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Processing of stereo scanner: from stereo plotter to pixel factory

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ABSTRACT

With the advent of airborne digital sensor, new photogrammetric softwares is needed in order to take into account the main advantages of these sensors. Such software should be able to handle large volume of digital data, to distribute the computation over multiple computers and to produce automatically accurate end-products. If these constraints can be met, it is then possible to produce cartographic products instantly over large areas: digital data is uploaded in a PIXEL FACTORY and accurate end-products are automatically produced by this factory. Within the paper, a description of such a framework will be presented and compared to classical photogrammetric systems.

1. INTRODUCTION

Today, aerial data are acquired as photographic film products or digital datasets, either from airborne platforms or by satellite. Regardless of the source, all such images must be corrected to compensate for distortions due to sensor position and motion before they can be used as a map. This photogrammetric process of image correction was invented decades ago, and as with virtually any industrial processes, has been computerised. “Softcopy” programs now work with digital data rather than actual film prints. However, to a great extent the workflow inherent to the photogrammetric process remains the same as it was years ago. Highly trained professionals can spend man-months of time modelling, measuring, adjusting, and balancing the multiple sources of error and distortion in a mosaic of image frames. The process may be digital, but the workflow is still manual.
In this paper, we will present a fully automated photogrammetric production framework named PIXEL FACTORY. Thanks to its automation, this framework allows enhanced productivity and new generation of products such as dense Digital Surface Model and True Ortho images[1]. These kinds of products were nearly impossible to get on classical systems due to the amount of manual works involved. This paper will describe the major advantages of such a process over traditional photogrammetry, either on the methodology or on the final product.
Moreover, new digital sensors coupled with IMU/GPS[2], like the ADS40 camera [1], are well-suited to such a framework as digital data are handled from aerial acquisition to end-products, pushbroom sensors help to reduce the amount of data to handle, and IMU/GPS measurements reduce tremendously the need of ground control points for the aerial triangulation as described later in this paper.

2. AERIAL SENSORS

Analog Cameras

Film cameras create an image by “pinhole projection”. Standard photogrammetric coverage is built frame-by-frame along a roll of film, as the aircraft advances along flight lines over the target region. Today’s analog camera systems are usually computer controlled, and compensate for forward

[1] TrueOrtho stands for orthophotos that are truly orthorectified: it implies to remove building lean, terrain displacement, and to improve accuracy to a remarkable degree.
[2] IMU/GPS stands for Inertial Measurement Unit coupled with a differential GPS receiver

motion as the plane moves during exposures. In a film camera, the optical clarity and geometric fidelity of the lens, as well as overall stability of the film transport system, are defining factors behind the quality of the end product. These metrics as well as the quality of photographic reproduction determine the resolution and rendering of the end product.

Digital Cameras

There are two types of digital cameras: one follows the frame-by-frame 'pinhole projection' paradigm, such as the DMC from Z/I Imaging, and the other is based on 'pushbroom' technology, such as the ADS40 from Leica System or the HRSC from DLR Institute. Pinhole projection cameras replace a film frame with a corresponding square or rectangular matrix of Charge-Coupled Device (CCD) pixels, whereas pushbroom sensors work with one or more linear arrays of CCDs. Main advantages of the digital sensor over analog cameras are [1]:

- aerial survey is done directly in digital format,
- digital sensors allow radiometry quantification in 12-bits or 16-bits, hence features in shadows, or the subtle differences across areas with little color variation, are more precisely rendered,
- digital sensors are able to acquire multi-spectral images whereas analog cameras will need multiple flights.

3. PIXEL FACTORY FRAMEWORK

Definition

PIXEL FACTORY comprises a set of tools and hardware dedicated to cartographic product manufacturing but with a great emphasis on image processing algorithms, hence the term *pixel*:

- optimized tools and image processing algorithms,
- optimized production workflows with parallelized processes,
- dedicated hardware configuration tailored to the requested productivity performances.

Figure 1 illustrates the workflow inside the PIXEL FACTORY for the Digital Surface Model & True-Ortho production. The plain boxes are processes that may be distributed over different computers in order to speed up the whole computation. This distributed behaviour of the system is only possible thanks to the design of the tools and hardware.

