# A LARGE FORMAT CAMERA SYSTEM FOR NATIONAL MAPPING PURPOSES

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**Résumé**

Le projet CAMv2 de l'IGN a débuté en 2006 et est composé de deux parties principales. Tout d'abord, une caméra quatre canaux de format moyen a été développée. Les éléments de base de ce nouveau système sont une tête de caméra construite autour du Kodak KAF-39 000, un capteur à barrettes de 39 megapixels (7216 x 5412 pixels). Trois systèmes opérèrent dans cette configuration à l'été 2009 pour la production nationale d'orthophotographies de l'IGN avec des têtes de caméra quadricolores (RVB et proche infra-rouge). Grâce à la polyvalence et à l'aspect modulaire de ce nouveau système de caméra, la seconde étape de notre projet a pu être atteinte: le regroupement de huit têtes de caméra sur le même élément gyro-stabilisé, permettant ainsi d'obtenir des images fusionnées de 155 megapixels, avec un rapport de fusion de 2 $\times$ 2 et une fauchée finale d'environ 14400 pixels. Cette configuration à large champ a été établie avec deux combinaisons de longueurs de focale. Une version 45-90 mm permet une acquisition dédiée aux modèles 3D de villes et une version 60-120 mm sert à la production d'orthophotographies. Une bonne qualité colorimétrique est obtenue avec ce système grâce à la création spécifique de filtres de couleur. Enfin, le système peut être relié à un FMS/INS afin d'obtenir un géoréférencement direct des images et une interface facile d'accès et de prise en main pour des opérateurs grâce à un logiciel de planification de vol dernier cri.

**Mots clés :** Caméra aérienne numérique, système modulaire, conception mécanique, qualité colorimétrique, fusion.

***Abstract***

*IGN CAMv2 project started in 2006 and is composed of two main steps. At first, a four-channel medium format camera system was developed. The basic element of this new system is a camera head built around the Kodak KAF-39 000, 39 mega-pixel array sensor (7,216 x 5,412 pixels). Three systems in this medium format colour configuration, with four nadir-viewing camera heads (RGB and Near-Infrared–NIR), operated for IGN national orthophotography production, during the summer 2009. Thanks to the versatile and modular aspect of the new camera system, the second step of our project was reachable: gathering eight camera heads on the same gyro-stabilised mount in order to achieve 155 megapixels pan-sharpened images with a pan-sharpening ratio of 2 $\times$ 2, and a final swath width of about 14,400 pixels. This large format configuration has been designed with two combinations of focal lengths. A 45-90 mm version allows 3D city models acquisition, and a 60-120 mm version for orthophotography acquisition. Good realistic colorimetric quality is obtained with this camera system thanks to specially designed colour filters. This system can be linked to a FMS/INS in order to obtain a direct geo-referencing of images, and the user friendliness for the operators of a state-of-the-art flight management software.*

***Keywords :*** *Digital aerial camera, modular system, mechanical design, colorimetric quality, pansharpening.*

## 1. Introduction

The last twelve years have witnessed the penetration of digital airborne cameras in the fields of photogrammetry and remote sensing (Heier, 1999; Sandau, 2010). Several devices are now available on the market, designed or not for specific purposes (Cramer, 2009; Jacobsen, 2010; Lemmens, 2011).

The French National Mapping Agency (IGN France) has developed, from 2006 in its research laboratory LOEMI, a new digital frame camera based on a new CCD (Charge-Coupled Device) array sensor: the Kodak KAF-39 000, 39 mega-pixel array sensor (7,216$\times$5,412 pixels). In 2009, the main characteristics of the camera system, listed below (Table 1), show that even if its minimum ground sample distance of 9 cm is sufficient for most of geomatic applications, a larger swath would be expected in order to reduce flight costs (Souchon et al., 2006; Paparoditis et al., 2006).

