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Swarm-technology for Large-area Photogrammetry Survey and Spatially Complex 3D Modelling

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Abstract : Swarm technology represents a breakthrough in the creation of 3D models using drone-based photogrammetry. The traditional single-drone approach for modelling of large areas(area >5 km²) or spatially complex objects (e.g., buildings, infrastructures) requires long flight times and is frequently associated with variable light- and meteorological conditions during periods spanning several days. This is especially true for drone copters. In this EU-supported project (www.target-h2020.eu) COTSdrones have been evaluated and the drone DJI *Mavic Pro* (MP*)* has been selected for optimal performance. Based on MP, the *Photogrammetry Swarm Kit* (PSK) has been developed, offering considerable time- and cost savings as compared to the traditional single drone approach.PSK is comprised of five MP drones housed in a specially designed, portable container, together with control unit and power supplyand aground control station.PSK uses WiFi communication and is adjusted to a Digital Elevation Model to ensure a precise flight. It offers three modes of data acquisition (Area Mode, Highlight Mode, Angle Mode). PSK has been field-tested in the European Union and the Republic of Kyrgyzstan and received the DRONE HERO EUROPE Award 2018.

Keyword*:* Drone, Swarm, Photogrammetry, 3D Modelling.

1. INTRODUCTION

Drone Swarming is a relatively new field of robotics research. Swarm technology enables drones to perform as an intelligent group, interpreting what is happening in real-time and self-organize. Using appropriate software, drones can ascend synchronously, communicate with each other and create cross-references. Drones flying in cooperation can create networks and transfer information. They can be used as mobile radio stations or WLAN transmitters in regions lacking infrastructure.

In the recent past the spectrum of swarm applications in very different fields has been growing fast, for example:

- *Ehang* created a swarm of a thousand drones with the ability to improvise and troubleshoot errors autonomously [1];
- *University of Cambridge* and*Koc University* unveiled the concept of Energy Neutral Internet of Drones. [2] Such a drone swarm shares information or energy with other drones that did not receive a communication or are running low on energy;
- *US Department of Defense* tested successfully a swarm of miniature drones with advanced swarm behaviour, such as collective decision-making, adaptive formation flying, and self-healing [3];
- *NASA* plans on deploying swarms of tiny spacecraft for space exploration [4];
- Medical community is looking into using swarms of nanobots for precision delivery of drugs, microsurgery, targeting toxins, and biological sensors [5].

Currently, about 30 nations are actively developing drone swarms—and even submersible drones—for military missions, including intelligence gathering, missile defence, precision missile strikes, and enhanced communication[6].

In the topic area high spatial resolution drone-based photogrammetry initial field applications were reported in 2016. [7, 8, 9] This method produced geo-referenced 3D point clouds from hundreds

to thousands of digital images, which in turn resulted in orthoimages covering areas up to 15 km² with a spatial resolution < 1cm/pixel.

The European Commission tasked the International Security Competence Centre GmbH (ISCC), Austria) within the framework of the EU H2020 project TARGET (http://www.target-h2020.eu/)to develop a drone-based methodology for the creation of 3D models of large areas using photogrammetry. This paper describes the developmentof an end-user friendly, drone-swarm technology, capable of modelling up to several hundred hectares within a reasonable time period, created in cooperation between ISCC GmbH and Georesearch For schungsgesellschaft mbH.

