Modern Photogrammetric Manned Airborne Imaging Sensors

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Key words: Manned airborne photogrammetric imaging, Photogrammetry, Digital Photogrammetry, Base to Height ratio

SUMMARY

Photogrammetric manned airborne imaging sensors are popular optical sensors used in topographic mapping. Photogrammetric manned airborne imaging sensors were passive, which depends upon the sunlight. Till now, optical imaging is mainly used in photogrammetric imaging works. Over the time, significant innovations and improvements have been made in the passive photogrammetric manned airborne imaging sensors which resulted in the form of sophisticated imaging sensors. This highlights the need to review these photogrammetric manned airborne imaging sensors.

In this study, different photogrammetric manned airborne imaging sensors are investigated. Photogrammetric manned airborne imaging sensors are first summarized and compared based on the technical parameters. Base to height (B/H) ratios are determined for the large-format current modern photogrammetric manned airborne imaging of type “Complementary Metal-Oxide Semiconductor” (CMOS) sensors such as Leica DMC III, Phase One-PAS 880 and IGI-DigiCAM 450.

The paper firstly starts with an introduction briefly mention the characteristics of the traditional old aerial film cameras which form the foundation of the geometry of photogrammetric old aerial photography and modern aerial digital imagery. The second section of the paper discuss in detail the imaging sensor technology of the two construction strategies of Charge Coupled Device (CCD) sensors; area array large format and linear array pushbroom sensors and the current modern Complementary Metal-Oxide Semiconductor (CMOS), area array large format sensors. The third section of the paper contains the parameters mentioned in the technical data sheets demonstrated by the manufacturers. In the fourth section the author determined the base to height (B/H) ratio for each one of the current modern CMOS sensors which are not published before. This indicate that the unpublished parameter (B/H) ratio reflects its weakness and it is suggested to modify the sensor setting by the all three manufacturers by rotating the length of the sensor to be in the flight direction instead of the width. The suggestion in this study proposes the increase of the value of B/H ratio by almost twice which makes them accurate for the use in stereo-photogrammetric mapping.

ملخص

مستشعرات التصوير الجوى المأهول لأعمال لمسح التصويرى هى مستشعرات ضوئية شائعة تستخدم فى إنتاج الخرائط الطبوغرافية.
مستشعرات التصوير الجوى المأهول لأعمال المسح التصويرى كانت خاملة حيث تعتمد على الشمس كمصدر للإضاءة. حتى الآن ، التصوير الضوئى يستخدم أساسا فى أعمال التصوير لأعمال المسح التصويرى.
عبر الزمن ، أجريت تحسينات وتحديثات هامة فى مستشعرات التصوير الجوى المأهول لأعمال لمسح التصويرى الخاملة حيث أنتجت فى صورة مستشعرات تصوير متطورة. وهذا يسلط الضوء على الحاجة إلى مراجعة مستشعرات التصوير الجوى المأهول لأعمال المسح التصويرى هذه.
في هذه الدراسة، تم التحقيق في مختلف مستشعرات التصوير المحمولة جوا المأهولة. تم أولا تلخيص مستشعرات التصوير المحمولة جوا لأعمال المسح التصويرى المختلفة ومقارنتها بناءً على المعاملات الفنية. تم تحديد نسب القاعدة إلى الارتفاع B/H لمستشعرات التصوير الرقمي كبيرة الأبعاد الحديثة " من نوع أشباه الموصلات الأكسيدية المعدنية " (CMOS) الحديثة مثل لايكا DMC III وفيزوان PAS 880 و وأى جى أى DigiCAM450.
تبدأ المقالة أولاً بمقدمة تذكر بإيجاز خصائص كاميرات الأفلام الجوية القديمة التقليدية التي تشكل أساس هندسة التصوير الفوتوغرافي الجوي القديم والتصوير الرقمى الجوي الحديث. القسم الثاني من المقالة يناقش بالتفصيل تكنولوجيا مستشعرات التصوير من حيث التكوين من نوعين من مستشعرات التصوير أحدهما يتكون من الوسائل المولدة للشحنة (CCD) على شكل ترتيب مساحى كبيراو على شكل ترتيب ترتيب خطى للمسح بالدفع للأمام pushbroom والآخر يتكون من أشباه الموصلات الأكسيدية المعدنية (CMOS) الحديثة على شكل ترتيب مساحى كبير. ويتضمن القسم الثالث من المقالة المعاملات المذكورة في أوراق البيانات الفنية التي أظهرها المصنعون. في القسم الرابع حدد المؤلف نسبة القاعدة إلى الارتفاع B/H لكل واحد من مستشعرات التصوير CMOS الحديثة الحالية التي لم يتم نشرها من قبل. وهذا يشير إلى أن نسبة B/H المعامل غير المنشور تعكس ضعفه ويقترح تعديل إعداد مستشعرات التصوير من قبل جميع المصنعين الثلاثة بتدوير طول المستشعر ليكون في اتجاه الطيران بدلاً من العرض.الاقتراح بهذه الدراسة يؤدى إلى زيادة قيمة نسبة B/H بمقدار الضعف تقريبا مما يجعل هذه المستشعرات دقيقة للاستخدام في رسم الخرائط بأساليب المساحة التصويرية المجسمة.