Consequently, since summer 2008, the CAMv2 project team worked on the synchronisation of two camera sub-systems, each composed of four camera heads. This work was helped by the modular structure of our CAMv2 system: the structure is not centralised, all channels are assembled in parallel. We are then sure that no data-flow bottleneck will appear as channels are

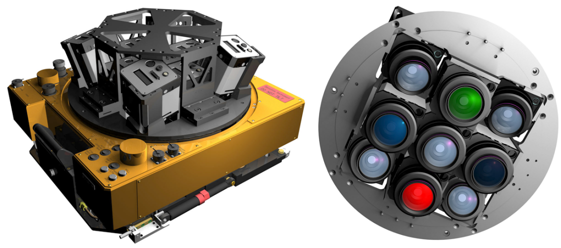

**Figure 1 :** Two virtual illustrations of the new large-format camera configuration.

added to the system (Souchon et al., 2010).

This work leaded to several flight tests of a camera system composed of two sub-systems located on two gyro-stabilised mounts:

- A colour sub-system composed of four nadir-viewing camera heads using specific Schott colour filters (Red Green Blue –RGB– and Near-Infrared –NIR), and Rodenstock Linos Apo-Sironar 45 mm f/4.5 lenses;
- A black and white sub-system composed of four tilted camera heads using panchromatic filters in front of Rodenstock Linos Apo-Sironar 90 mm f/5.6 lenses.

This second sub-system, installed on a second window in the plane, was synchronised with the first one in order to acquire a "butterfly" image of twice better resolution that was used for pan-sharpening fusion.
Even if the images acquired by this camera system were of good quality we quickly decided to work on a new mechanical design in order to gather on the same mount on the same window the eight camera heads making up the system: the IGN CAMv2 large format camera system.

## 2. The large format camera design

As a preliminary work a new gyro-stabilised mount was chosen. Our laboratory-made mount didn't fit anymore with the quantity of camera heads we wanted to synchronise. At that time, September 2009, a SOMAG GSM3000 was already used in one of our planes. A mechanical interface was designed (See Figure 1) in order to fix our large format camera system on a GSM3000 mount. A large format camera system gathering four (possibly five) nadir-viewing camera heads equipped with 45mm lenses and four tilted camera heads equipped with 90 mm lenses.
This mechanical design takes benefits of many features of our camera system:

- The dowel and magnet on each lateral face of the camera heads are used. They allow a rigid fixation of the camera heads together as well as an easy way of taking off a camera head to be replaced, or four camera heads to get a medium format camera system without black and white sub-system (see Figure 2).
- The two mechanical designs for the camera bodies. As described in (Souchon et al., 2010), a technical choice at the beginning of the project was to have two mechanical designs for the camera body, depending of the focal length used. A direct consequence is that a 45 mm camera head (including lens and filter) has the same size than a 90 mm camera head (also including lens and filter). No long cumbersome mechanical pieces are used, and then there are less risks of occultation of one camera field of view by another one (see Figure 3).

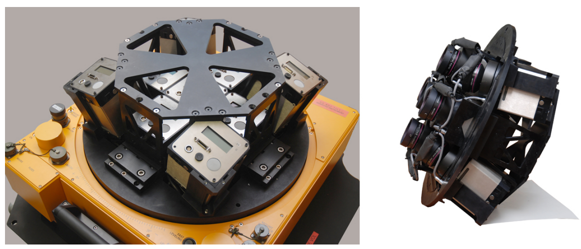

**Figure 3 :** Two photographs of the 45-90 mm large format system in which size of each camera head is visible.

To sum up, this system is still versatile. A large range of associations of lenses can be used if two conditions are respected: (1) the ratio between the two focal lengths must be about 2; (2) eight mechanical pieces of the mount, that decide the inclination angle of the tilted cameras, must be changed.

This motivates why two configurations of this large format digital camera system now exist in IGN: a 45-90 mm configuration, and a 60-120 mm one. The 60-120 mm configuration is more adapted for orthophotography acquisition when 20% overlap between flight strips is required. Comparatively, 30% or 40% are necessary with a Microsoft Vexcel UltraCamXp (Wiechert and Gruber, 2006) because of its shorter focal length. The 45-90 mm configuration is well-adapted for 3D city models surveys as well as for orthophotography over high mountains area (Figure 4).