Data Acquisition & pre-processing

As stated in the introduction, aerial pushbroom sensors are really tailored to the PIXEL FACTORY paradigm. Indeed, processing of long strips of stereoscopic images optimizes the whole flow and allows mass-production over large areas. This is possible thanks to workflow optimizations linked to stereo acquisition geometry pertaining to each sensor as explained in the following paragraphs.

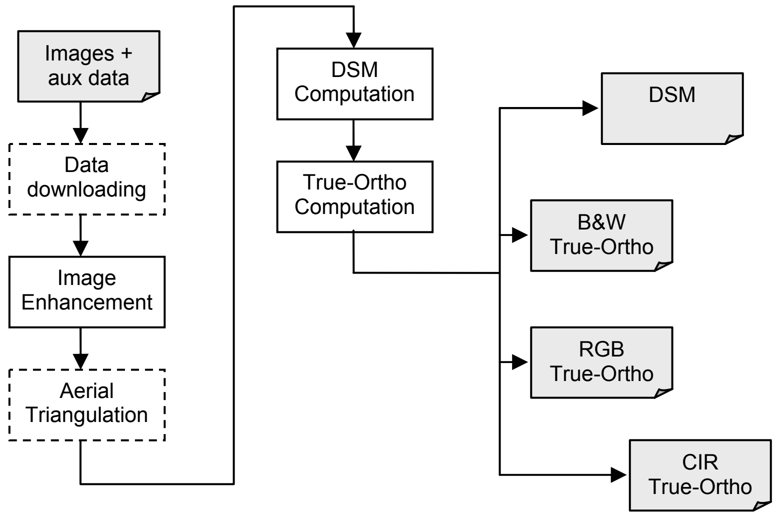

Figure 1: Pixel Factory Workflow

Frame-based systems

In aerial frame-based systems, stereopairs are acquired as the plane moves forward along a flight line. Along-track overlap is achieved by acquiring a frame every few seconds, and using the inherent angular differences within each frame. As images are acquired within a few seconds of each other, correlation from one image to the next is relatively simple. Traditional frame systems usually work with a 60% along-track overlap, with 30% cross-track overlap (also called sidelap) providing tie-points across flight lines to link the along-track stereopairs. This method ensures that at least two views of every point will be acquired.

Pushbroom Digital sensors

The general concept of a 60% along-track overlap does not apply in a pushbroom sensor, since swaths of data are acquired as a continuous strip, not as a frame-by-frame matrix of discrete images. As the pushbroom sensor moves along the flight line, each point on the ground is captured from a discrete, known angle as depicted in figure 2.

In order to produce True-Ortho with the PIXEL FACTORY, flight with 50% sidelap are necessary to ensure redundant side-to-side views of each ground feature. This method captures at least six views of every ground feature. Depending on mission profiles, the sidelap can be adapted: generally more than 50% is required for dense urban, and less than 50% for sub-urban areas depending on the camera focal length. As a comparison, 80% overlap along-track and cross-track are needed with frame-based systems, for a focal length of 150 mm, to allow True-Ortho production with the PIXEL FACTORY. This overlap is necessary to ensure that each point on the ground is seen from an almost nadir view, and to have a better estimate of the digital surface terrain. This ends up with a huge amount of data compared to a pushbroom system (roughly by a factor of 4).

Image Pre-processing

By considering all the images at the same time when doing the different radiometric correction (atmospheric correction, radiometry enhancement …), global homogeneity between images is guaranteed during the whole process which is crucial when doing the True-Ortho computation.

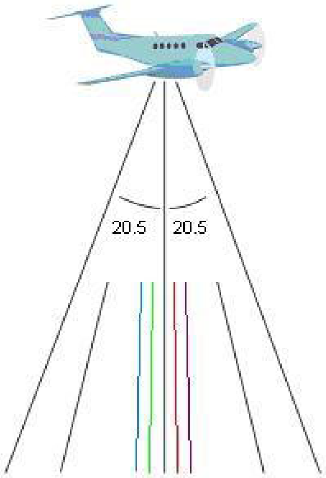

Figure 2: Pushbroom stereo acquisition (HRSC-AX Sensor)

Aerial Triangulation

The plane carrying out the aerial survey is equipped with a high-end Inertial Measurement Unit (IMU) and Differential GPS receiver, making it possible to know very precisely the attitude and position of the aircraft at any moment of the flight: IMU precisely calculates pitch, roll, and yaw to within a few ten-thousandths of a degree at 200Hz and the sensor position is updated every second by dual-frequency cinematic GPS with an accuracy within centimeters. Thus, aerial triangulation is greatly facilitated thanks to the use of IMU/GPS measurements. Even with few ground control points (roughly 3 per flight) accurate geometric measurements can be performed [4]. This figure can be compared to the average number of ground control points to be captured per photo, when working with traditional photogrammetry systems.

