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Unmanned Aerial Systems in Use for Mapping at Blom

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ABSTRACT

New technologies open new opportunities. So do unmanned airborne systems (UAS) for the mapping industry. In our company we apply one system, PAMS from SmartPlanes AB, Sweden, and report in this paper about our experiences with it on its daily use in projects. Recently, a multitude of activities with unmanned airborne vehicles (UAV) becomes reported on. There is growing interest in the commercial, industrial, and academic mapping user communities. As an introduction, the major components of an UAS are identified. This paper focuses on the lightweight PAMS. It is an UAS and gets applied on a day-to-day basis as part of our standard aerial imaging tasks for more than two years. We present the unmanned airborne vehicle in some detail as well as the overall system components such as autopilot, ground station, flight mission planning and control, and first level image processing. The paper continues with reporting on experiences gained in operating an UAS for aerial mapping purposes including aspects of flying in unattended flight mission mode. Various examples show the applicability of the PAMS UAS in geospatial tasks. They proof that UAS are capable delivering data for professional results such as orthomosaic GIS-backdrops, digital surface or terrain models and more. Some remarks on achieved accuracies give an idea on obtainable qualities. A discussion about safety features puts some light on important formal matters when entering unmanned flying activities and rounds up this paper. Conclusions summarize the state of the art of an operational UAS from the point of the view of the author.

1. MOTIVATION

What's new? This question drives many of us. Why do we want to know what's new? One possible answer is, because we hope to achieve more with less work, efforts, and money. Another possible answer might be, because we want to enter new fields, new markets, and new opportunities. A few years ago our tech-scan pointed us onto the unmanned airborne vehicles (UAV) technology and their application for mapping purposes. We soon were convinced that UAVs when integrated into autonomously operating systems, basically being a sort of a robot, will at least have the potential to open new business opportunities if not more in terms of having the potential of revolutionizing our traditional flying approach with manned aircrafts. We identified various interests in approaching UAS-based aerial mapping. One was to enable ourselves to operate a system capable to image smaller areas with the mimic of a traditional photo mission flown by manned survey aircraft. With respect to data processing we wanted to be able apply our photogrammetric knowledge as much as possible, for example to join several blocks into a bigger area. Other interests were to fly below the cloud coverage, to fly in an as wide a weather window as possible, to be highly mobile, to have low mobilization costs, to operate the UAS with one person, to encounter as little administrative trouble as possible, to operate the most reliable and most advanced UAS, and, last but not least, to offer services at attractive price levels, of course. These and some other interests motivated us to seriously enter this new field of technology.

2. INTRODUCTION

One may think about an unmanned aerial system "that's a toy". It is not. We will show in this paper that one can apply unmanned aerial systems (UAS) for traditional aerial mapping tasks – on a commercial basis. There are limitations to it, but there are new openings to it, too. Geospatial information is going ubiquitous and thus getting an infrastructure-commodity. Many of us use navigation systems and positioning services daily in our cars and smartphones. The demand for more detailed but also local geospatial information increases. Technological progress paves the way for new endeavors and thus new fields of applications. Miniaturization creates new business opportunities, e.g. the integration of a consumer digital camera and other components into an unmanned aerial vehicle (UAV). Latter one is equipped with special, miniaturized electronics and can execute a survey flight covering smaller areas in a fully autonomous manner.