Three 60-120 mm systems have been realised, and have already acquired several French departments during summer 2011 for IGN country-wide orthophotography production. At the beginning of 2011, their integration in IGN production process was complete with the acquisition of a Flight Management Software (FMS) and an Inertial Measurement Unit (IMU). Main characteristics of Table 1 can be completed by the Table 2 below.

| Characteristic | Specification |
|---|---|
| CCD array size | 7,216 x 5,412 pixels, Kodak KAF-39 000 |
| Pixel size | 6.8 x 6.8 $\mu$m$^2$ |
| Full well capacity of each pixel | 60,000 electrons |
| Dynamic range | 3,000 |
| Noise | 1.2 grey level RMS |
| Radiometric resolution | 12 bits/channel |
| Frame rate | 1 image/2 s |
| Minimum stereo GSD | 9 cm (60% stereo overlap, 100 m/s plane speed) |
| Storage capacity | Unlimited (500 GB hot removable hard disks) |
| Electronic motion compensation | TDI with 0.5 pixel accuracy |
| Focal lengths | 45, 55, 70, 80, 90, 100, 105, 135, 150, 210 mm |
| Shutter | Rollei Electronic Shutter 0 |
| Exposure time | 3 ms (1/300 s) minimum, no upper bound |
| Exposure time control | Yes, by a photodiode placed in the chamber |
| Synchronization accuracy | < 10 $\mu$s |

**Table 1 :** Main characteristics of the IGN CAMv2 system in 2009.

**Figure 2 :** From the left to the right: CAMv2 system in medium format, in large format and in its large format equipped with an IMU.

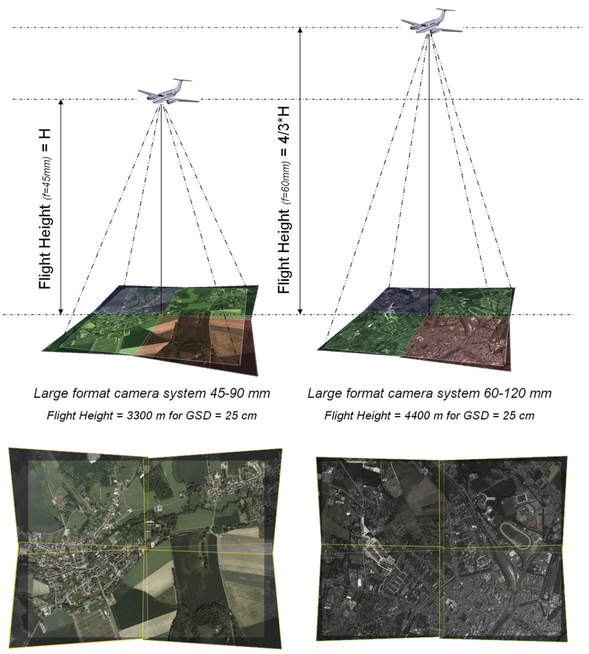


**Figure 4 :** Comparison of the flight height and of the global aspect of panchromatic mosaic with the two configurations. GSD is for Ground Sampling Distance.

| Characteristic | Specification |
|---|---|
| Swath width | 14,600 pixels |
| Minimum stereo GSD | 4.5 cm (60% stereo overlap, 100 m/s plane speed) |
| Focal lengths | 45-90 mm or 60-120 mm |
| PAN + XS ratio | 2$\times$2 |
| FMS/INS | yes |

**Table 2 :** Final characteristics of the IGN CAMv2 large format camera system.

## 3. Consequence of pansharpening ratio of 2 $\times$ 2: a better colour resolution

As a direct consequence of our design, the pansharpening ratio of our large format camera system is of 2 $\times$ 2. It means that one colour pixel will give its colour information to four black and white ones of the panchromatic mosaic. It was a strong technical goal at the beginning of the project that has been respected. Actually on the market, among the large format camera systems using frame CCD, only one version of the Z/I Imaging DMC II (Neumann, 2011) is approaching this low value with a 4.18 pansharpening ratio. Most of the other designs have a value around 3 $\times$ 3 pixels. It is the case of Microsoft Vexcel UltraCam family, from the UltraCamD to the UltraCam Eagle, pansharpening ratio is exactly 9 (Leberl et al., 2012).