2. SWARM BASED PHOTOGRAMMETRY

Creating high resolution 3D models covering areas as large as a few km² requires typically hundreds of conventional drone flight operations in the target area lasting several days. In this project a photogrammetry-capable swarm drone technology was developed with commercial-off-the-shelve (COTS), low-cost, mass produced, unmanned aerial vehicles (UAV). Multiple such UAVs,forming a swarm, provide the large number of photos needed for 3D modelling (typically several thousands of digital images) within typically one day of operation. This approach has three mutually supportive advantages:

- *COTS:* This feature ensures world-wide availability of UAVs and spare parts, good integration in software products,and excellent cost/benefit ratio;
- *Shorter Operational Time:* Drone swarming can cover the area to be modelled in a significantly shorter time than a single drone; the actual time saving is directly proportional to the number of drones deployed in the swarm. The number ofCOTS drones in this project was limited to five;
- *Less Variable Boundary Conditions*: Due to the shorter period of deploying a drone swarm (typical swarm UAV mission duration: one day) meteorological conditions and light conditions are more likely to remain unchanged as compared to a single drone-based photogrammetry mission lasting several days.

2.1 Drone

Based on the results of an international drone-market survey, ISCC selected the DJI *Mavic Pro* (MP) as the basis for the drone swarm (https://www.dji.com/de/mavic). System reliability is key in a complex photogrammetry field mission: MP has 24 high-performance computing cores, a transmission system with a 7km range, five vision sensors, and a 4K camera stabilized by a 3-axis mechanical gimbal. Another advantage of MP with regard to swarm-transport and field work is its size: the volume of an MP is comparable to a 1 liter-bottle. The drone has the following aircraft specifications:

- Diagonal size (propellers excluded): 335 mm
- Weight (battery, propellers, gimbal cover included): 743 g
- Maximum speed: 65 km/h
- Maximum flight time (no wind): 27 min
- Maximum service ceiling above Sea Level: 5 000 m
- Operating temperature: 0° to 40°C
- Satellite positioning systems: GLONASS (Russia) and GPS (USA)
- Hovering accuracy: vertical - +/- 0.1 m; horizontal - +/- 0.3 m

Consumer drones deploy three types of "sense and avoid" technology, enabling them to fly also indoors to a limited extent: (1) Sonar – Sound waves bouncing off a nearby surface. Sonar can detect large objects (like the ground) at a distance up to 6 m; (2) Infrared – Infrared sensors limited to toy drone mode (various technical shortcomings); (3) Camera - Downward facing low-resolution camera, capable of pattern recognition (e.g., floor tiles). MP uses a deep neural network approach with high resolution cameras on the drone body. These cameras feed information into a specialized processor,which provides computer vision. The cameras, along with two ultrasonic sonar sensors, assist with indoor flight and ground sensing, as well as increase drone stability.

Three intelligent flight modes are incorporated in the MP drone system: (1) *Obstacle Avoidance*: In combination with the front sensors the drone can determine how to clear objects, such as vehicles, etc.; (2) *Active Track*: Forward cameras recognize and track objects, such as persons, etc.; it allows MP to position itself around the subject in various ways; (3) *TapFly*: Allowing for "point and fly" on the screen control, this mode includes avoidance and/or recognition of objects.

2.2 Camera

The main objective of a photogrammetry mission is the provision of sharp, high-contrast photos from all angles together with their orientation data, which can be post-processed to create a photorealistic 3D model without any gaps. MP can take photos in RAW format (*.dng), enabling the user to post-process photos without any loss of information. For example, modelling a glacier the low contrast of the snow cover requires optimization of several parameters prior to photogrammetry-based modelling (whitebalance, exposure, contrast, highlights, shadows, whites, blacks). Furthermore, MP stores automatically GPS-data, as well as spatial orientation of each photo as EXIF data. This facilitates quality control on site and accelerates processing of the data during 3D modelling.

Drone camera quality is essential for the quality of the 3D model and needs to equal the quality of a mirror-less camera. The quality of a video/photo depends on the camera sensor size and type, the lens and on the

ability speed(bit-rate) that the camera sensor can send those images into memory (SD card). The larger the sensor and the faster the rate, the better the potential quality of the final image and/or video. Whilst most consumer-level camera drones use bit-rates of 20-50 Mbps, the MP bit-rate is 60 Mbps. MP has a still-photo resolution of 12 Megapixel, comparable to the upper range of consumer-level cameras. It uses a sensor (SONY 1/2.3") and a bright lens (f/2.2), which allows more light to impact on the sensor, resulting in a higher (sharper) image quality. Focus of the MP 28 mm lens is adjustable and automatic, as opposed to the fixed focus on most consumer-grade digital cameras. A maximum exposure of 8 seconds is possible due to the 3-axis gimbal stabilization. A headset displays an 85° view from the drone with two 1920 x 1080 display screens, up to 1080p image transmission and low latency wireless connection.

