Real-time mapping from a helicopter with a new optical sensor system

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Zusammenfassung: Ein neues optisches echtzeitfähiges real-time Sensorsystem auf einem Hubschrauber (4k System) für Einsätze bei Katastrophen, Großereignissen und anderen Überwachungsaufgaben ist nun als Prototyp einsatzfähig. Der Sensor wurde gewichtsoptimiert, klein und mit preisgünstigen Bauteilen in einem Pylon seitlich am Hubschrauber konzipiert. Es mussten jedoch aufgrund der geforderten Funktionalität und der Echtzeitfähigkeit real-time Fähigkeit hier Kompromisse eingegangen werden. Integriert sind neben der automatischen Orthophotoerstellung verschiedene thematische Prozessoren wie z.B. die automatische Verkehrsdatenextraktion. Der Sensor ist mit der neuesten Generation handelsüblicher High-End Kleinbildkameras bestückt, die je nach Anwendung konfiguriert werden können. Dabei decken die Kameras bestückt mit 50mm Objektiven ein Blickfeld von bis zu 104° ab, beim Einsatz von 100mm Objektiven werden Auflösungen bis zu 3.5 cm bei einer Flughöhe von 500m ü.G. erreicht. Zusätzlich kann mit einer Kamera der nahe Infrarotbereich erfasst werden oder ein hochaufgelöstes Video (4k Video) aufgenommen werden.
In diesem Paper werden die Systemkomponenten, die technischen Eigenschaften des Sensors beschrieben sowie die verschiedenen Einsatzmöglichkeiten des Systems skizziert.

1 Introduction

Helicopters are a valuable mean of transportation for security authorities and organisations (BOS). The German federal office of civil protection and disaster assistance (BBK) provides together with the federal police (Bundespolizei) a fleet of helicopters, which can be deployed for transportation flights during natural disasters etc. Although, sensors customized for the needs of the BOS and rescue forces exist, e.g. from FLIR, wide-area and real-time mapping sensors are not in use yet. The German Aerospace Center (DLR) makes now the first step towards a real-time mapping sensor by developing the first prototype of the so called *4k system* with a certificate of airworthiness for DLR's BO105 helicopter. The name of the sensor is derived from the 4k video capability and is also a reference to the DLR 3K and the 3K+ camera system [KURZ 2012]. Figure 1 shows a simulation of the 4k system mounted on the BO-105 using an external cargo carrier weapon carrier mount as link between 4k system and helicopter fuselage. In the following chapters, the system components, the technical and geometrical properties as well as the scenarios for real-time applications of the 4k system are presented and discussed.
A detailed discussion of the geometrical and radiometric properties of the cameras, the reached accuracies and a description of the real-time processing chain as it is installed at the 3k system is given in [KURZ 2012].

2 The 4k system

The 4k system is designed weight-optimized, small, and relatively low-cost, but equipped with a full real-time image processing chain including a high-capacity data downlink to the ground station. Figure 2 shows the composition of the 4k system, which consists of three non-metric off-the-shelf cameras, a microwave datalink system including two antennas, three

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processing units and a GNSS/IMU system. Table 1 lists the properties of the most important system components.

Fig. 1: 4k system mounted on the helicopter BO-105 (Simulation)

Although relatively small off-the-shelf components were used, the 4k system weighs 81.4 kg and the dimensions are 542 x 869 x 595 mm in width, length, and height. In the design phase, the preservation of full functionality and performance were rated higher than further miniaturization and weight reduction.