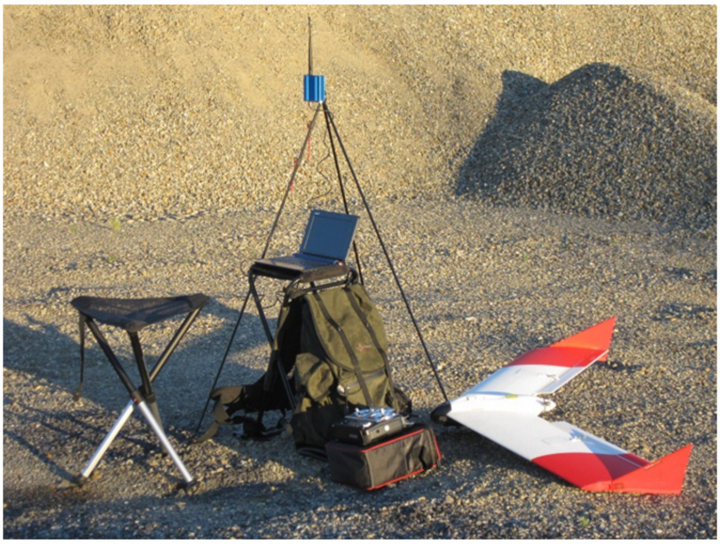


Figure 1: SmartOne and groundstations setup

We apply the commercially available UAS-product PAMS (Personal Aerial Mapping System) from SmartPlanes, Sweden. The system is capable to deliver georeferenced aerial images, which we process into orthomosaics, digital surface or terrain models (DSM or DTM) and use to derive other data such as e.g. volumes or contours. In the following we describe a system which automatically collects aerial images and processes them in a highly automated manner into the aforementioned geospatial image information. Operating new technology introduces risks but new challenges, too.

3. SYSTEM DESCRIPTION

The Swedish company SmartPlanes AB, Skellefteå, develops, manufactures and distributes PAMS. They work on and with PAMS since early 2006. The system is based on a *flying wing* serving as airplane platform for the UAV. This airplane concept is known since the early 30ies of last century, when the German brothers Horten introduced it into aeronautics and since known as *Horten-wing* or *delta-wing*. Such an airplane has no tail, see Fig. 1, and thus only two rudders, the so-called elevons. They combine and control elevator and aileron meaning up – down and left – right movements of the airplane. For a long time this airplane concept suffered from its complex steering control, which of course still is valid, as physics does not change. However, progress in control theory and electronics helped getting the steering control of a flying wing well manageable.

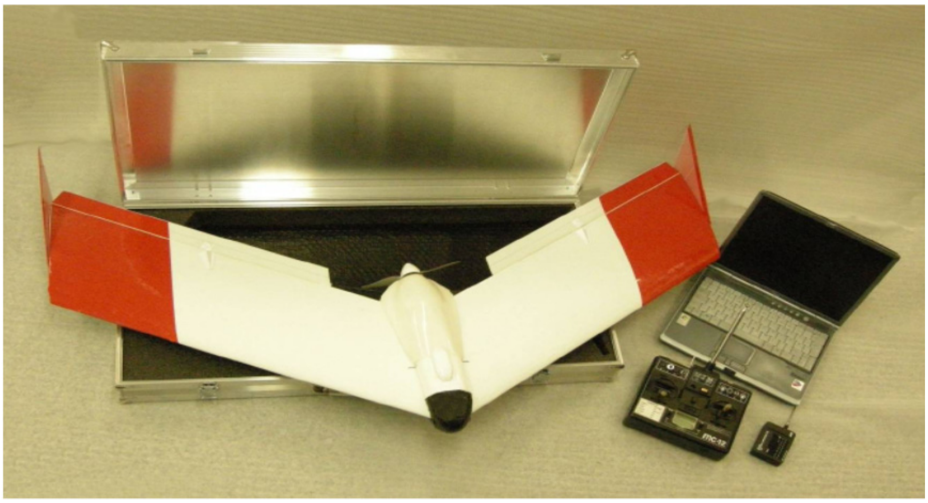


Figure 2: PAMS' SmartOne UAV with transport box, groundstation computer, accessories

