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PHASEONE 190MP AERIAL SYSTEM: CAMERA DESIGN PRINCIPLES AND PRODUCTIVITY ANALYSIS

LOTNICZY SYSTEM 190 MP: KONSTRUKCJA KAMERY I ANALIZA JEJ WYDAJNOŚCI

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KEY WORDS: medium format camera, productivity, Phase One, CMOS, iXU-RS190.

ABSTRACT: Phase One next generation iXU-RS1900 aerial system is based on 100MP medium format camera. It comprises two 90 mm lenses and two CMOS image sensors with pixel size of 4.6 μm shifted outward according to the optical axis of the lenses. Each lens is vertically oriented, providing nadir images with an equal ground resolution. The two stitched images form a large frame with 16,470 pixels across the flight line and 11,570 pixels along the flight providing 190 MP image. The total FOV across flight line is 45.7 deg and FOV along flight line is 33 deg. Productivity analysis for aerial survey cameras may be expressed as an aerial survey productivity (image coverage per hour of flight), distance between flight lines, time required to fly AOI (Area of Interest), or number of flight lines per AOI. The new iXU-RS1900 camera enables an increase in the distance between flight lines and improves aerial survey productivity by 43%. It needs only 34 min of flight to cover the central area of most cities in Europe. Thus, with the new CMOS sensor and short exposure time, high quality aerial imagery may be reached without using an FMC technique.

1. INTRODUCTION

In parallel with the so-called large format cameras, medium format cameras are developing. They are stand-alone air imaging systems for mapping applications such as large format cameras, or are complementary to other systems (airborne laser scanning systems, aerial oblique camera systems, etc.).

Many research centers and authors undertake research and testing of geometric and radiometric quality as well as the efficiency of imagery acquired by such cameras (Raizman, 2012; Raizman, 2014; Raizman, 2016; Kerner et al., 2016; Tölg et al., 2026).

The market for medium format cameras is rapidly increasing; however available medium format systems differ greatly in terms of performance, reliability, accuracy and price. In order to get a status report on the current situation and an insight into the geometric and radiometric properties, EuroSDR has initiated a project on medium format digital cameras (Grenzdörffer, 2008; Grenzdörffer, 2010).

Phase One Industrial's 100MP medium format aerial camera systems have earned a worldwide reputation for its high performance. They are commonly used in small and medium size area mapping projects, corridor mapping, LiDAR mapping, urban mapping, 3D

City modeling and oblique imagery capturing, construction and infrastructure monitoring and inspection.

The100MP aerial camera specifications offer small pixel size (4.6 μm), very high image capture rate -1 frame every 0.6 seconds, exposure time of up to 1/2500 sec, and a set of metric lenses with different focal lengths (50, 70, 90, 110, 150 mm).These specifications enable the 100MP aerial cameras to provide an effective and advanced solution in many areas of aerial mapping, monitoring and object inspection.

The camera's small size (10x10x20 cm including lenses) and its light weight (less than 2 kg) provide an excellent solution to be easily installed in every light or small aircraft, gyrocopters, medium size drones, or UAVs that significantly reduce diverse mapping projects' operational costs.

Priced at a fraction of the cost of large format cameras and with all the advantages outlined above, Phase One medium format cameras have become a product of choice in many areas of aerial mapping, monitoring and inspection.

2. THE NEXT GENERATION OF PHASE ONE INDUSTRIAL'S AERIAL CAMERAS

PhaseOne introduces the 190MP Aerial System that integrates two aerial camera models:

- Phase One IXU-RS1900 - comprises two 90 mm lenses for capturing RGB information
- Phase One IXU-RS1900 4-Band - includes an additional 50 mm focal length lens and achromatic 100 MP sensor for capturing near infra-red information and provide 4-Band (RGB,NIR) as well as CIR images.

The 190MP Aerial System utilizes the integration of two image sensors and two lenses. This optical integration together with dedicated software enables a generation of a 190MP single central projection image from two 100MP nadir images.

The 190MP Aerial System can be integrated with a flight management software or with additional supporting peripheral equipment provided by Phase One or as OEM components for further integration by third party companies.

2.1. Camera Design Considerations

The iXU-RS1900 comprises two 90 mm lenses and two CMOS image sensors with pixel size of 4.6 μm shifted outward according to the optical axis of the lenses. Each lens is vertically oriented, providing nadir images with an equal ground resolution. Each image sensor captures an opposite side from the flight line, meaning that the right sensor captures the left side, and the left sensor captures the right side. There is an overlapping area between the images for stitching. The image sensors are installed with their long side along the flight line. Each sensor provides an image of 8,708 pixel across the flight line, and 11,608 pixel image along the flight line. The two stitched images form a large frame with 16,470 pixels across the flight line and 11,570 pixels along the flight providing 190 MP image. The total FOV across flight line is 45.7 deg and FOV along flight line is 33 deg.