Digital Surface Model Computation

One main advantage of the PIXEL FACTORY over traditional photogrammetric system lies in the Digital Surface Model Computation. Whereas traditional photogrammetry has to estimate manually elevation information, the PIXEL FACTORY is able to compute automatically a dense DSM with a GSD between 25 cm to 1 meter without any human interaction. Some photogrammetric systems offer automatic DSM computation, but they are not well integrated in an overall workflow process equipped with hardware allowing really mass production with high productivity.

Once images are loaded into the PIXEL FACTORY, algorithms create hundreds of stereo pairs and distribute the computations over available computers in order to parallelize and speed up the automatic stereo-matching. Multi-correlation is fulfilled between along-track and side-lap stereo-pairs. Following this automated point-by-point measurement process, the merged result is a photogrammetrically derived Digital Surface Model (DSM) as shown in figure 3. The elevation estimation is thus far more reliable; at the end, the density of elevation information available is not anymore proportional to the human resources allocated to the image processing. The quality is also homogeneous disregarding the area processed.

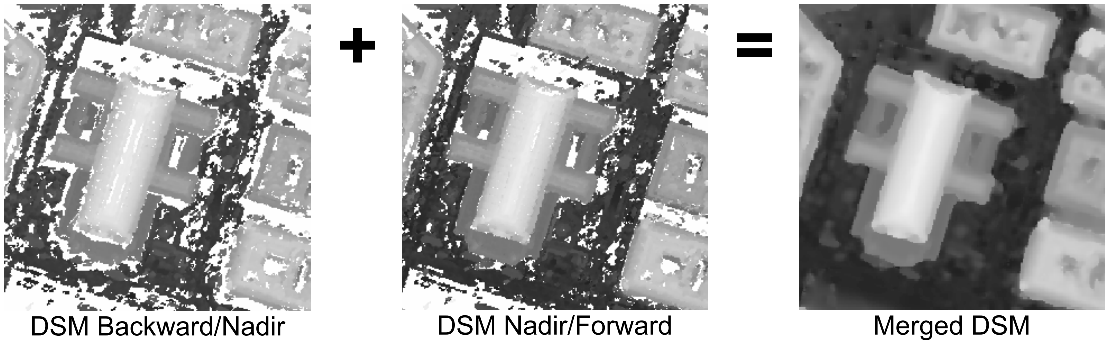

Figure 3: Merging of distributed stereo-matching results (Images are gray encoded DSM)

The elevation information does not correspond solely to the elevation of the bald ground, but takes also into account all the above-ground elements, whether natural or artificial: buildings, bridges, vegetation… The correlation algorithm allows matching the first point of the surface encountered, which is not always the ground. Only this DSM allows performing a true orthorectification of the orthophoto, which guarantees a perfect geometry in any point of the image.

True-Ortho Computation

In traditional photogrammetry, the orthophoto is obtained by rectifying each image individually, then by mosaicking the whole set, trying to minimise the effect of parallax in each image (leaning buildings). In the PIXEL FACTORY, the orthorectification is done in the reverse way: each pixel of the orthophoto to obtain is considered individually, and the best visible point at this very position is determined among the initial images, together with its altitude in the DSM. This operation is fully automated as well as distributed. Such a process guarantees that each point on the ground or above the ground is seen vertically (building leans have been eliminated) with a minimal amount of time and human effort, figure 4. Furthermore, the effect of mosaicking and vignetting, inherent to individual photos usage as in traditional photogrammetry is avoided by this all-in-one restitution algorithm.