PAMS is a highly compact system and packs for transport into two small pieces of luggage, a 20 l backpack and an 8 kg box of dimension 85 cm x 45 cm x 15 cm, see Fig. 2. It is thus ideally prepared for easy transportation and high mobility in e.g. any car or as luggage in a passenger airplane. The system has hundreds of

hours of operation without serious failures. That it has a weight of less than 1.1kg when operating in air is intriguing. Nonetheless, it appeared very robust to us and proved so. When investigating in late 2005 the state of the art in UAV for mapping purposes, the author saw the flying wing concept for a mapping-UAS first at SmartPlanes with their PAMS. Other systems such as from Belgian GateWing or Swiss Sensefly are based on the flying wing airframe type as well.
The two major components of PAMS are the SmartOne UAV and the groundstation. Both make up the UAS. The flying wing, model name SmartOne, consists of two wing halves, which join firmly together for flying and get detached for transport. Fins complete the wing-ends. Horten-wing purists might decline fins; however, they improve aerodynamics for this wing profile. The airframe has undergone aerodynamic design computations and possesses astonishing flying performance. It has a wingspan of approximately 120 cm and houses the servos for the rudders, the antenna for its bi-directional data-modem and the receiver for the manual remote control mode. The fuselage puts over the joint wings and contains the bays for battery and camera, the autopilot with GPS and IMU, and the motor, see Fig. 3. The autopilot is the heart of PAMS. Once started it can take over full control of flying operations and executes an a priori uploaded flight plan completely autonomously. It uses single frequency GPS for navigation and IMU for leveling support and attitude registration. To the autopilot connect five additional subsystems. They are the two servos, the bi-directional modem, the receiver for manual remote control, and a USB port. The 10 Mpix camera connects via the USB port to the autopilot, which executes location dependent exposures. Further, the USB port is used for updating the firmware of the autopilot, if and when needed.

Figure 3: SmartOne UAV in starting phase

The autopilot communicates with the groundstation via an 868 MHz bi-directional modem and downlinks status parameters such as attitude, GPS position, time and location of exposure, flying altitude above ground, voltage level of battery, speed over ground, and other useful control parameters for the "grounded pilot". As single power source serves an 11.1 V litium-polymer (LiPo) high density energy battery with e.g. 2200 mAh. It enables the UAV to fly with full load for approximately 45 min, of which, however, usually only 20 min to 30 min are required to complete one flight mission. The LiPo feeds a single, aft mounted 200 W motor. This aft mounting pushes the airplane and is as well a safety feature in case of impact.

The pilot can take over at any given time full manual control via the 2.4 GHz remote control device, which communicates with aforementioned receiver. This is another safety feature and is, in the opinion of the author, a mandatory system property. Even if the UAS possesses an auto-avoid-collision capability, which

PAMS does not, manual control is needed to take pilot driven and other than pre-programmed decisions for flight directions, at any time. The autonomous flying operation under exclusive control of the autopilot, names “Auto2” and the manual remote control mode, named “manual” are complemented with a third control mode, the semi-automatic mode, named “Auto1”. In this 3rd mode the pilot interactively can control speed and direction when needed. As soon as the pilot releases the remote control device, the autopilot takes over control keeping speed and level of the plane. This is the preferred mode for starting and landing phases.
The UAS is further equipped with a tracker system. In case of the sudden death of the battery, the autopilot will put the flying wing into the fail safe mode. This means it shuts off the propeller, and positions the rudders so that the UAV sails down in a spiral shape. The landing location might be out of visible range or obstructed. The tracker will point the pilot towards the UAV and thus helps finding it. It has a range of up to 5 km.
The groundstation is software and fulfills several tasks, see Fig. 4. It enables flight mission planning, flight preparation, flight mission control, and flight reporting. The user can plan the flight mission, which is one photogrammetric block to be flown, either in office or on site. One can load any georeferenced background image, e.g. an orthophoto or a map, on top of which the dimensions of the block to be flown are digitized. The block can be scaled, rotated and shifted over the background image. The ability to rotate the block is important, since one attempts to fly perpendicular to the wind direction, if the location of the area of interest allows this. The other parameter for the flight mission is either the flying height above ground level (AGL) or the desired ground sampling distance (GSD). The user enters either one of both parameters. Optionally, the user can modify the overlap of the images and strips. It defaults to an 80/80 overlap situation. This overkill in terms of overlap is beneficial for later automated data processing and de-selecting potentially blurred images while maintaining sufficient stereo resp. manifold overlap. Further, one can determine in which geodetic coordinate system the user’s georeferenced background information refers to. The groundstation maintains the appropriate geodetic transformation between the GPS-coordinate system based on WGS84 and the local geodetic coordinate system.