As IGN acquired images with its UltraCamXp and with its own camera system over the French town of Elancourt, we have data allowing us to compare the impact in images of a difference of pansharpening ratio. The two surveys we compared, flown at the end of October, were separated by two days; the climatic conditions and the flight plan were the same. The GSD in the images was of 10 cm. This study led us to several conclusions:

- The pansharpening ratio of 9 does not lead to the same level of colour details as the ratio of 4 (Figure 5);
- The pansharpening ratio of 9 does not allow to preserve the colour saturation of low resolution multispectral images, certainly in order to avoid too visible artefacts;
- A strong enhancement of sharpness is processed in Vexcel images, perhaps to compensate the pansharpening ratio: it leads to dark halos on the limits of objects.

**Figure 5 : Left**: two extracts of images acquired with UltraCamXp (GSD 10 cm). **Right**: the same areas in images acquired with IGN CAMv2 camera system (GSD 10 cm). **Top**: a playground for children shows the European flag and its 12 yellow stars. **Bottom**: a sport field with lines of different colours depending on the sport.

## 4. The choice of the colour filters

In order to have the best colour quality in final images, an effort has been made in the choice of the filters that are in front of the lenses. To be able to reproduce the same colour space as the one visible by the complex duo retina-human brain, we had to define specific filters with specific transmission curves. These filters must be as selective as possible to avoid redundancy, but in the same time must allow, by a linear transformation, to reach a solution as close as possible to the response of the eye.

The use of multilayer dielectric filters is prohibited since we use wide angle lenses: the response of this kind of filter depends on the incidence of light. The choice is thus limited to tinted glass filters.

A study has been carried out in IGN, and a suitable combination of Schott glasses was found (Figure 6), allowing the restitution of a colour space sufficiently close to the space of visible colours.

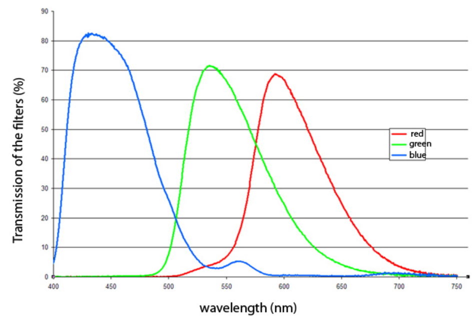


**Figure 6 :** Transmission curves of the three colour filters made by Schott for our system.

One can easily see in Figure 6 that the transmission curves of our spectral channels have a non negligible overlap just like cones of retina. The advantage is that thanks to that overlap, we are able to obtain realistic colours. The disadvantages is that these realistic colours will only be obtained with the help of the ICC (International Colour Consortium) profile (ICC, 2005) of our camera system.

## 5. The ICC profile contribution

An ICC profile has been computed from the measured sensitivity of the filters, combined with the global sensitivity of the sensor. It is used during the post-processing to obtain sRGB images that are used in the processing lines of IGN. Finding this ICC profile means, actually, determining the best linear function of the raw RGB that matches the CIE XYZ values for all the possible sources. In fact, optimizing the profile for only the most frequent sources found in natural or built terrain is more adequate for an aerial sensor. This leads to optimize the profile for sources of wide spectral bandwidth, which are more energetic than narrow bandwidth sources. Indeed, they are all diffusing the solar light. It would not be the case for night-time surveys, where light sources are mainly vapour discharge devices. Of course in such a case, the colour rendering is already poor due to metamerism, even with human eyes.