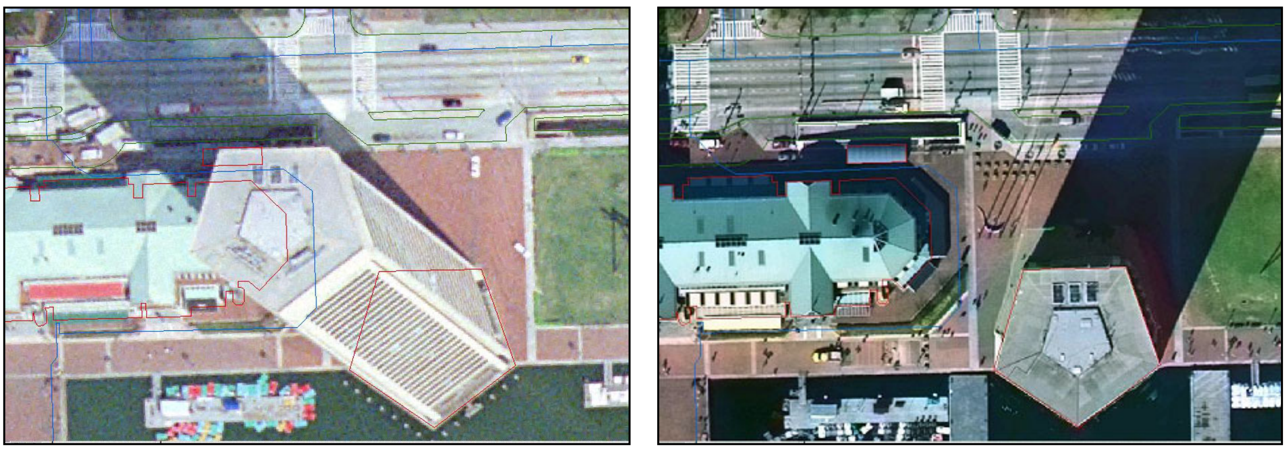

Figure 4: (From left to right) Comparison of orthoimage and true ortho-image (with building outlines overlaid)[3]

Thanks to the simultaneous acquisition of multi-spectral images, the PIXEL FACTORY can output at the same time panchromatic, natural color and false color orthoimages as illustrated in the next figure 5.

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[3] HRSC Imagery copyright ISTAR/DLR, 2002.