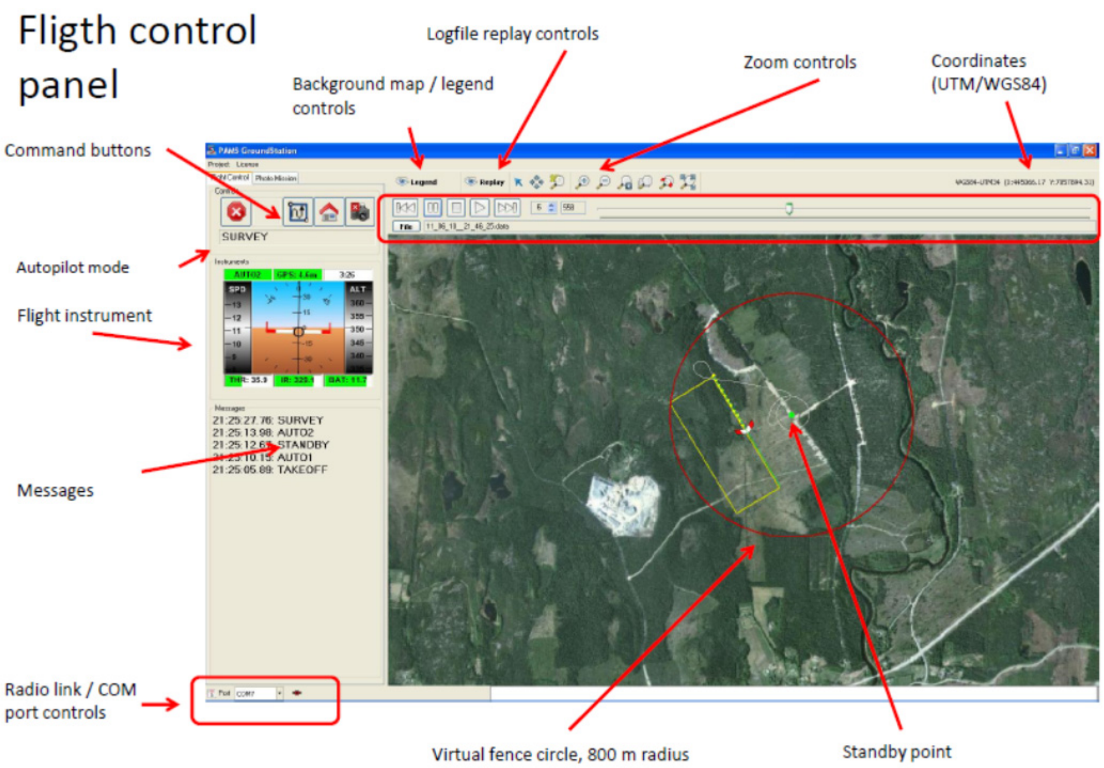


Figure 4: Groundstation display with explanations

During flight preparation the SmartOne UAV gets powered on while groundstation and bi-directional modem are powered up as well. Switching on the UAV causes the initial reading of its GPS location constituting the so-called home point of the flight mission. It also initiates the communication between autopilot and groundstation via the modem. Once initialized, the groundstation locates the UAV with a symbol over the georeferenced background image and the planned extent of the block with all of its image exposure locations. The transmission of various parameters between autopilot to groundstation terminates the mission preparation. If all parameters are within valid range, they appear with green background. Otherwise yellow or red signalize warning or error conditions. This traffic light principle makes operating the groundstation easy.
The flight mission control monitors the execution of the photo flight. It segregates the mission into three phases, take off, mission, and landing. The take off is mostly done in Auto1 mode and brings the UAV up to some height, e.g. 50 m to 60 m above ground. The pilot switches then into Auto2 mode, which starts the mission phase consisting of three parts. It begins with part 1 of the mission, which takes the UAV up to approximately 100 m AGL and puts it into the “parking position” which is flying a horizontal circle above with its home point as center point of the circle. During parking, the pilot checks airspace and flight performance of the UAV, as well as the performance of the autopilot which ought to keep the plane on a true circle while compensating for wind. Once the pilot is satisfied, a button push starts part 2, the actual photo mission. The autopilot takes the UAV up to photo-mission altitude in a spiraling flight pattern above the home point. Once approaching the proper height above ground level, the autopilot steers the UAV to the entry point of the first strip of the block and starts block execution taking location based exposures. After block completion, the 3rd part of the mission begins, which is returning, sinking down and entering into parking position above the home point again. The pilot can check once more the airspace and wind conditions and initiates in the groundstation the third phase, landing. This is mostly done in Auto1 mode, where the pilot points the UAV towards the landing spot, takes off speed and lets the autopilot keep level the plane and observes it sailing downwards.

Figure 5: PAMS landed in snow – one can operate it in winter, too

After touch-down, see Fig. 5, the pilot switches off the UAV which terminates the flight mission. This initiates the generation of a flight report with GPS relevant information. This part of the groundstation software furthermore can import an existing report and re-play the flight mission. This way, the user can observe a movie and study the flight with all of its recorded data and as often as needed.

Images are stored off-line on the SD-card in the camera. After import into the notebook running the groundstation software and in connection with the recorded GPS data, one can produce sort of a quick mosaic. This gives an overview and visual control that full coverage is achieved and takes a few seconds to produce.