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1. INTRODUCTION

Traditionally, aerial photogrammetric mapping was done using large format film cameras have a standard square film format, 230 mm x 230 mm. Calculation for mission planning is based on this square film format. The most common focal lengths are 150 mm and 300 mm for wide angle and normal angle cameras respectively. There are other focal lengths were available as well. Because of the square film format, the fields of views are equal in both along and across flight directions.

The optical system of a film camera has a very high resolution. The last advanced cameras have more than 100 line pairs/mm optical resolution. This is required to meet the specs of high resolution film, although for film based aerial colour photos, only 40 to 50 line pairs/mm resolutions can be achieved on average. This is influenced by the film type, atmospheric effects like dust and haze, and film development.

Photogrammetry development was closely related with the aviation and photography development. Photogrammetric cameras work the same way as the amateur camera but they must fulfil the high geometric accuracy demands. During more than 100 years, photos have been taken on glass plates or film material (negative or positive) (Linder, 2016).

Photogrammetry and its contribution to our society were defined over 100 years ago. Many discoveries and inventions have followed. Photogrammetry is a combination of art, science and technology, which strives to derive locations, shapes and other information of objects from images with the best cost/accuracy ratio possible (Fricker, P., Chapuis A., Walker, A. S., 2004).

The advantages that an imaging platform at a certain height can offer have been exploited for more than a century. Imaging sensors on imaging platforms offer a repetitive, synoptic and therefore privileged image of the territory (Alamús, et. al., 2018).

Around the turn of the 21st century fully digital manned airborne photogrammetric imaging cameras and high-powered computers for data processing had been appeared. The recent years were characterized by rapid developments in the field of manned airborne photogrammetric imaging sensors technology.

In modern photogrammetric manned airborne imaging, analogue film cameras are replaced by digital sensor cameras. The acquisition of airborne digital sensor camera is a major investment with no comparison to the old analogue film cameras.

Manned airborne photogrammetric imaging platforms are the main platforms for photogrammetric imaging, which provide medium coverage with high resolution imagery and high geometric accuracy. Photogrammetric mapping transforms optical imaging data into decision -support information.

Most large and medium-scale Topographic or GIS maps data is derived from manned aircrafts, whether fixed-wing or rotary.

Currently, digital cameras are divided into several categories: large format cameras (e.g. the Hexagon DMC III and Phase One PAS 880), medium format cameras and small format cameras.

Digital photogrammetry is the science of measuring in digital images and it is belonging to the field of remote sensing and traditionally integrates with geodesy. Digital images measurements provide quantitative data such as the length, width and height of objects (Linder, 2016).

In digital photogrammetry, three-dimensional coordinates of any object point are observed and calculated by stereoscopic viewing of two or more adjacent digital images for the same object point but taken from different positions (Linder, 2016).

Digital photogrammetry reconstructs all geometric parameters of the situation when taking the digital images to calculate the three-dimensional co-ordinates (x, y, z) of any object point represented in two or more adjacent digital images and digitize points, lines and areas for map production or calculate distances, areas, volumes, slopes and much more (Linder, 2016).

Today digital societies require a continuous supply of updated, reliable and accurate geographical data, and new technologies are arriving with increasing speed. The manned airborne photogrammetric imaging is by far the main source of high resolution geographical data in the geodatabases (Neumann, 2019).