2.3 Photogrammetry Swarm Kit

ISCC has developed, in cooperation with Georesearch For schungsgesellschaftmbH, the *Photogrammetry Swarm Kit* (PSK). PSK is comprised of five MP drones (Note: PSK can be adapted to include a larger number of drones), housed in a specially designed, portable container, together with control unit and power supply for a smart and fast swarm data generating process(Fig. 1). Field missions require a compact carrying case, preferably in compliance with international Civil Aviation Regulations for luggage. Meeting these requirements, a ruggedized container was designed for up to five MP drones, five radio control units, five smartphones, a WiFi Hotspot and a notebook as ground control station.The plastic housing is water-, dust- and drop-resistant to withstand rough transport in the field under extreme weather conditions.

2.4 Flight Programming

The PSK uses WiFi communication and is adjusted to a Digital Elevation Model (DEM) to ensure a precise flight, even at high altitude and other challenging environments.
The PSK offers three modes of data acquisition:

- **Area Mode:** Five drones are used simultaneously to record large areas within short periods of time. Each drone is assigned a defined sub-area within the Area-of-Interest (AOI).
  Application: 3D modelling of a large area;
- **Highlight Mode:** Same operating principle as Area Mode. Relevant sub-areas (highlights) of the AOI are recorded at higher resolutions (e.g. for detailed planning in modelling large projects).
  Application: 3D overview model, plus 3D models of one or more pre-defined AOIs with enhanced resolution.