An optional software package, Aerial Mapper, takes this input data, i.e. GPS recordings, camera information, and aerial images, and produces within a few minutes a mosaic. For this an automatic aerial triangulation takes place and applies its results when projecting all aerial images into a horizontal plane. The author calls this result an *airmosaic*, as it is not an orthomosaic, but comes

pretty close to it, in particular if the surface imaged has little elevation differences, which due to the small block extents often is the case. Technically, an airmosaic is a plane rectification consecutively executed on all aerial images of the block.
Higher level results, such as orthomosaic and DTM or DSM are obtainable via an Internet service. We use services from GERMATICS, www.germatics.com, where one uploads aerial images, camera specification and GPS data onto their FTP-site. They process the data and deliver either an orthomosaic ora DSM / DTM or both within a few days. Regarding ground control points (GCP), we observed that they are pretty much application dependent. If volumes are needed only, GCP are not needed. Often, it is enough to use 2 to 4 GCP for georeferencing the orthomosaic. In any case where GCP are needed either one obtains from GERMATICS proposals of their locations with supporting images, or one already has GCP measured and delivers them to GERAMTICS.

4. OPERATIONAL ASPECTS AND EXPERIENCES

There are a number of aspects to consider when operating a UAS. Some relate to the flying, some more to administrative issues. In general, two aspects have to be considered always. The foremost important one is *Saftey first!*. The second important one is: National regulations apply!
From the point of view of the author, the pilot must be able to be on command of a flight mission at any given time during its execution. Two mandatory consequences follow from this. First, the pilot must be in the position to take over manual flight control at any time. Second, flight operations have to be done within visible range only. Airspace might be disturbed by other flying vehicles or birds or due to sudden climatic changes like rain or wind, all of which requiring an intermediate recognition and reaction thus resulting into a modification the flight path. PAMS allows different stages of reaction. One can abort a flight mission via the groundstation such that the autopilot immediately returns the UAV into parking position from where the pilot can land it. If more interaction is required, the pilot can take over full manual control.

Figure 6: Hand start to the Göltzschtal-Bridge Project

Due to the electronics provided PAMS is designed for flight operations within visible range, i.e. the pilot must be able to have direct, uninterrupted visual contact with the UAV during all the times of a flight. Depending on national regulations “visible range” might result into different maximum distances between pilot and flying UAV. PAMS has integrated a so-called virtual 3D-fence within which it operates when in Auto2 mode.