While other sources such as satellites imagery or unmanned aerial vehicles, UAVs or 'drones', imagery are playing an important part in building the geodatabases, the main source of high-resolution geographical information remains, overwhelmingly, the manned airborne photogrammetric imagery (Neumann, 2019).

Manned airborne photogrammetric digital imagery is a direct result of technology developed for imaging from orbiting satellites (Paine, D. P. and Kiser, J. D., 2012).

This paper concentrates on the way new manned airborne photogrammetric large format imaging sensors have been defined, which in the last two decades has caused dramatic changes in the field of manned airborne photogrammetric image acquisition.

2. IMAGING SENSOR TECHNOLOGY

Reflected light which enters digital cameras is collected via Charge Coupled Device, CCD, or Complementary Metal-Oxide Semiconductor, CMOS, imaging sensors within the camera body and the light energy is then converted into electrons.

CCD and CMOS imaging sensors are typically smaller than a human fingernail. The surface of each sensor contains an array of thousands or millions of tiny photo cells, each of which transforms the reflected light from one small portion of the object into electrons and record a single pixel of the resulting image captured by the lens eye when the shutter is opened and closed.

The greater the number of tiny photo cells on the sensor surface, the greater the picture quality. The Mega Pixel, MP, reference used within digital camera specifications refers to the number of tiny photo cells on the CCD or CMOS imaging sensor surface. One MP is equal to 1 million pixels. Cameras which have higher MP ratings typically are capable of higher resolution images.

The principal difference between CCD and CMOS imaging sensors lies in the tiny photo cells where the charge is converted into voltage (Stemmer Imaging White Paper, 2016):

2.1 Charge Coupled Device, CCD

In a CCD imaging sensor, a vertical and horizontal charge transport first takes place. The serial charge to voltage conversion of all tiny photo cells takes place outside the sensor in the camera electronics as shown in Fig. (1).

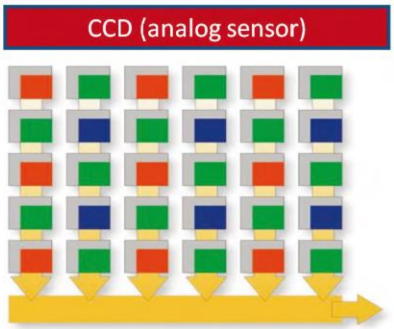

Figure (1) Principle of the interline transfer CCD - A/D conversion outside of the sensor (Stemmer Imaging, 2016)

Today there are two construction strategies of manned airborne photogrammetric imaging CCD sensors: area array large format and linear array pushbroom sensors (Linder, 2016) they will be discussed in detail below:

2.1.1. Area Array Large Format Sensors

Area array large format sensors keep the central perspective principle well-known from traditional film cameras called frame camera, a large area sensor is required.

At the beginning, efforts are made to use four overlapping smaller PAN area array large sensors 80 Mega Pixel, MP, of industrial standard and then match the four PAN image parts together like the first generation of DMC by Zeiss/Intergraph, Z/I, Imaging as shown in Fig. (2).

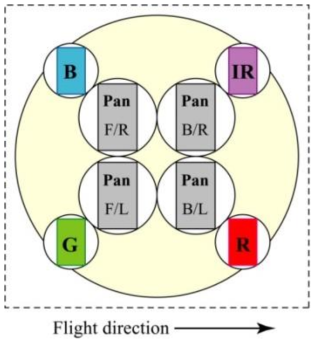

Figure (2) Four overlapping smaller CCD area sensors of industrial standard and then match the four image parts together.

Then the second generation DMC II by Z/I Imaging was the first manned airborne digital mapping camera using a single PAN area array ultra large CCD sensor 250 MP with 5.6 µm pixel size to avoid stitching of smaller CCDs as shown in Fig. (3).