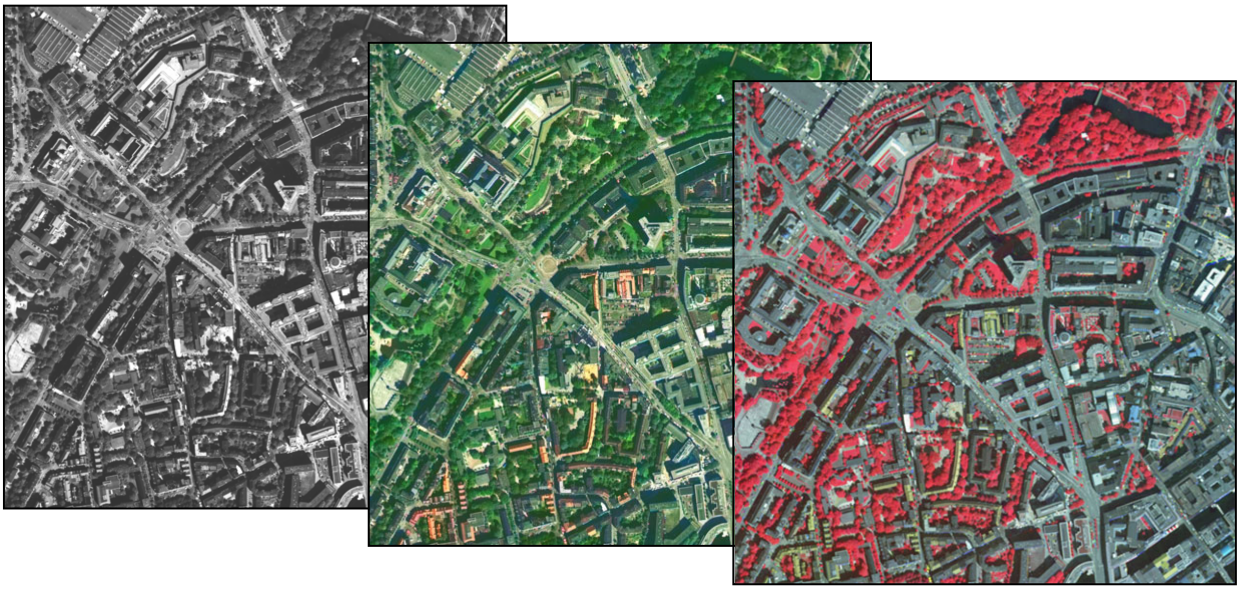

Figure 5: Orthoimages computed with the PIXEL FACTORY at the same time (from left to right: panchromatic, natural color and false color orthoimage with 25cm GSD)[4]

4. CONCLUSION

In this paper we have presented a complete framework named PIXEL FACTORY. Behind this term, is a complex and optimized framework comprised of algorithms, workflows, and hardware dedicated to one goal: mass production of digital surface model and orthoimage (true or ground orthoimages). This system is tailored to new digital cameras like the ADS40 sensor and makes an efficient use of push-broom acquisition, which ends-up with less data to be processed than frame-based acquisition. Thanks to dedicated hardware system (optimized network, cluster of computers, large mass storage) and algorithms, which take into account this hardware architecture, parallel computation is also a great benefit to accelerate the production workflow. To shortly list the main advantages of the PIXEL FACTORY, with digital sensors, over classic photogrammetric systems:

- direct capture of images in digital format,
- simultaneous acquisition of high resolution multi-spectral images,
- easy aerial triangulation,
- automated calculation of the altitude,
- reliability and accuracy of the altitude information,
- true ortho-rectification,
- framework tailored for mass production.

As an example, figure 6 shows the San Francisco Bay area (13000 km² at 1m GSD) which has been produced in less than two months after data acquisition. Another example (in figure 8) is the Grand Canyon (500km long at 25cm GSD) which was produced in 90 days after the flight survey (flight survey done in 30 days).

[4] HRSC Imagery copyright ISTAR/DLR, 2002

Figure 6: True-Ortho over the San Francisco bay (13000 km²) at 1 meter GSD (measured horizontal accuracy: 0.8 m, and vertical accuracy: 1 m)[5]

Automated outputs of the PIXEL FACTORY are possible layers for any further processing, either digital-based or manual-based as depicted in figure 7.

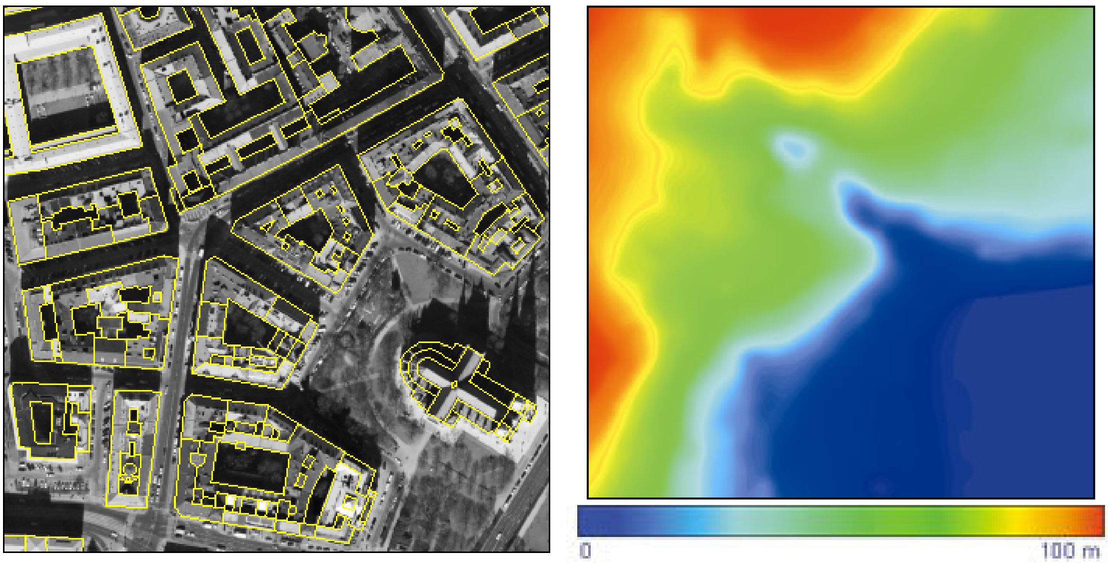

Figure 7: Value-added layers derived from outputs of the Pixel Factory (2D Vectors and DTM)[4]