One of the 3D-fence implementations is e.g. a cylinder with 800 m radius around and a ceiling at 300 m above the home point. If the autopilot detects the UAV to go outside this 3D-fence it unconditionally aborts the flight mission and returns the UAV to parking position. Such a situation might happen, if the block extents are large and wind pushes the UAV outside the virtual 3D-fence.

If for any reason the pilot or the autopilot aborts a flight mission and the block shall be flown in another attempt, it is advisable to replace the battery with a new one. A typical flight mission of e.g. 600 m long strips and 400 m width in 200 m AGL takes about 20 min to 25 min to fly and generates some 220 images. From 300 m AGL we experienced 10 cm GSD and consequently 5 cm GSD from 150 m AGL. Largest blocks we have flown had the maximum strip length of 999 m and a block width of 550 m in 250 m AGL covering on ground an area of approximately 1.300 m x 730 m taking about 30 min to fly and producing some 310 aerial images.

As the SmartOne UAV is an airplane and not a so-called "vertical-take-off-and-land" vehicle, it requires a corridor for take-off and landing. Take-off is initiated with a hand-start, see Fig. 6. Depending on the skills of the pilot this can be a shorter and / or narrower corridor, e.g. a narrow forest road. Learning to fly can be accomplished in 2-3 days. This means, the person trained, the "pilot", is able to bring up and land the UAV with support of Auto1 safely and to plan a flight mission. It does not indicate, you are a model airplane pilot, though. As with all new activities, some constant exercise in flying is needed to maintain and to extend flying skills.

Weather is the most important factor when flying. We did fly in summer with temperatures above 35 Celsius as well as in winter at -10 Celsius. Wind is more of a factor. Novice pilots should not fly at wind speeds beyond 10 m/sec. Experienced pilots might fly at 15 m/sec and more. If possible we try to orient the block such that its strips are perpendicular to the wind direction. This might introduce big banking angles, but the high overlap of 80/80 ensures sufficient manifold overlap everywhere in the block, and one can fly at a close to constant speed in both directions, which is healthy for battery life, too. The area of interest versus wind direction however might require flying upwind and downwind. We experienced in a project close to the German North Sea coast line extreme winds and had as low as 5 m/sec or 18 km/h upwind speed and more than 28 m/sec or 101 km/h downwind speed. Still, PAMS delivered perfectly fine images, and all were in correct locations, i.e. evenly distributed and at pre-planned exposure locations. In some of our projects we encountered when flying close to the ridge of a steep hill revolving air masses causing push-downs and up-lifts in the magnitude of up to +/- 10 m while flying on the same strip at 140 m AGL. The autopilot managed this wind condition pretty fine. It was more a challenge of handling bigger scale differences in the imagery of the block when producing DSM and orthomosaic data, but it was doable. In general, we are positively surprised at which winds this light UAV manages to remain stable and to deliver the required results.

Figure 7: Golf course, perspective view, orthomosaic draped over DSM

5. EXAMPLES

There are so many examples that it is hard to choose from. We did flights over different areas, some of which we present here. Golf course operators are interested in presentation and visualization possibilities as well as having a basis for planning. We flew various golf courses with resolutions down to 5 cm GSD and heights above ground between 150 m to 200 m. Fig. 7 shows a section of a golf course.

All together this course was 5 blocks totaling to 1137 aerial images, which were processed to one orthomosaic and one DSM with a raster spacing of 40 cm.

Another example is a metro station in northern Germany. No up to date orthomosaic was available in the state ortho data base. The train operator contracted us to quickly produce an orthomosaic. Fig. 8 shows this orthomosaic, and Fig. 9 shows a section of the according DSM displaying the modeling capabilities with PAMS' imagery.