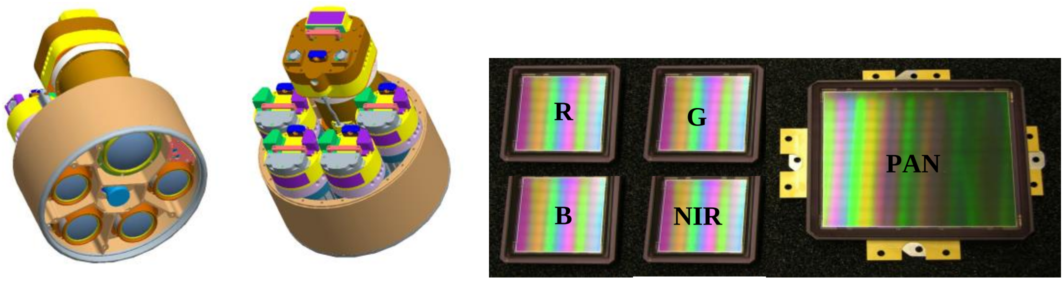

Figure (3) A single PAN ultra large area CCD sensor used for the PAN camera head and four multispectral cameras (RGB and NIR) in DMC II (after Neumann, 2013).

2.1.2. <u>Linear Arrays Sensors</u>

Linear arrays are, of course, the basic building blocks for airborne pushbroom scanners producing continuous strip images of the terrain. The ground coverage of these scanners is dependent on the length of the linear array that is fitted to the scanner.
Line array sensors are used across the flight direction, which collect data continually during the flight such as those used in ADS series from Leica Fig. (4). This is a bit similar to the techniques known from spaceborne imaging sensors on satellites.

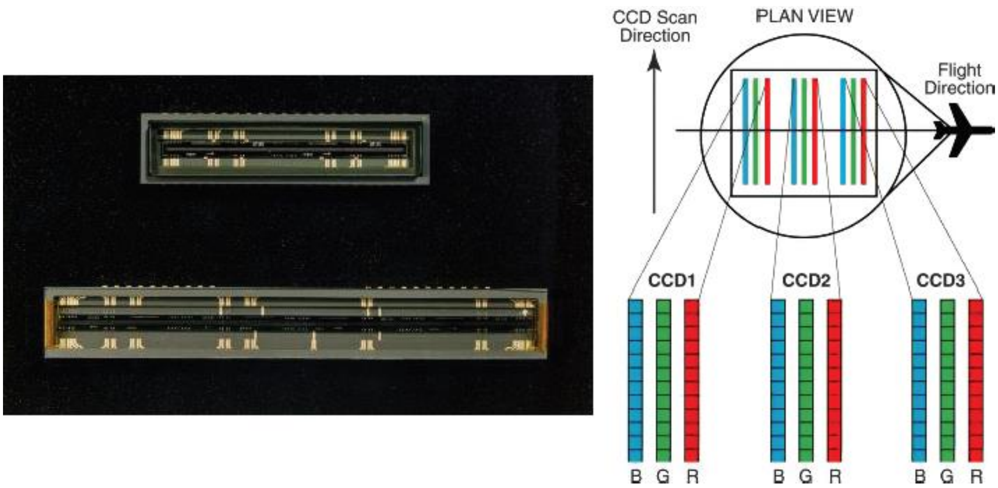

Figure (4) (a) CCD linear arrays. The upper photo shows a 4k pixel array; the lower photo shows a 12k pixel array.
(b) Colour images are produced using trilinear arrays deployed in airborne pushbroom scanners.

In the late 1990s, Leica Geosystems licensed the technology and used the experience gained by German Aerospace Centre, DLR, to build its own first generation ADS40 three-line

pushbroom scanner. Each of the three (backward-, nadir- and forward-pointing) lines comprises a pair of CCD linear arrays as shown in Fig. (5) (Petrie and Walker, 2007).
Leica Geosystems approached the extraordinary opportunity to enter the new millennium with a totally new challenge, the transition from film to digital images. For engineers respectful of the historic legacy of Wild Heerbrugg and Leica Geosystems, a decision to break with the past and make an historic technological step forward in a pivotal role was a unique experience (Fricker, P., Chapuis A., Walker, A. S., 2004).