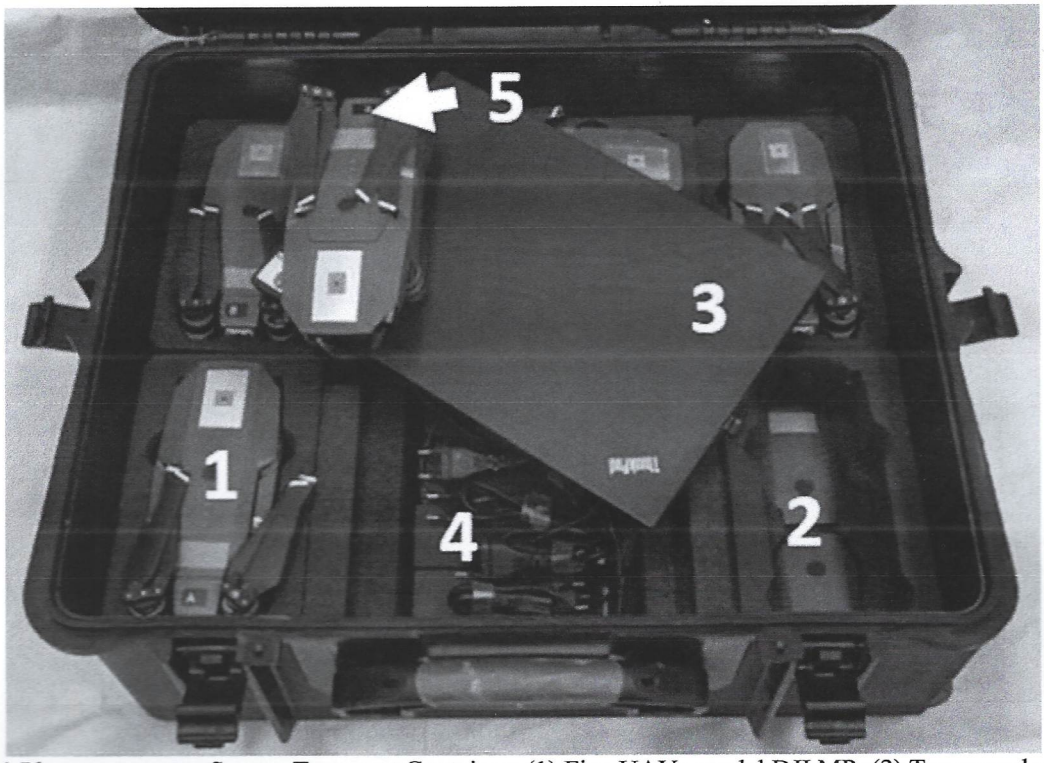


Figure 1:Photogrammetry Swarm Transport Container: (1) Five UAVs-model DJI MP; (2) Ten spare batteries; (3) Notebook computer; (4) Battery charger &spare parts; (5) Tape,

- **Angle Mode:** Five drones are used simultaneously to record spatially complex objects. Relevant spatial orientations of the investigated object are captured by complementary acquisition angles.
  Application: 3D modelling of a complex object.

In the current swarm drone configuration each drone communicates with the other four drones and the ground station, whilst carrying out the photogrammetry mission. At present, a single operator can control an entire swarm of up to five drones. Actual mission planning and execution is carried out under remote control by the Mission Controller. Currently, this includes the pre-programming of the flight routes for the five drones forming a swarm (*MavicPRO*, code A to E in Fig. 2).The complexity of flight mission planning reflects the geographical features of the area to be modelled, e.g., waypoint programming for a 3D model of a surface mine with complex surface structure is shown in Fig. 3.

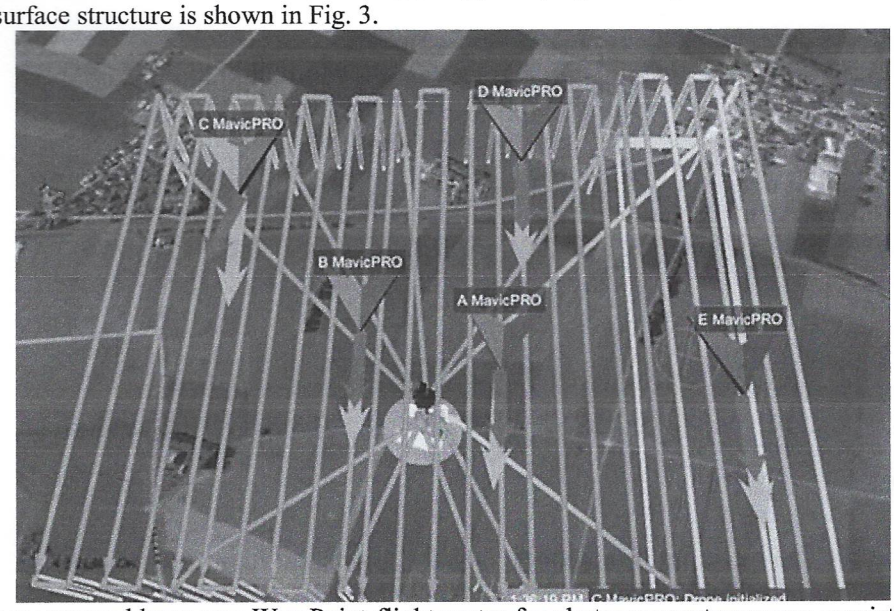


Figure 2. Pre-programmed large area Way Point-flight routes for photogrammetry swarm consisting of five MP drones (Code A to E).