Figure 8: Orthomosaic of a metro station

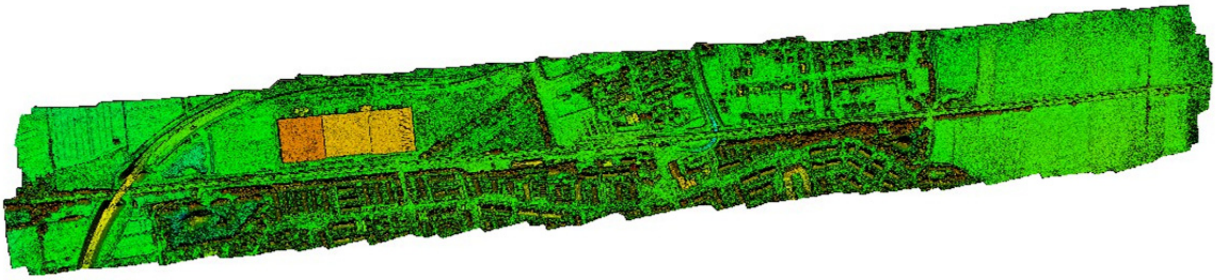


Figure 9: DSM derived from 1197 aerial images flown over above-mentioned metro station

In total four blocks were flown producing some 1190 aerial images at 200m AGL. Flying time was one day. The full resolution orthomosaic has 5 cm GSD and its according DSM a raster spacing of 30 cm. Challenging was to fly over built up areas and finding appropriate spots for take off and landing. We would not fly areas being more located inside a town.
Waste dump operators are interested in volumes. Below example shows in Fig. 11 perspective view of the DSM of such a waste dump. One clearly can see that it is now used for placing solar panels. Fig. 10a and 10b show the according color-coded DSM orthomosaic. This project was flown in two blocks each at an altitude above ground of 150 m and produced 427 aerial images.