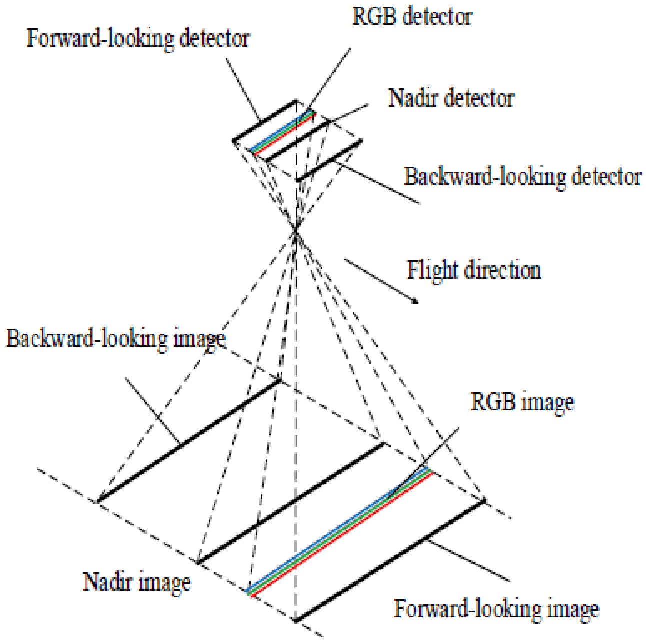

Figure (5) CCD Linear array used in ADS100

Airborne pushbroom sensors like last generation of the ADS series, ADS100 uses linear arrays with 20 000 tiny photo cell detectors Fig. (4-a).
ADS100 has small Field of View FOV along track of 25.6° forward and 19.4° backward which affect the Base to Height ratio, which makes it difficult to meet the demand of large-scale topographic mapping.

2.2 Complementary Metal-Oxide Semiconductor, CMOS

In contrast to CCD, the charge to voltage conversion in CMOS sensors occurs in every tiny photo cell on the sensor. Corresponding to the activated line, the signal is amplified via the readout circuit, noise-minimized and digitized, and finally transmitted in parallel via a configurable number of Low Voltage Differential Signaling wires shown in Fig. (6).
Nowadays PAN area array ultra large CMOS sensor 391MP with 3.9 µm pixel size is available and used in Leica Geosystems DMC III Fig. (7-a).
The Leica DMC III uses the same lens system that was employed for the DMC II models. It is equipped with a very large single CMOS PAN sensor with a physical rectangular size of 26112 x 15000 pixels, with a pixel size of 3.9µm (Mueller and Neumann, 2016).

The Phase One Aerial System 880, PAS 880 has 280MP nadir and four 150MP oblique cameras; the system provides over 20,000 pixels across flight lines for the nadir and 14,000 pixels per oblique sensor Fig. (7-b) (Phase one, 2021).

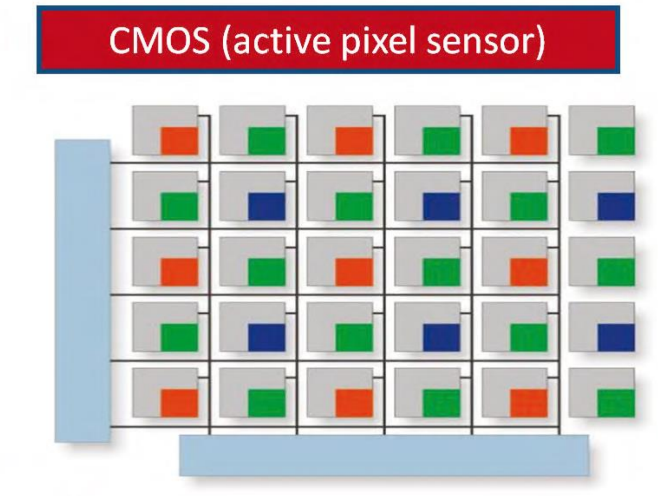

Figure (6) Principle of the interline transfer of the CMOS sensor - A/D conversion in the sensor (Stemmer Imaging, 2016)

The IGI DigiCAM-450 equipped also with a very large CMOS RGB sensor with a physical rectangular size of 30,460 x 14,100 pixels, with a pixel size of 3.76µm (IGI mbH, 2021) as shown in Fig. (7-c).

Figure (7) (a) Leica DMC III (b) Phase One PAS 880 (c) IGI DigiCAM-450

3. COMPARISON OF MODERN PHOTOGRAMMETRIC MANNED AIRBORNE IMAGING LARGE-FORMAT CMOS SENSORS

Table (1) lists the different parameters of the current modern CMOS sensors, which are Leica DMC III, the Phase One PAS 880 and IGI DigiCAM 450.