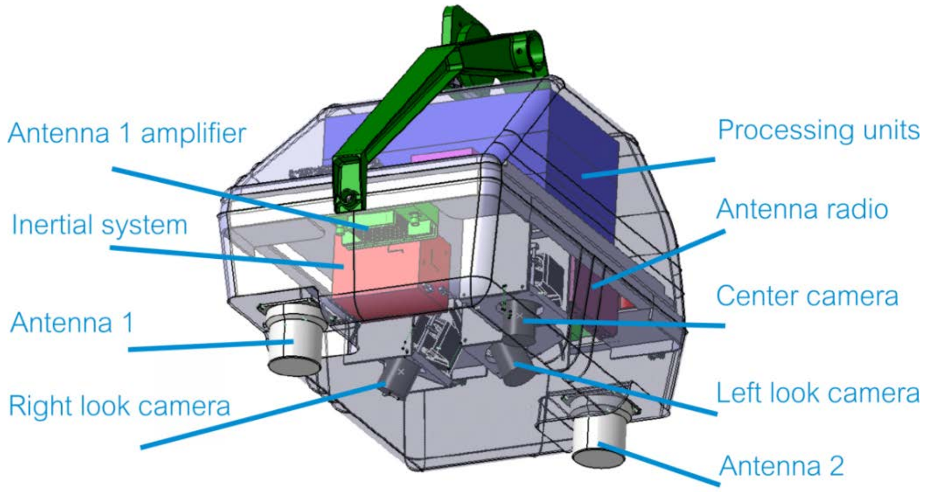

Fig. 2: System components of the 4k system

The 4k system is certified for the BO105 helicopter and mounted on an external cargo carrier on the right side 10cm above the helicopter skids. The platform and housing of the 4k system is decoupled from the helicopter vibrations by using four absorbers inside the system housing. These absorbers mainly decouple from the vibrations caused by the main rotor and the four rotor blades (7Hz, 28Hz). Additionally, the eigen frequency of the sensor structure should be far away from the main and spurious oscillations of the rotor to prevent damages to the system [F. Bauer].

The system is connected to the 28V/35A power supply of the helicopter and to the GPS antenna near the tail rotor. The system can be commanded from inside the helicopter via LAN or from the ground station via data link.

Three optical non-metric cameras are integrated in the sensor with different looking directions. The latest camera generation from Canon EOS, two 1D-X and one 1D-C, are installed on the platform, which each is capable of acquiring 17.9 MPix images with a frame rate of up to 14Hz.

Tab. 2: Properties of 4k system hardware components

	Component	**Size [mm]**	**Weight [kg]**	**Properties**
2×	Microwave antenna (SRS[1])	120×120×113	2×0.75	Bidirectional C band data link system with 11 Mbit/s eff. data rate, for distances up to 80km line-of-sight.
1×	Network radio (SRS)	58×120×230	1.00	
2×	Amplifier (SRS)	78×108×220	2×1.60	
3×	Canon EOS 1D X/C cameras	158×163.6×82.7	3×1.34	See table 2
3×	Zeiss lenses	ø72 length 65	3×0.53	
1×	IMU (IGI[2] Aerocontrol IId)	200×132×137	2.10	Real-time GNSS/IMU measuring and processing unit, RMS position 0.1 m, yaw 0.05°, roll/pitch 0.01°
1×	GPS/IMU processor (IGI)	65×140×205	1.80	
1x	Camera trigger box	190×110×60	0.6	Raspberry Pi[3] minicomputer with programmed trigger intervals
3×	PC unit	430×310×90	8.5	
1×	Housing + plattform …	542×869×595	40.1	Carbon fiber hull, aluminum structure
			Σ 81.4	

Additionally, the Canon EOS 1D-C is capable of acquiring 4k movies with a resolution of 4096 x 2160 pixels at 24 fps and is installed in nadir direction. Table 2 lists the properties of the integrated Canon cameras.

Alternatively, three different lenses from Zeiss with 35mm, 50mm and 100mm focal length can be deployed, which leads to different ground sampling distances (GSD) and different footprint sizes on the ground. In Figure 3, the viewing configuration and footprint sizes of the most common camera and viewing configurations are visualized. One requirement for all viewing configurations is, that the skid should not occlude the field of view.