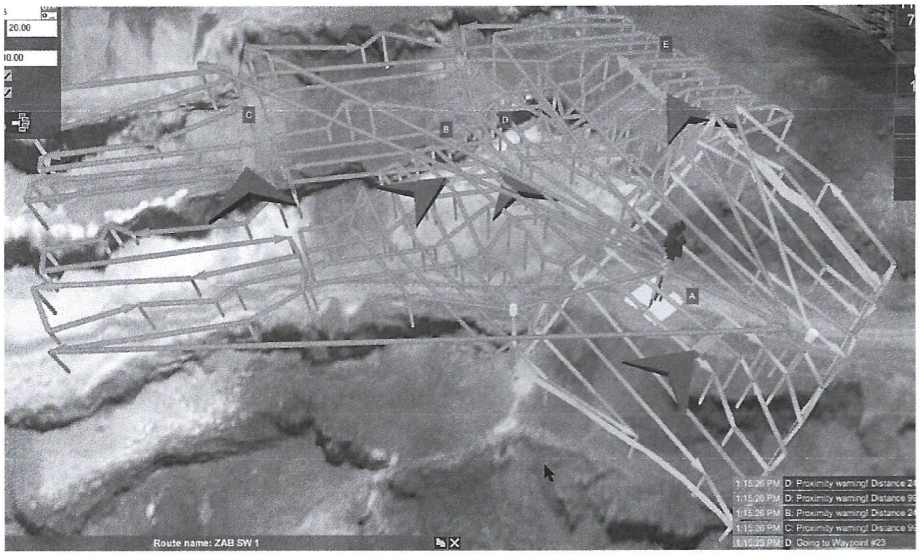


Figure 3: PSH flight mission planning for high resolution (< 1 cm accuracy deformation measurement)3D photogrammetry model of surface mine, ZAB-Erzberg (Austria).

2.5 Field Test and Results

The complete PSK underwent extensive field tests in Europe (Austria, Germany) and Central Asia (Kyrgyzstan). Fig. 4 shows the MP swarm in action hovering over the landscape to be modelled; PSK Transport Container located in forefront of the photo.In Fig. 5 the result of drone-based photorealistic 3D modelling of a large area is shown. Fig. 6 shows the photorealistic 3D model of a large airport terminal.

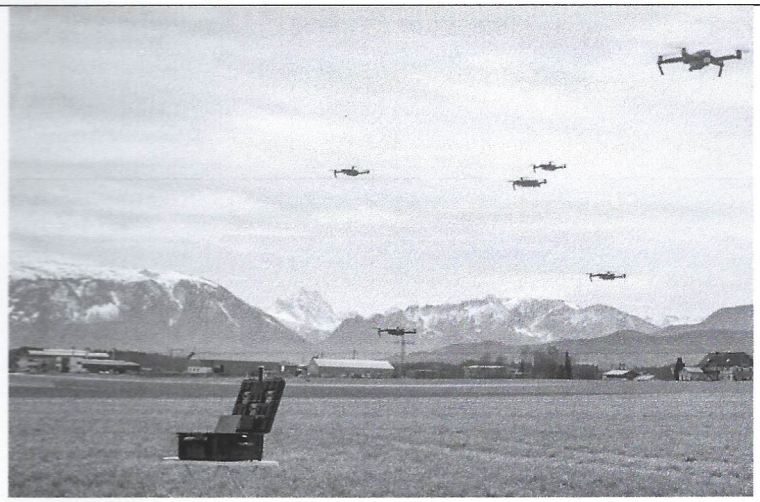


Figure 4: Photogrammetry Swarm in action, with five MP drones in swarm formation hovering above the transport container during a test flight in 2018; a sixth drone is filming the swarm.