Table (1) The parameters of the current CMOS digital imaging cameras

	Parameter	Leica DMC III	Phase One PAS 880	IGI DigiCAM 450
PAN	Pixel across track	25,728	Not include PAN Heads	
	Pixel along track	14,592		
	FOV across track	57.2°		
	FOV along track	34.4°		
	Focal length	92.0 mm		
	Pixel size µm	3.9		
	GSD@500m	2.1 cm		
MS	Pixel across track	8,956	20,150	30,460
	Pixel along track	6,708	14,118	14,100
	FOV across track	61.7°	45.7°	
	FOV along track	48.2°	32.9°	
	Focal length mm	45	90	90mm RGB, 40mm NIR
	Pixel size µm	6.0	3.76	3.76
	GSD@500m (cm)	6.7	2	2
General	Number of camera heads	5	2	2
	Ratio of PAN: MS resolution	1:3.1		
	Frame rate	1.9 sec	0.5 sec	0.6 sec
	Colour channels	R,G,B, NIR		RGBI, RGB, CIR
	Resolution per pixel	14-bit	14-bit	16 bit
	FMC, mechanical	Yes		FMC by BCM
	Dynamic range	78 dB	83 dB	83 dB
	Onboard storage	9.6 TB to store up to 7900 images	Integrated, 6 x 2TB	Storage Units for >13,500 events (8 or 4 TB) with IGI Redundant Storage Technology
	Weight	63 kg		
	Power consumption	280 W, camera incl. MM30 storage modules		190W @ 28 VDC
	Altitude non pressurised	25,000 ft (7,620 m)		No limit

From this table it is noticed that all the three large format CMOS sensors have a rectangular format with the length across the flight direction and the width along the flight direction. This affects the simulation of geometry of their images to that of the traditional square format film cameras and also affects the value of the B/H ratios of each of them which is not published although it is a main parameter for photogrammetric topographic mapping.

Also manufacturers need to be asked about the square format of the sensor which affects the geometry of images.
These two points may represent the plan for development of these CMOS cameras.
It is noticed that the development of these CMOS cameras is going slowly due to the economic conditions existing worldwide and due to the available technology of CMOS sensors and onboard storage capabilities, which are two main issues affecting the development.

4. RESULTS AND DISCUSSION

4.1 Determination of Base to Height (B/H) Ratio

Base to Height ratio is the ratio of the air base B, which is the distance between any two successive exposure stations along a flight line, to the flying height above average ground H. An expression for the B/H is As follows:

$$\frac{B}{H} = [(100 - o_{end})/100] * \frac{w}{f}$$

where:

w is the width of the CMOS rectangular format sensor in the flight direction,
o_{end} is the pecentage overlap between two sucessive images,
f is focal length.

4.1.1 <u>Base to Height (B/H) Ratio for Current Manufacturers Setting</u>

In the DMC III:
o_{end} = 60 (For 60 % overlap),
w = 14,592 x 3.9 = 56,908.8 µm = 56.9088 mm and
f = 92 mm which yield a base to height ratio calculated as:

B/H = 0.25

While in the IGI DigiCAM 450:
o_{end} = 60 (For 60 % overlap),
w = 14,100x3.76 = 53,016 µm = 53.016 mm and,
f = 90 mm which yield a base to height ratio calculated as:

B/H = 0.24

And in the Phase One PAS 880 has to height ratio calculated as:
o_{end} = 60 (For 60 % overlap),
w = 14,118x3.76 = 53,084 µm = 53.084 mm and,
f = 90 mm which yield a base to height ratio calculated as:

B/H = 0.24

While if the length is rotated to be in the direction of flight and the width across the flight direction, the B/H ratio will be increased by almost twice as it will be determined in the following section, but this need to be asked to the manufacturers.

4.1.2 Base to Height (B/H) Ratio for Author Suggestion Setting

In the DMC III:
o_{end} = 60 (For 60 % overlap),
w = 25,728 x 3.9 = 100,339.2 µm = 100.3392 mm and
f = 92 mm which yield a base to height ratio calculated as:

B/H = 0.44

While in the IGI DigiCAM 450:
o_{end} = 60 (For 60 % overlap),
w = 20,150x3.76 = 75,764 µm = 75.764 mm and,
f = 90 mm which yield a base to height ratio calculated as:

B/H = 0.34

And in the Phase One PAS 880 has to height ratio calculated as:
o_{end} =60 (For 60 % overlap)
w = 30,460x3.76 = 114529.6 µm = 114.5296 mm and,
f = 90 mm which yield a base to height ratio calculated as:

B/H = 0.51

In the photogrammetric mapping imagery, the greater base-height ratio is the higher elevation precision. Elevation accuracy is the highest when the base-height ratio is equal to one.