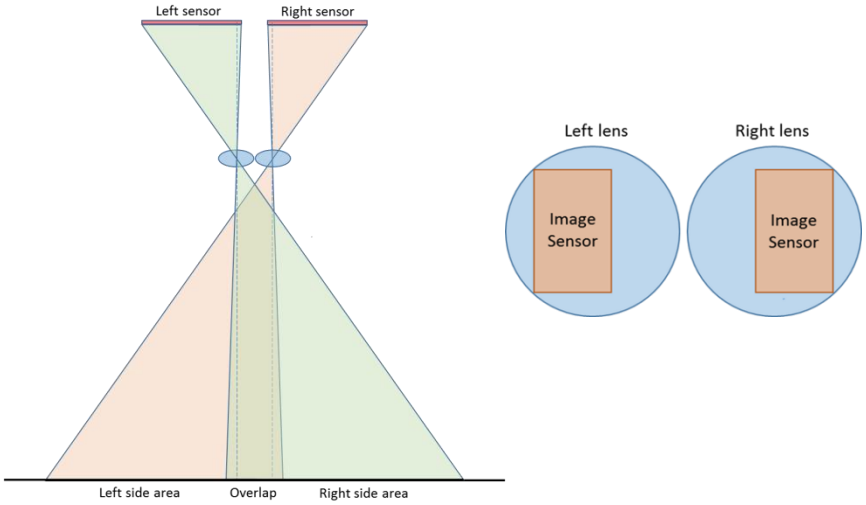

Fig. 1. Camera Design Scheme

This optical integration enables:

- An increased FOV of the optical system across the flight, resulting in a higher aerial survey productivity.
- Higher stereoscopic accuracy due to larger FOV along the flight and larger B/H parameter.

The final large format image is delivered as a central projection seamless undistorted image in TIFF or JPEG formats.

2.2. PhaseOne iXU-RS1900 series – Main Parameters

Main parameters of PhaseOne iXU-RS1900 series are presented in table 1.

Table 1. Main parameters of PhaseOne iXU-RS1900 series

Camera Type	**iXU-RS1900**	**iXU-RS1900 4-band**
Camera Specifications		
Lenses type	Rodenstock	
Number of lenses	2	3
Focal length (mm)	90	90 & 50
FOV (across / along flight line, deg)	45.7/ 33.0	
Aperture	f/5.6	
Exposure principle	Leaf shutter	
Exposure (sec)	1/2000 to 1/125	

Image capture rate	1 frame every 0.6 sec	
Light Sensitivity (ISO)	50-6400	
Dynamic Range (db)	>84	
Spectral characteristics	R,G,B	R,G,B,NIR NIR option 1 – from 720 nm NIR option 2 – from 830 nm
Sensor Specifications		
CMOS number	2	3
CMOS pixel size (μm)	4.6	
CMOS array (pix)	11,608 x 8,708	
Analog-to-digital-conversion (bit)	14	
Frame / Image Specifications		
Frame geometry	Central projection	
Image size (pixel)	16,470 x 11,570	
Image volume (MP)	190	
Color	RGB	RGB, NIR, CIR,4-band
Pansharpen ratio	N/A	1:1.8
Typical image size (MB)	570	760
Image format	PhaseOne RAW, Undistorted TIFF, JPEG	
Optional on-board interfaces		
iX Controller	up to 6 separate USB3 ports	
Pilot monitor for navigation	Yes	
Operator monitor for camera management	Yes	
Gyro-stabilizer	SOMAG DSM400	
INS/GNSS	Applanix, NovAtel, …	
Events synchronization speed (μsec)	100	

3. IXU-RS1900 – A BETTER CHOICE FOR 3D CITY, DENSEDSM AND OBLIQUE IMAGERY

Large forward overlap is a necessary factor for high quality 3D City modeling, dense DSM and oblique imagery. The iXU-RS1900cameras have an extremely high image capture rate of 0.6 sec. supporting large forward overlap at high aircraft ground speed.

The following table 2 presents the connection between forward overlap and ground speed.