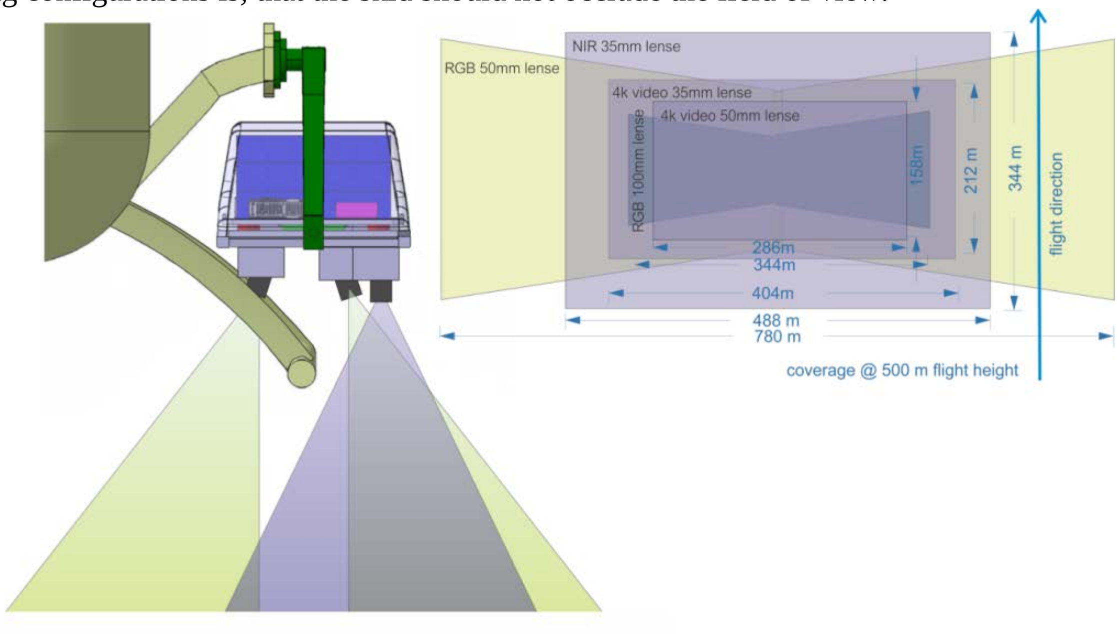

Fig. 3: Viewing configuration and footprints of 4k sensor cameras

[1] SRS: Schulze Radio Systems http://www.srsw.de

[2] IGI: Ingenieur Gesellschaft für Interfaces mbH http://www.igi.eu

[3] Raspberry Pi: http://www.raspberrypi.org/

Tab. 2: Properties of the Canon EOS cameras

	Canon EOS 1D-X	*Canon EOS 1D-C*
Lenses	Zeiss Makro Planar 2/50, 2/100 Zeiss Distagon T* 35	Zeiss Makro Planar 2/50, 2/100 Zeiss Distagon T* 35
Sensor / Pixel size	Full frame CMOS / 6.944µm	Full frame CMOS / 6.944µm
Image size	5184 x 3456 pixel, ratio 3:2 (17.9 MPix)	5184 x 3456 pixel, ratio 3:2 (17.9 MPix)
Image format	JPEG (Canon L10-L1) RAW (14Bit)	JPEG (Canon L10-L1) RAW (14Bit)
4k movies		4096 x 2160 pixel, ratio 1.9:1 8.85 MPix max. 24 fps / 4:2:2 YUV 8 bit 1.7 Gbps (uncompressed) 0.5 Gbps (MJPEG compressed)
ISO	100-204800	100-204800
Max. frame rate / max. images	14 fps / 180 images	14 fps / 180 images
Exposure time	30s – 1/8000s	30s – 1/8000s
Data interface	LAN (EDSDK software interface)	LAN (EDSDK software interface)

- Canon EOS 1Ds Mark II
  with Zeiss Distagon T* 35 IR
- Manual aperture
- Filter 850-1100nm
  (original filter removed)

Fig. 4: Properties of the near infrared sensitive camera

Tab. 3: Viewing configuration of 4k sensor cameras

	Wide area RGB 50mm lense	RGB 50mm lense	RGB 100mm lense	NIR 35mm lense	4k video 35mm lense	4k video 50mm lense
Viewing directions	1× Nadir 2× ±32°	2× ±19°	2× ±9°	Nadir	Nadir	Nadir
FOV	±52° across, ±13° along	±38° across, ±13° along	±19° across, ±7° along	±26° across, ±19° along	±22° across, ±12° along	±16° across, ±9° along
Coverage / GSD@500m	1280m × 230m / 6.9cm nadir	780m × 230m / 6.9cm nadir	344m × 122m / 3.5cm nadir	488m × 344m / 9.9cm nadir	404m × 212m / 9.9cm nadir	286m × 158m 6.9cm
Coverage / GSD@1000m	2560m × 460m / 13.8cm nadir	1560m × 460m / 13.8cm nadir	688m × 244m / 7.0cm nadir	976m × 688m / 19.8cm nadir	808m × 424m / 19.8cm nadir	572m × 316m 13.8cm

Additionally, one camera is modified to be sensitive in the near infrared region. Figure 4 shows the properties of the near infrared sensitive camera. The internal filter was removed and a 850nm low pass filter was attached.