Unfortunately such procedure is not enough to obtain good colours on aerial imagery, since most of the distortion of colour is caused by the haze removal process, which subtracts at each pixel a coloured quantity that is determined with heuristic models, of course not perfect. This leads to an important colour distortion, especially on dark image areas.

Another source of problem for colour rendering is the use of pan-sharpening techniques. The different algorithms used lead to unavoidable colour artefacts, especially with large pan-sharpening factors. But the combination of the panchromatic channel with the colour image results in an unpredictable colour profile. Moreover, if the pan-sharpening is performed before the haze removal step, it can interfere with the haze evaluation process, resulting in another source of distortion.
Consequently, the problem to obtain good colour quality aerial images remains, especially with automatic processes, but the use of filters optimized for human vision is a step in this direction (see Figure 7).

## 6. The link with FMS/INS

Earlier version of the embedded software controlling the camera used a constant acquisition rate along flight strip computed from the speed and height of the aircraft (received from a GPS receiver) and the desired overlap. Picture geo-referencing was done thanks to an electric signal sent to the GPS receiver at the beginning and at the end of the exposure time. Only the GPS time was recorded for each image acquired, and the precise positioning of its perspective centre was computed by post-processing of the GPS trajectory. However, precise orientation of the camera at the instant of the exposure was unknown.

As IGN bought a gyrostabilized mount (SOMAG/GSM 3000), it was also decided to buy an IMU (IXsea / AIRINS) and a dedicated Flight Management System – FMS (Flotron / TopoFlight Navigator). Integration of these components was made by IXsea which also provided the software tools necessary to post-process GPS and IMU data to obtain precise direct geo-referencing of the pictures. This direct geo-referencing is essentially used as an initial approaching solution for the orthophotography computation, and the results are far better than without the INS. The direct geo-referencing is also essential for some specific cases of aerial acquisitions: night surveys with large parts of images without any details and then without any tie points, flights on large forested areas like in Guyana, surveys based on very long flight strips for river monitoring for instance. . .

As our camera software was initially designed to be used without a FMS, it was necessary to add a new software engine for the picture release. A simple text protocol over TCP/IP was designed between our camera software and the FMS (more specifically the camera handler part of the FMS). Basically, the FMS sends commands and the camera responds with a status code (! for acknowledge, ? for not acknowledge), and a message.
As the camera generates itself the name of the pictures, using the mission name, the number of the flight line and an auto incrementing counter, some information must be provided by the FMS before the picture is taken. Moreover, FMS sends every second the height and the speed of the aircraft to allow the computation of the Time Delayed Integration (TDI) for the Forward Motion Compensation (FMC). The camera system can of course send a not acknowledge code, as an error code, at any time in case of dysfunction. IMU can measure and send instantaneously angular speeds to the system for a real time detection of possible blur effect due to parasitic movement during exposure.
The camera sends an electric signal to the IMU (instead of the GPS receiver in previous configuration) at the beginning of the exposure. This GPS absolute time is recorded by the IMU software and is used in post-processing. As the Middle Exposure Time (MET) is the significant value for picture geo-referencing, it is mandatory to record a Middle Exposure Correction to compute the exact MET from the beginning exposure time.

## 7. Conclusions

The results obtained with our large format camera system during the summer 2011 for orthophotography acquisition, and during the following winter for Digital Terrain Model acquisition, confirm us in our initial choice to develop our own modular large format system.
The right combination of the right focal lengths is not only a source of better image quality due to its pan-sharpening ratio of $2 \times 2$. It also allows the use of our system over all French departments (mountainous ones as well as sea shore areas) with an overlap between flight strips lower than the one used with industrial large format camera systems that IGN already operated in its planes. This lower overlap partially compensates our final swath of 14,600 pixels that is somehow smaller than the one of commercial cameras (Wiechert and Gruber, 2006). But let it consider the "real swath", taking into account the number of columns of the final image and the necessary lateral overlap that is computed in order to avoid too many hidden parts in images. Our "real swath" is equivalent to the ones of the other large format cameras on the market, and will allow us to update every three years the orthophotography of the whole French territory.