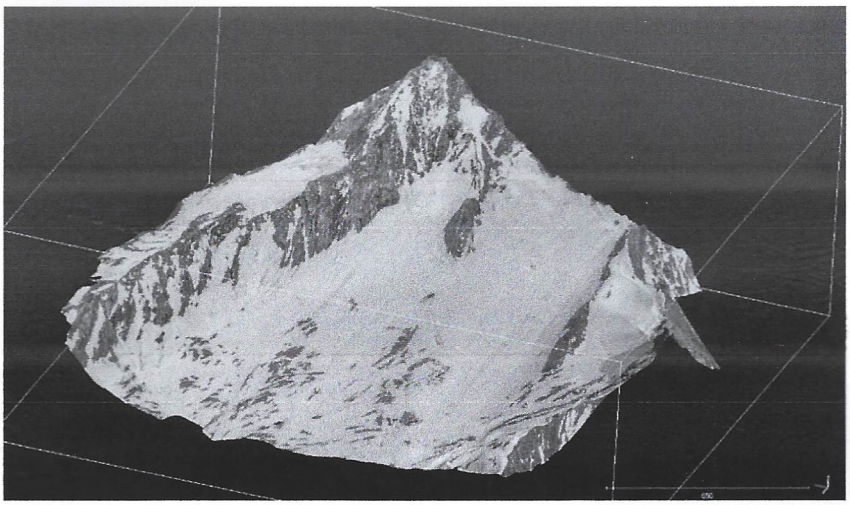


Figure 5: Photorealistic 3D photogrammetry model of Austrian glacier*Kitzsteinhorn* (altitude: 3 200m; area: 2.8km²) using PSK; total flight time for mission: 17 min.

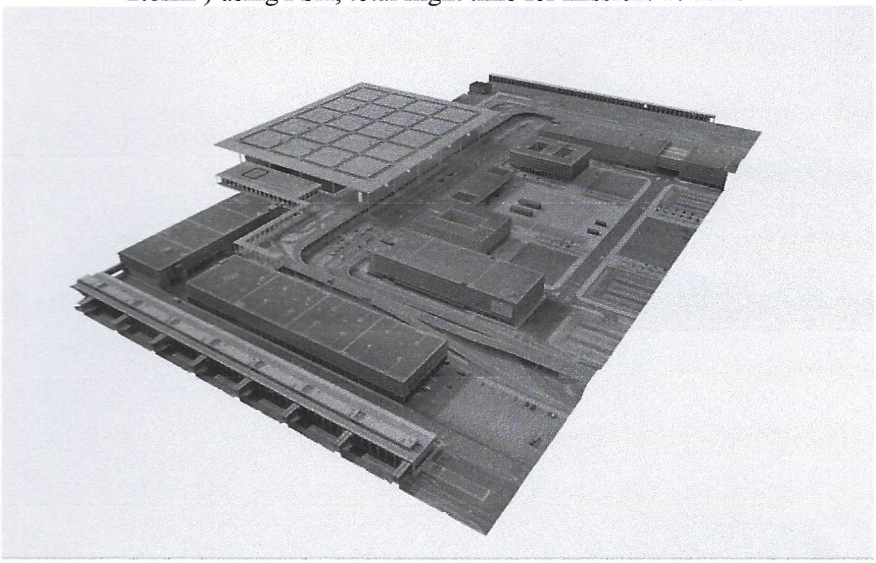


Figure 6: Photorealistic 3D photogrammetry model of airport terminal, Berlin (Germany).

The PSK has been used for modelling a large area(8 km²) in the Republic of Kyrgyzstan in 2018 (resolution 12.5cm/pixel). Five drones, following eleven individually programmed flight plans,covered a distance of 80 km in 50 min (Fig. 7). This represents a time saving of about five hours as compared to the deployment of a single drone. Fig. 8 shows the results of this mission, i.e., the Orthoimage (left) and Digital Elevation Model as a Hillshade (right) of a radioactive contaminated area (8km²) in in the MailluuSuu Area.