Table 2. Relation between forward overlap and ground speed for iXU-RS1900

GSD (cm)	2.5	5.0	7.5	10.0
Ground speed (knot)	90	110	130	150
Maximal Forward overlap (%)	**90%**	**92%**	**94%**	**96%**

The following table 3 presents the speed and forward overlap to maintain high quality imagery with lower than 1 pixel motion blur:

Table 3. Speed and forward speed for iXU-RS1900 to maintain motion blur lower than 1 pixel

GSD (cm)	2.5	5.0	7.5	10.0
Ground speed (knot)	95	190	290	385
Motion blur (pix)	**0.98**	**0.98**	**0.99**	**0.98**
Forward overlap (%)	**90%**	**87%**	**86%**	**86%**

4. IXU-RS1900 – PRODUCTIVITY ANALYSIS

Productivity analysis for aerial survey cameras may be expressed as an aerial survey productivity (image coverage per hour of flight), distance between flight lines, time required to fly AOI (Area of Interest), or number of flight lines per AOI.

The following table 4 presents the main aerial survey parameters for Phase One cameras for GSD = 5 cm, side overlap 30% and aircraft ground speed = 190 knot.

Table 4. The main aerial survey parameters for Phase One cameras for selected GSD, overlaps and aircraft speed

Camera	iXU-RS1900	iXU-RS1000				
Focal length (mm)	90	50	70	90	110	150
Frame area size (Mpix)	190	100	100	100	100	100
FOV across track (deg)	45.7	56.2	41.8	33.0	27.3	20.2
FOV along track (deg)	33.0	43.7	31.9	25.1	20.6	15.2
Flight altitude (foot)	3,209	1,783	2,496	3,209	3,923	5,349
Flight altitude (m)	978	543	761	978	1,196	1,630
Maximal Possible Forward Overlap (%)	90%	87%	87%	87%	87%	87%
Orthophoto angle (2α, degree)	33	41	30	23	19	14
Building lean (%)	30%	37%	27%	21%	17%	12%
Frame Width (cross track, m)	827	580	580	580	580	580
Frame Height (along track, m)	580	435	435	435	435	435
One strip coverage (sq.km/hour)	291	204	204	204	204	204
Multi strip coverage (sq.km/hour)	204	143	143	143	143	143
Distance between Flight Lines (m)	579	406	406	406	406	406

Objective criteria, independent of the ground speed of the plane and AOI's shape, is the distance between flight lines. The following chart presents the distance between flight lines for Phase One cameras with different focal length and with constant side overlap of 30%, which is most suitable for stereoscopic mapping.

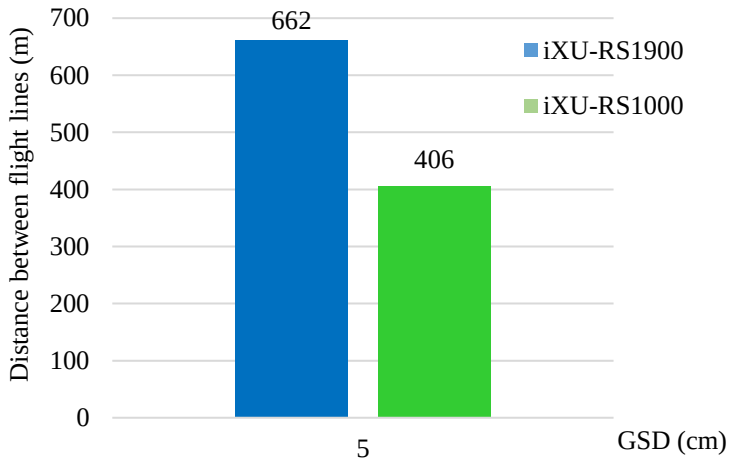

Fig. 2. Distance between flight lines for GSD 5 cm

The new iXU-RS1900 camera enables an increase in the distance between flight lines and improves aerial survey productivity by 43%.

The following chart presents the total flight time (in minutes including turns) required for capturing an area of 5 km by 5 km (25 km²) with 5cm ground resolution that commonly corresponds to the area of a typical European city center:

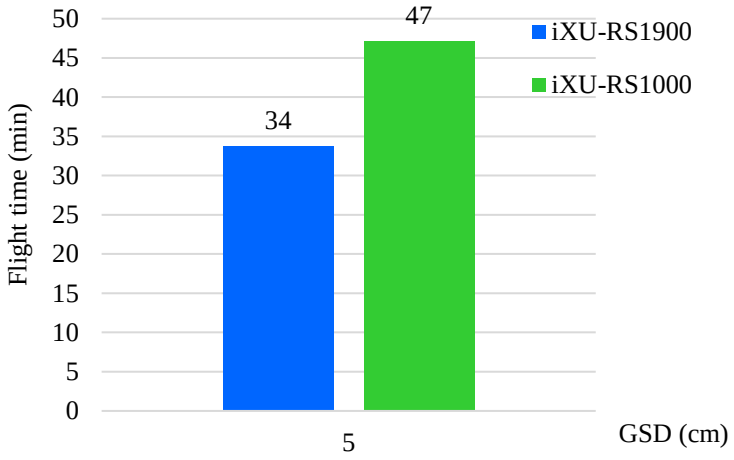

Fig. 3. Flight time for GSD 5 cm

With iXU-RS1900 only 34 min of flight needed to cover the central area of most cities in Europe.

