of 31 PAMS flight missions, 7.306 aerial images**

In another application a stone quarry was flown (see Figure 6). Here the quarry operator wanted to know various volumes. The quarry extends over 1.3km and is about 400m wide. The area were flown in 2 blocks, each 700m long and about 450m wide in a total time of about 3 hours. Data processing to DSM and OrthoMosaic took about 4 hours. Volume determination is executed using standard software packages able to handle 3D-data (see Figure 7).

One can imagine numerous other applications, specially in disaster management (e.g. land slides evaluation) and also in the security sector. The PAMS UAS opens a new market segment, which could be named “local geo-spatial-image awareness”.

5. CONCLUSION AND OUTLOOK

Autonomous aerial sensing as implemented in the PAMS UAS is a quantum step in geo-spatial technology as it migrates highly specialized procedures to simple and reliable personal aerial mapping actions for everyone. It creates a new discipline which can be called “UAV-Mapping”. The UAV is the sensor platform and aerial imaging is the first sensor implementation into a UAS. Other sensors such as LIDAR or thermal sensors, are expected to emerge for use in ultra light weight UAV.

UAV-Mapping is a new system solution for the capture of geo-referenced aerial images and generates on-site, with AirMosaics geo-spatial imagery, solutions ready for delivery and use in e.g. geographic information systems (GIS). The Internet-Service approach for more complex, photogrammetric tasks, opens access for non-specialists to easily generate high-quality OrthoMosaics and highly accurate Digital Surface Models. This in turn might give UAV-Mapping the right commercial push. It opens new possibilities for manifold applications and helps satisfy public or private geospatial awareness needs. Early adapters with affiliation to geospatial demands will offer new services in areas up to now hidden, and, due to their small extents, too small to be covered economically by manned survey aircraft operations. So far, PAMS complements the existing aerial surveying activities of the respective mapping industry. Moreover, it widens the geospatial airborne sensing domain, and it appears that PAMS' technology will naturally give an additional lift to the geospatial industry.

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BIOGRAPHICAL NOTES

Dr. Werner Mayr, *1958, studied Geodesy and Surveying from 1979 to 1985 at the Technical University of Munich (TUM), and graduated as Dipl.-Ing. He started to work for VEXCEL Corp. in Boulder, Colorado, as production engineer and programmer for close range photogrammetry and radargrammetry. In 1987 he got granted a stipend for a doctoral thesis at TUM with Prof. Ebner. From 1990 to 1997 was member of the development team of Carl Zeiss' photogrammetry division and guided it. During this time he focussed on introduction of digital photogrammetry into the product portfolio of Carl Zeiss, Oberkochen. In 1993 he obtained his doctoral degree from TUM. After his affiliation with Carl Zeiss he followed an appointment with Siemens for its SICAD GIS division from 1997 to 1999 in Munich. From 1999 to 2003 was with INPHO, Stuttgart. During this period he guided a big development project, which ultimately was outsourced into a new company CONPIE, which he guided for five years. Since early 2009 he is as managing director with Blom Deutschland, the German subsidiary of the largest European mapping entity Blom ASA, Oslo, Norway.

Dr. Ralf Schroth, born in Berlin in the year 1953, studied Geodesy and Surveying from 1972 up to 1977 at the University of Stuttgart. After the probationary period for the national surveying administration in the Land Baden-Wuerttemberg he got his degree as legal surveyor in 1979.
He worked as a scientific assistant at the Institute for Photogrammetry at the University of Stuttgart under the leadership of Prof. Fritz Ackermann till 1984. There he was active in the fields of research and development, giving lectures in Photogrammetry and adjustment theory, software development for aerial triangulation and photo-reproduction. In 1985 obtaining the degree of Doktor-Ingenieur.
From 1984 till 2008 he has been working with the company Hansa Luftbild in Muenster, where he was acting in different managing positions like as managing director and member of the board of the Hansa Luftbild Group.
Since 2008 Ralf Schroth is working for the Norwegian Blom Group as managing director in Germany, business development director for central and eastern Europe and organizing the off-shore production in Romania.
Ralf Schroth has more than 25 years experiences in business administration and management, project management, Photogrammetry and Geo-Information systems. He introduced different GI-systems at the Hansa Luftbild Group and was in charge of them. Already in 1988 he was announced as a member of the management board at Hansa Luftbild GmbH and co-founded an international group of companies. He was also responsible for general contracting projects on the Arabian Peninsula. He was board member in several affiliated companies in Germany and abroad.
Since 1991 he is a lecturer at the University of Hanover for business administration and management for surveying engineers. In 1997 he got the appointment as honorary Professor from the University of Hanover. From 2004 till 2008 he was also lecturer at the Institute of Geomatics at the Polytechnic University of Barcelona.

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