The camera is now sensitive to light from 850nm to around 1100nm. Together with the other two cameras four-band multispectral images can be acquired for some scenarios described in

chapter 3. The figure shows the Canon EOS 1Ds Mark II, whereas in the final version of the 4k system a NIR sensitive Canon EOS 1D-X will be installed.
In principle, the cameras of the 4k sensor are arranged to provide one nadir view and two oblique views. The oblique viewing angle is configurable freely with a maximum of 32°. There are two basic configurations. In the first configuration the two oblique looking cameras have a small overlap in the nadir direction (e.g. mode M2 in Fig. 5) whereas the nadir looking camera, e.g. the NIR sensitive camera, is fully overlapping with the oblique looking cameras. In the second configuration, all three cameras have a small overlap to reach the maximum FOV of 104°. Table 3 lists the viewing directions, the FOV, the coverages for two flight heights, and the GSD for each camera of the most common configurations as described in chapter 3.

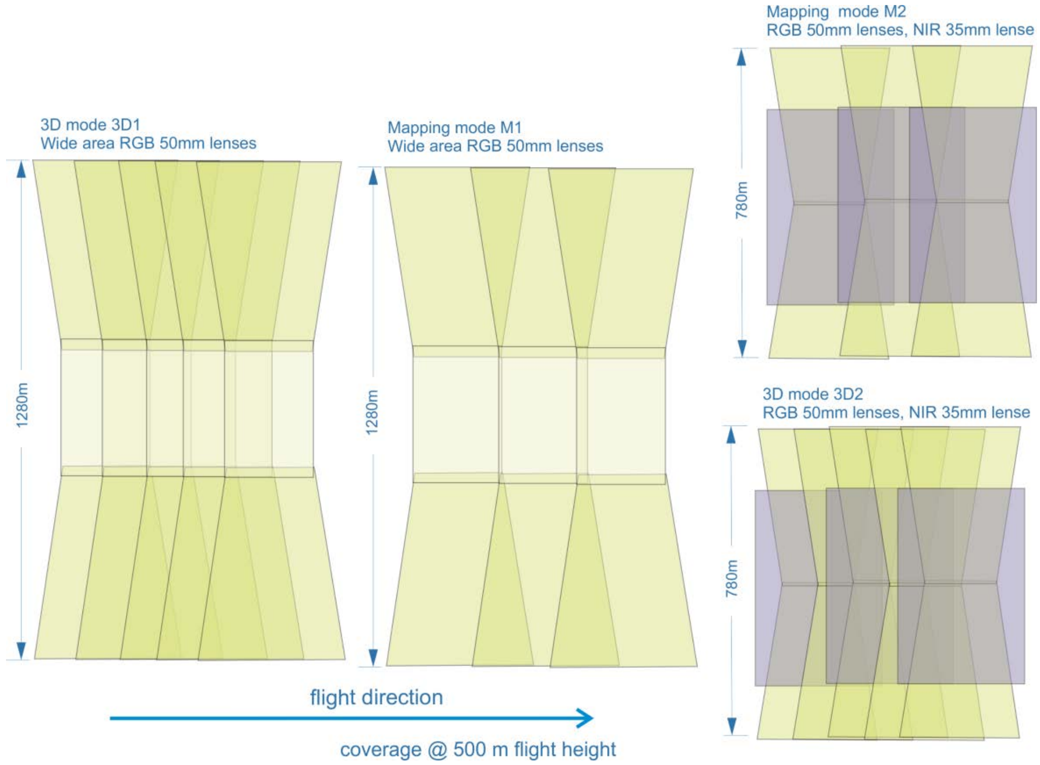

Fig. 5: Footprints of different 3D and mapping mode configurations

3 Scenarios for real-time applications

In this chapter, scenarios are designed and analysed in order to guarantee optimal data rates at the cameras, at the PC units and externally at the data downlink due to limited capacities. As the capacity of the microwave data link is limited to 11Mbit/s (1.4MB/s) the external data rate must be adjusted to this value. For higher data rates in particular for the downlink of 4k video stream data, an optical air-to-ground data link with a capacity of 1.25Gbit/s [MOLL 2013] was planned to be integrated, but in the first version of the 4k system this component is not included due to budget limitations.
Thus, only the final products, like traffic data, 3D maps, or compressed ortho images are sent to the ground station in real time. The 4k video stream is used to automatically extract information onboard, but it cannot be sent to the ground station directly.

3.1 Real-time mapping and 3D generation

There are two main configurations for mapping and 3D generation, namely the wide area mode without NIR band, and another reduced-FOV mode which includes the NIR band. For 3D generation, an along track overlap of 66% is proposed. Figure 5 illustrates the 3D and mapping configurations. Real-time 3D generation is still an ongoing research topic. The geometric and radiometric properties of mapping with the 3K system can be found in [KURZ 2012].

3.2 4k scenarios for traffic monitoring

A detailed description of the processing chain for automatic traffic data extraction can be found in [Kurz 2010]. Images are acquired in the so called burst mode, i.e. three images with a high frame rate are acquired to detect and track vehicles, then the camera pauses and starts again with 5% overlap to the last burst. Additionally, 4k videos can be acquired parallel to the oblique cameras to improve the tracking of vehicles in complex traffic situation. The analysis of 4k videos is an ongoing research topic. Figure 6 illustrates the traffic monitoring configurations of the 4k system. In the sideward configuration, the helicopter turns 90° and flights sideward to get a better view along straight roads.