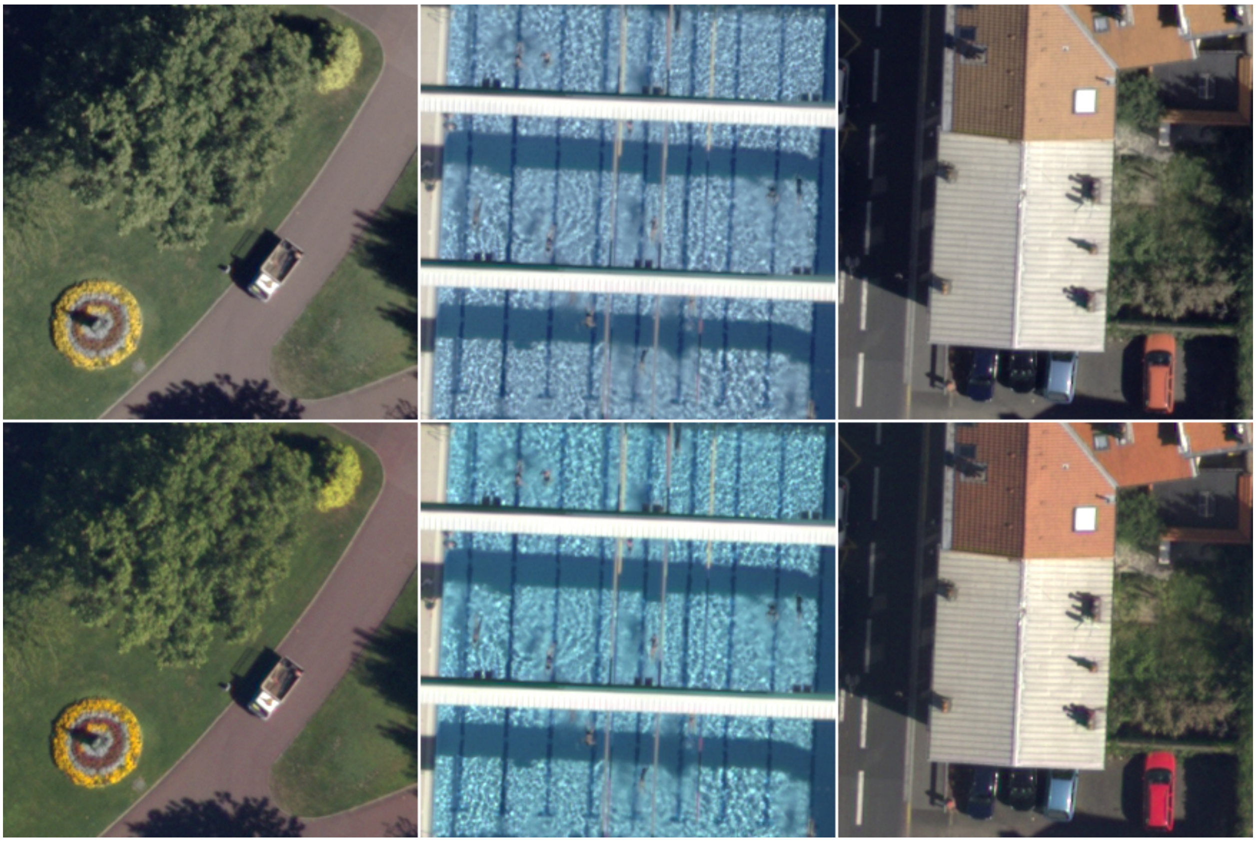

**Figure 7 :** Comparison of 3 extracts of the same image (GSD=8 cm). With no ICC profile contribution (images on the top), colours are dull, with ICC profile contribution (bottom images), colours are vivid.

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