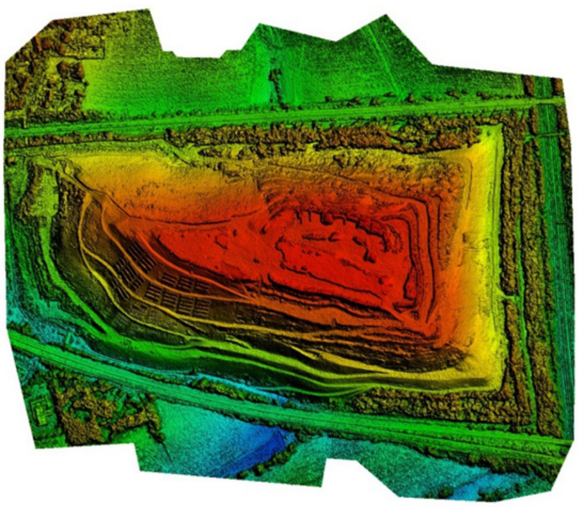


Figure 10a: DSM of waste dump

Figure 10b: Orthomosaic of waste dump

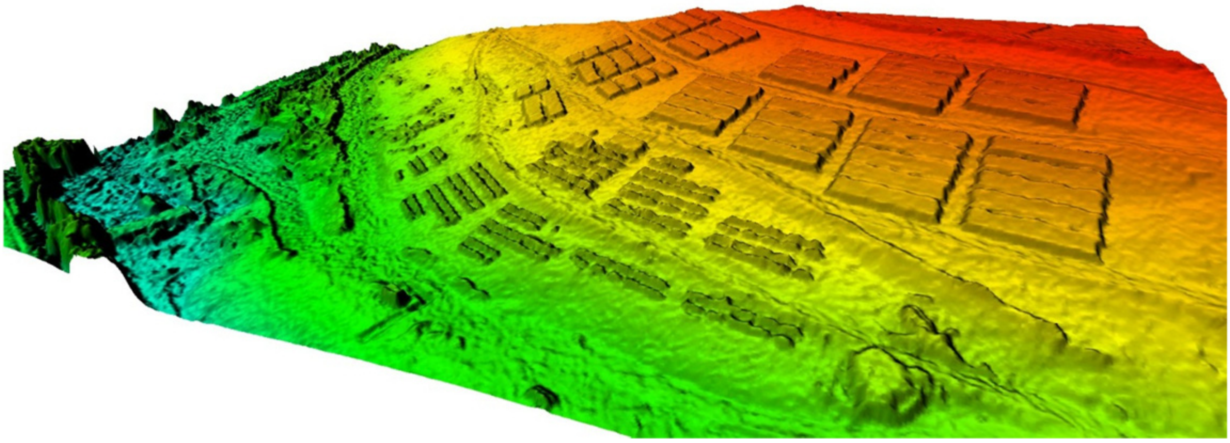
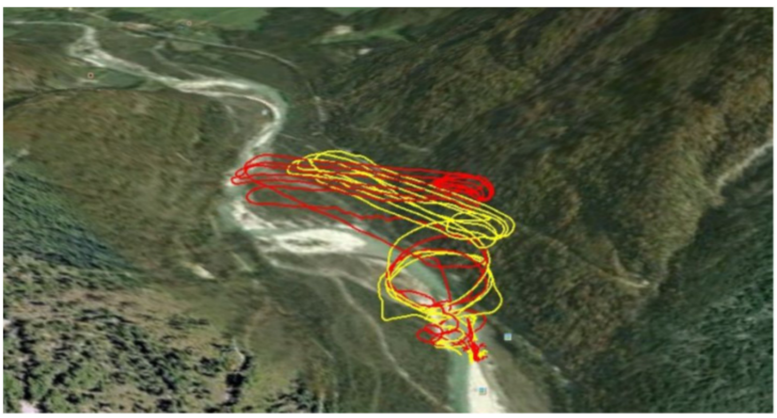


Figure 11: DSM of a waste dump pile, displaying its south side where solar panels are placed

In an environmental project the river authority of a state in Germany wanted to know the volume of a pile of coarse gravel which has been put into the river for re-naturalization purposes. The river shall distribute over time this pile of coarse gravel and thus stimulate the river meander more, which in turn gives more habitats for fish. In order to control the volume put in and also the volume taken off by the river over time, this pile is flown periodically. Fig. 12a shows the orthomosaic of the area flown and Fig. 12b the pile of coarse gravel being of interest. We measured 5.992 m^3 which was close enough to the ordered 6.000 m^3.

Figure 12a: Orthomosaic of river environment

Figure 12b: Perspective view of gravel pile



Above environmental example was flown in 2 blocks in a narrow Alpine valley. Fig. 13 shows the 2 flight missions in 2 color-coded, red and yellow, flight paths. The flights took place in about 180 m AGL and took about 2 hours to set up equipment, find the right starting and landing spots.

Figure 13: PAMS flight paths

6. CONCLUSIONS AND OUTLOOK

From the point of view of the author, UAS-based mapping entered a stage where one can consider it to be used commercially in appropriate projects. Quite a number of projects, commercial ones as well as pilot or test projects, always showed the applicability of this new, exciting technology. It is to be expected that a number of systems will enter the market place. An open question might be the data processing towards orthomosaics and DSMs. However, as PAMS solves it might be one way to go. It opens the aces to aerial mapping also for non specialists. This might widen the knowledge about our communities' capabilities as well as its services. There are many instances of possible applications ranging from environmental applications, golf courses, forestry, agriculture, archeology, police, emergency units, to disaster management, planning, and many more. Operational issues are very important to be considered. One enters a new field when operating a flying vehicle, in particular an unmanned and autonomously operating one and for a commercial purpose. National standards and regulations have to be obeyed. Airplane-based UAS-solutions seem to be more suited to mimic the traditional aerial mapping approach. Quadcopter- or in general rotary-wing-based UAS-solutions seem to fulfill other applications. UAS-mapping opens the door to new, up to now not served projects, and it is not competing but complementary to traditional aerial mapping operations. The toys-for-big-boys industry reached the professional, commercial level.

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