5. IMAGE QUALITY

Image quality is defined, inter alia, by motion blur, which is the blurring of an image due to movement of the subject and/or imaging system during the exposure time. The Phase One iXU-RS1900 cameras are all equipped with highly sensitive CMOS sensors and high-speed central shutter that enable a very short exposure time of up to 1/2000 sec.

Motion blur is traditionally compensated by one of the Forward Motion Compensation (FMC) techniques. The electronic compensation TDI technique has been commonly used for CCD sensors. With CMOS sensors, the TDI technique was replaced with much higher sensor sensitivity that along with shorter exposure time and advanced Phase One shutter technologies, results in high quality aerial imagery required for mapping.

The following table 5 displays the maximal possible aircraft ground speed for different ground resolutions and for exposure time of 1/2000 sec, which still maintain the motion blur less than one pixel for all Phase One cameras with pixel size of 4.6 μm independently of the focal length:

Table 5. Maximal possible aircraft ground speed for different ground resolutions and for exposure time of 1/2000 sec and resulted motion blur

GSD (cm)	2.5	5.0	7.5	10.0
Ground speed (knot)	95	190	290	385
Motion blur (pix)	**0.98**	**0.98**	**0.99**	**0.98**

Flying at a regular ground speed for the same GSDs brings lower motion blur (Table 6):

Table 6. Regular ground speed for different ground resolutions and for exposure time of 1/2000 sec and resulted motion blur

GSD (cm)	2.5	5.0	7.5	10.0
Ground speed (knot)	90	110	130	150
Motion blur (pix)	**0.93**	**0.57**	**0.45**	**0.39**

Thus, with the new CMOS sensor and short exposure time, high quality aerial imagery may be reached without using an FMC technique.

6. CONCLUSIONS

The Phase One Industrial's iXU-RS1900 metric aerial cameras offer large format performance with outstanding features such as: small pixel size (4.6 μm), large image area (190 MP), high image capture rate of 0.6 sec for an image, exposure time of up to 1/2000 sec, focal length of 90 mm, optional NIR channel and relatively low price. They compete with other large format cameras in all areas of aerial mapping, remote sensing, precision agriculture, surveillance, disaster management and monitoring.

Still small size of the camera, light weight and low power consumption make it compatible with nearly all types of light aviation vehicles, thus reducing the expenses of mapping projects.

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LOTNICZY SYSTEM 190 MP: KONSTRUKCJA KAMERY I ANALIZA JEJ WYDAJNOŚCI

SŁOWA KLUCZOWE: kamera średnioformatowa, wydajność, Phase One, CMOS, iXU-RS190.

Streszczenie

Kamera lotnicza nowej generacji firmy Phase One iXU-RS190 bazuje na kamerze średnioformatowej 100MP. Łączy dwa obiektywy 90 mm i dwa przetworniki obrazu CMOS z pikselem 4.6 μm, przesunięte na zewnątrz względem osi obiektywów. Każdy obiektyw ma pionowo zorientowaną oś, co daje jednakową rozdzielczość terenową zdjęć. Dwa połączone obrazy tworzą kadr o 16 470 pikselach w poprzek i 11 570 pikselach wzdłuż lotu, łącznie o rozdzielczości 190 Mpix. Odpowiada to kątom widzenia 45.7° i 33° odpowiednio w poprzek i wzdłuż lotu. Analiza wydajności kamer lotniczych może być wyrażana jako wydajność obrazowania (powierzchnia kryta zdjęcia na godzinę lotu), odległość między szeregami, czas lotu konieczny na pokrycie obszaru zainteresowania, czy liczbą szeregów na takim obszarze. Nowa kamera iXU-RS190 umożliwia zwiększenie odległości między szeregami i poprawia wydajność o 43%. Potrzebuje tylko 34 minuty lotu na pokrycie centralnej części większości miast europejskich. Z nowym przetwornikiem CMOS i krótkimi ekspozycjami wysoka jakość zdjęć lotniczych może być osiągnięta bez konieczności stosowania technik kompensacji rozmazania (FMC).

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