4.2 Representation of Base to Height (B/H) Ratio results

Table (2) lists the determined B/H ratios of the current CMOS photogrammetric sensors for both current manufacturers setting and author suggestion setting.

Table (2) B/H Ratios determined for current CMOS photogrammetric sensors

	Leica DMC III	**Phase One PAS 880**	**IGI DigiCAM 450**
B/H for Current Manufacturers Setting	0.25	0.24	0.24
B/H for Author Suggestion Setting	0.44	0.34	0.51

From table (2) it is noticeable that the B/H ratio of IGI DigiCAM 450 sensor will be increased by more than twice, that of Leica DMC III sensor will be increased by almost twice and that of Phase One PAS 880 sensor will be the least increased one. Fig. (8) highlights these results in a char representation.

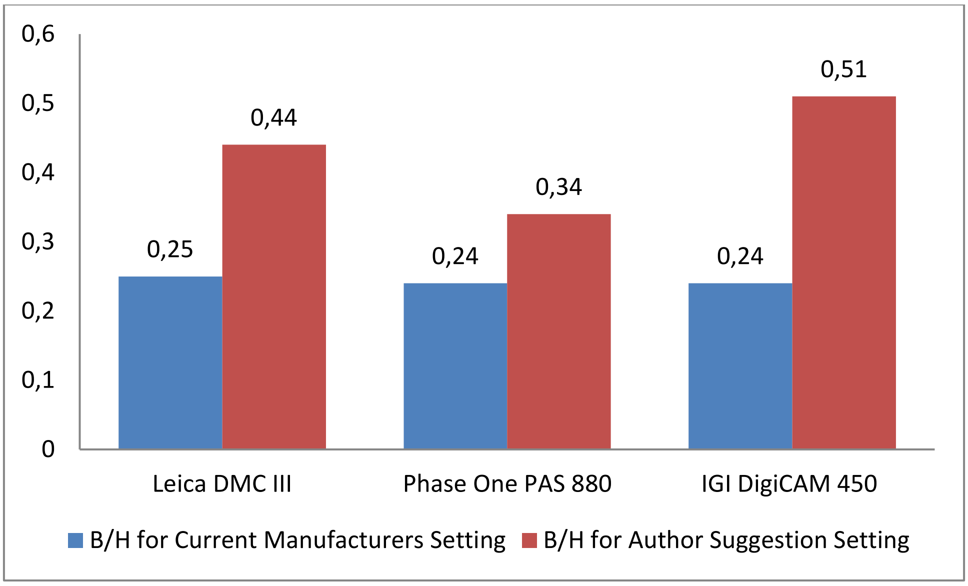

Figure (8) Chart representation for results of B/H ratios determined for current CMOS photogrammetric sensors for both current manufacturers setting and author suggestion setting

5. CONCLUSION

From the above sections it can be concluded that; The disadvantages of CCD linear array manned airborne photogrammetric sensors, such as Leica ADS100 are small field of view and low resolution, which makes it difficult to meet the demand of large-scale topographic mapping. The rectangular format of the modern large format CMOS sensor does not simulate till now the square format of the film camera. This affects the base height ratio which is an important factor for photogrammetric topographic mapping. This situation will remain until the following technologies appear; On board storage capabilities are advanced to the level that can store or record data of 800 MP or more in part of second and CMOS sensor manufacturing technology will be able to produce a square large format sensor of 20150x20150 and more to simulate the square format of traditional film camera. Digital Cameras manufacturers may consider rotating the current available CMOS sensors to make the length of the sensor in the direction of flight to enhance the base height ratio of the system.

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BIOGRAPHICAL NOTES

Dr. Elsayed Ammar, acquired his PhD in Surveying engineering (Surveying and Photogrammetry), from Benha University, Egypt in 2010. He was working in the Egyptian Military surveying Department in the period from 1987 to 2009 in the mapping group and GIS centre. Dr. Ammar is currently a lecturer of surveying subjects in the Department of Civil Engineering at The Higher Institute for Engineering and Technology in Elmenofia. Dr. Elsayed Ammar research interests in the domains of geomatics sciences and technologies;

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