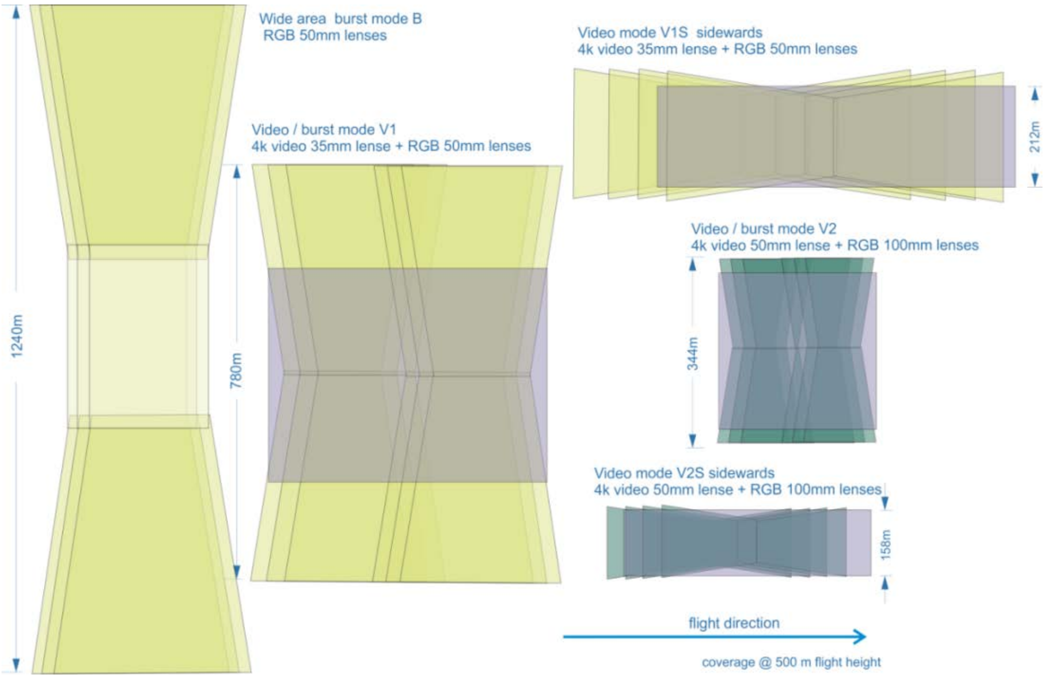

Fig. 6: Footprints of different traffic monitoring configurations

3.3 4k scenarios for person monitoring

Person monitoring includes the automatic detection and tracking of single persons and the automatic analysis of dense areas with persons. In the case of mass events, two basic configurations are proposed, a wide-area control mode and a detailed analysis of single area-of-interest. In the first mode, single images will be automatically analyzed for extraordinary situations, in the second mode the detected area of interest will be analyzed including 4k videos for a longer time period (slow rotation of the helicopter). Figure 7 illustrates the different person monitoring configurations. Person monitoring is still an ongoing research topic.

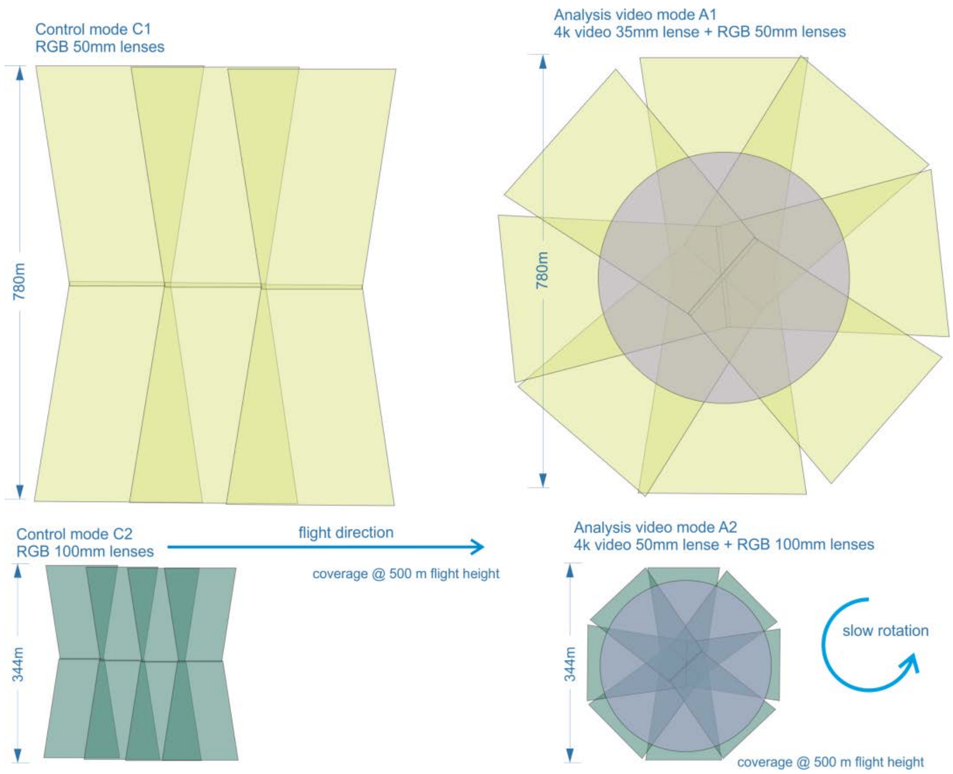

Fig. 7: Footprints of different person monitoring configurations

3.4 Analysis of scenarios

In this chapter, the scenarios are analyzed regarding the internal and external data rates. In general, the data rates are defined by some requirement, e.g. all data must be processed in real-time and must be finished before new data is acquired as well as a continuous footprint is almost always required for mapping purposes. Thus, the analysis is made for two flight speeds as the speed influences the final data rates. Table 4 compares the internal and external data rates for all scenarios based on two helicopter flight speeds. The external data rate at the data link mainly depends on the compression rate of the images. It can be seen, that most external data rates are below the capacity of 1.4MB/s of the data link, for the other scenarios higher compression rates than the proposed 80% JPEG are necessary. In any case the 4k video data rate is too high for the direct downlink, thus the analysis of the video must be performed onboard which is still to be developed.