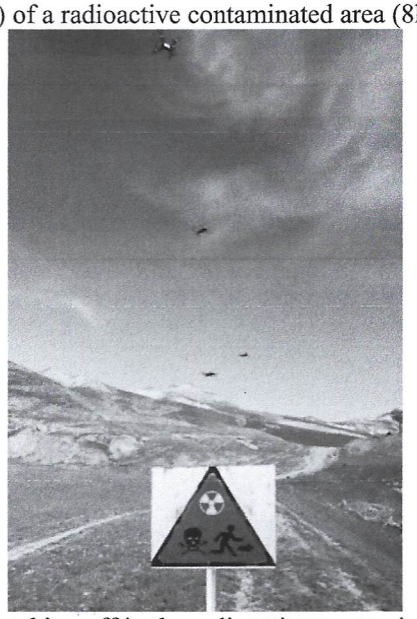


Figure 7: Swarm drones taking off in the radioactive contaminated MailluuSuu Area (Republic of Kyrgyzstan)

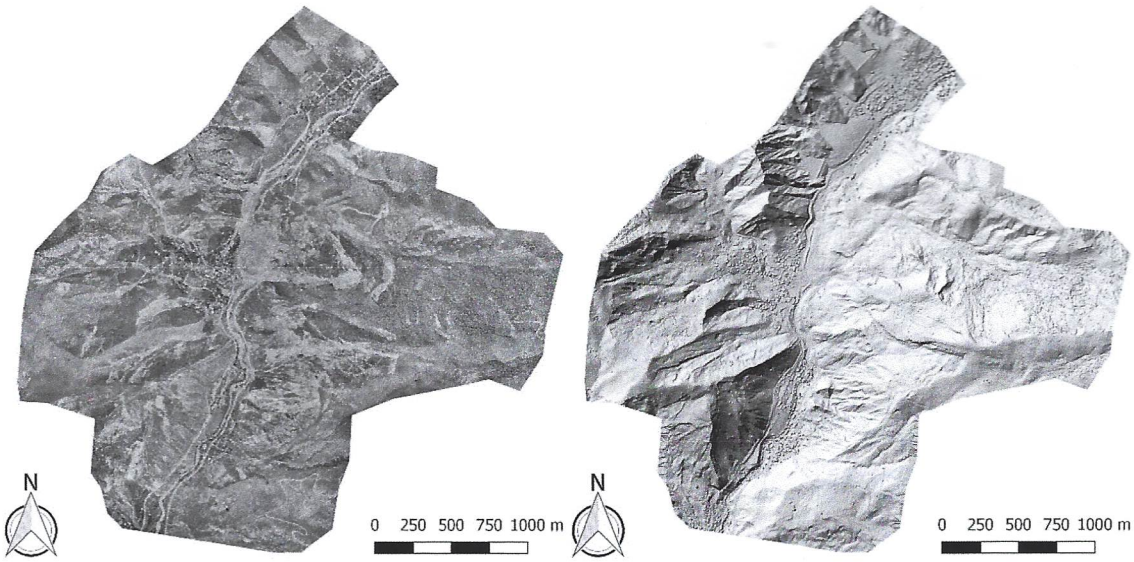


Figure 8: Orthoimage (left) and Digital Elevation Modell as a Hillshade (Right) of radioactive contaminated area (8km²) in the Republic of Kyrgyzstan

3. CONCLUSIONS

The PSK system enables the end user to program and operate a swarm drone system, capable of creating high-resolution 3D models of large areas. Due to the swarm-technology the modelling process requires less time than with a single droneand is therefore more cost-effective. The PSK approach, using COTS unmanned aerial vehicles, demonstrated successfully that:

(a) Operational time can be shortened,
(b) Image quality can be improved due to more stable lighting conditions during shorter flights,

(c) Purchasing costs for the whole system and operating costs can be reduced significantly by deploying COTS drones in a swarm formation instead of a specially designed, high-end, single drone.

Field tests have demonstrated the functioning of the PSK swarm system by photorealistic modelling of large areas and spatially complex 3D structures. The value of this innovative concept was acknowledged by the international jury of the DRONE HERO EUROPE 2018 competition by awarding the first place in the category *Start Up*(https://www.dronecommunity.biz/drone-hero-europe/winners-2018/) to ISCC and its partner GEORESEARCH.

4. ACKNOWLEDGEMENTS

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