4 Summary

In this paper, the system components, the technical properties and the scenarios for real time mapping applications of the recently developed *4k system* are presented and discussed. The sensor and flight configuration for different real time applications are analyzed with focus on the limitations regarding the data rates at the cameras, the PC units and the data downlink. It can be shown, that based on the customized configurations all envisaged applications are feasible.

First campaigns with the 4k systems are planned for March 2014, thus there is no experimental data yet.

Tab. 4: Comparison of internal and external data rates for all scenarios and for two helicopter flight speeds (*Internal*: data rates from the cameras, JPEG 100%, no video compression; *External*: data rates after processing, only maps ready for downlink, JPEG 80%, MJPEG video compression)

Mode	Description	GSD@500m	Data rate@50km/h [MB/s]		Data rate@150km/h [MB/s]	
			Internal	External	Internal	External
3D1	Wide-area DSM generation, 66% overlap, 3xRGB 50mm	6.9cm	5.5	0.6 (RGB) 0.2 (DSM)	16.5	1.8 (RGB) 0.6 (DSM)
3D2	Wide-area DSM generation, 66% overlap, 2xRGB 50mm 1x NIR 35mm	6.9cm 9.9cm (NIR)	3.6 0.2 (NIR)	0.4 (RGB) 0.2 (NIR) 0.2 (DSM)	10.8 0.6 (NIR)	1.2 (RGB) 0.6 (NIR) 0.6 (DSM)
M1	Wide-area mapping, 5% overlap, 3x RGB 50mm	6.9cm	1.9	0.6	5.7	1.8
M2	Wide-area mapping, 5% overlap, 2xRGB 50mm, 1x NIR 35mm	6.9cm 9.9cm (NIR)	1.3 0.2 (NIR)	0.4 0.2 (NIR)	3.9 0.6 (NIR)	1.1 0.6 (NIR)
B	Wide-area burst mode, 5% overlap, 3xRGB 50mm	6.9cm	5.7	0.6	17.1	1.8
V1(s)	Video + 3xburst mode, 5% overlap, 2xRGB 50mm, 1x4k video 35mm	6.9cm 9.9.cm (4k)	3.8 (RGB) 180.0 (4k)	0.4 60.0 (4k)	11.4 (RGB) 180.0 (4k)	1.1 60.0 (4k)
V2(s)	Video + 3xburst mode, 5% overlap, 2xRGB 100mm, 1x4k video 50mm	3.5cm 6.9cm (4k)	7.6 (RGB) 180.0 (4k)	0.8 60.0 (4k)	22.8 (RGB) 180.0 (4k)	2.4 60.0 (4k)
C1	Control mode, 5% overlap, 2xRGB 50mm	6.9cm	1.3	1.3		
C2	Control mode, 5% overlap, 2xRGB 100mm	3.5cm	1.3	1.3		
A1	Video analysis mode, 2xRGB 50mm 1Hz, 1x4k video 35mm	6.9cm 9.9.cm (4k)	20.0 180.0 (4k)	7.0 60.0 (4k)		
A2	Video analysis mode, 2xRGB 100mm 1Hz, 1x4k video 50mm	3.5cm 6.9cm (4k)	20.0 180.0 (4k)	7.0 60.0 (4k)		

5 Literature

BAUER, F. 2014: Schwingungsanalyse zum Anbau einer Bildüberwachungsausrüstung an den Außenpylon eines Hubschraubers. Diplomarbeit. Hochschule für angewandte Wissenschaften München.

KURZ, F. ET. AL, 2012: Low-cost optical Camera System for real-time Mapping Applications. Photogrammetrie Fernerkundung Geoinformation, Jahrgang 2012 (2), Seiten 159-176. DOI: 10.1127/1432-8364/2012/0109. ISSN 1432-8364.

KURZ, F. ET. AL, 2010: Fernerkundliche Anwendungen zur Verkehrs- und Lageerfassung. In: Fernerkundung im urbanen Raum Wissenschaftliche Buchgesellschaft. Seiten 106-115. ISBN 978 3534234813.

MOLL, F., 2013: Free-space laser system for secure air-to-ground quantum communications. SPIE Newsroom. DOI: 10.1117/2.1201311.005189. ISSN 1818-2259.