[5] HRSC Imagery copyright ISTAR/DLR, 2001

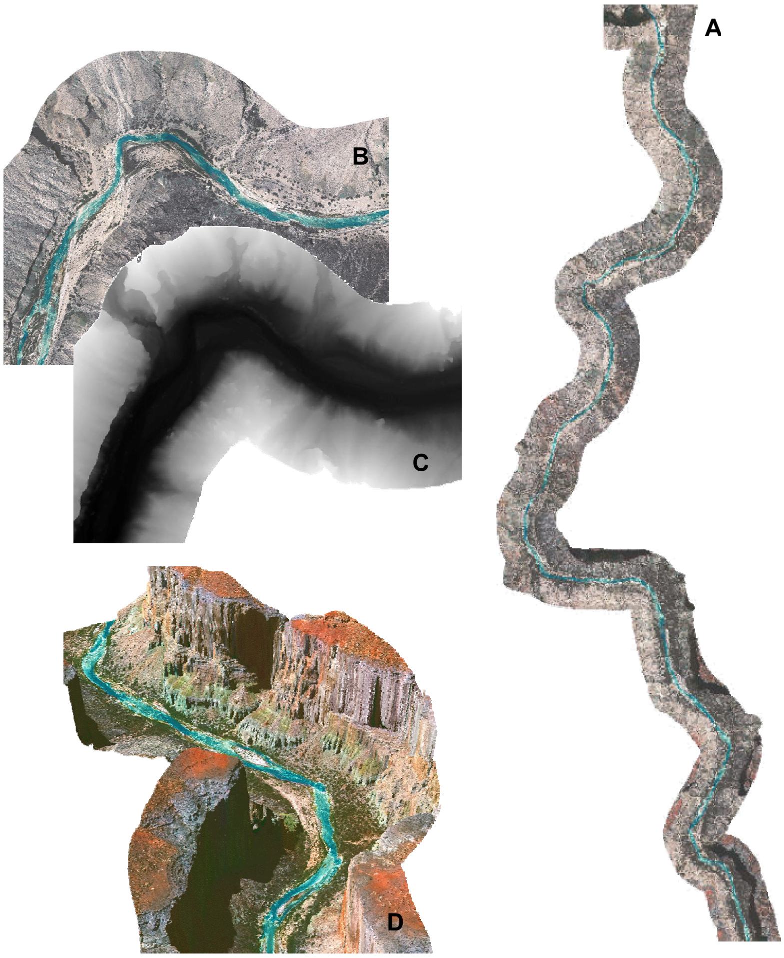

Figure 8: Grand Canyon Products: (A) True natural color orthoimage over whole area at 25cm GSD, (B & C) Zoom over a particular area with the True orthoimage and DSM, (D) Perspective view synthetised from the false color orthoimage at 25 cm GSD (measured horizontal accuracy: 20 cm, and vertical accuracy: 25 cm)[6]

Most commonly required layers [5] include:
- Digital Terrain Model: it can be extracted by semi-automatically filtering the DSM, similar to LIDAR filtering.
- 2D Street vectors: such two-dimensional vectors can easily be edited on-screen, using the True Ortho as a background image, on any inexpensive GIS software. The vector features edited are directly as accurate as their source, the True Ortho.
- 3D Buildings: here again, instead of digitising building outlines in 3D, it's possible to delineate the buildings on the true-ortho and automatically attribute these 2D buildings vector with the altitude averaged from the DSM values.
- Land Use Maps: combining the former layers, together with classification based on the multispectral images, allows producing different types of high-quality Land Use Maps.

Lastly, one important feature of the PIXEL FACTORY is its abilities to handle very different sensors: either analog or digital sensors. As an example, the next figure shows a true-orthoimage computed from data acquired with a helicopter equipped with the STARLABO digital sensor over Yokohama, Japan.

[6] HRSC Imagery copyright ISTAR/DLR, 2002

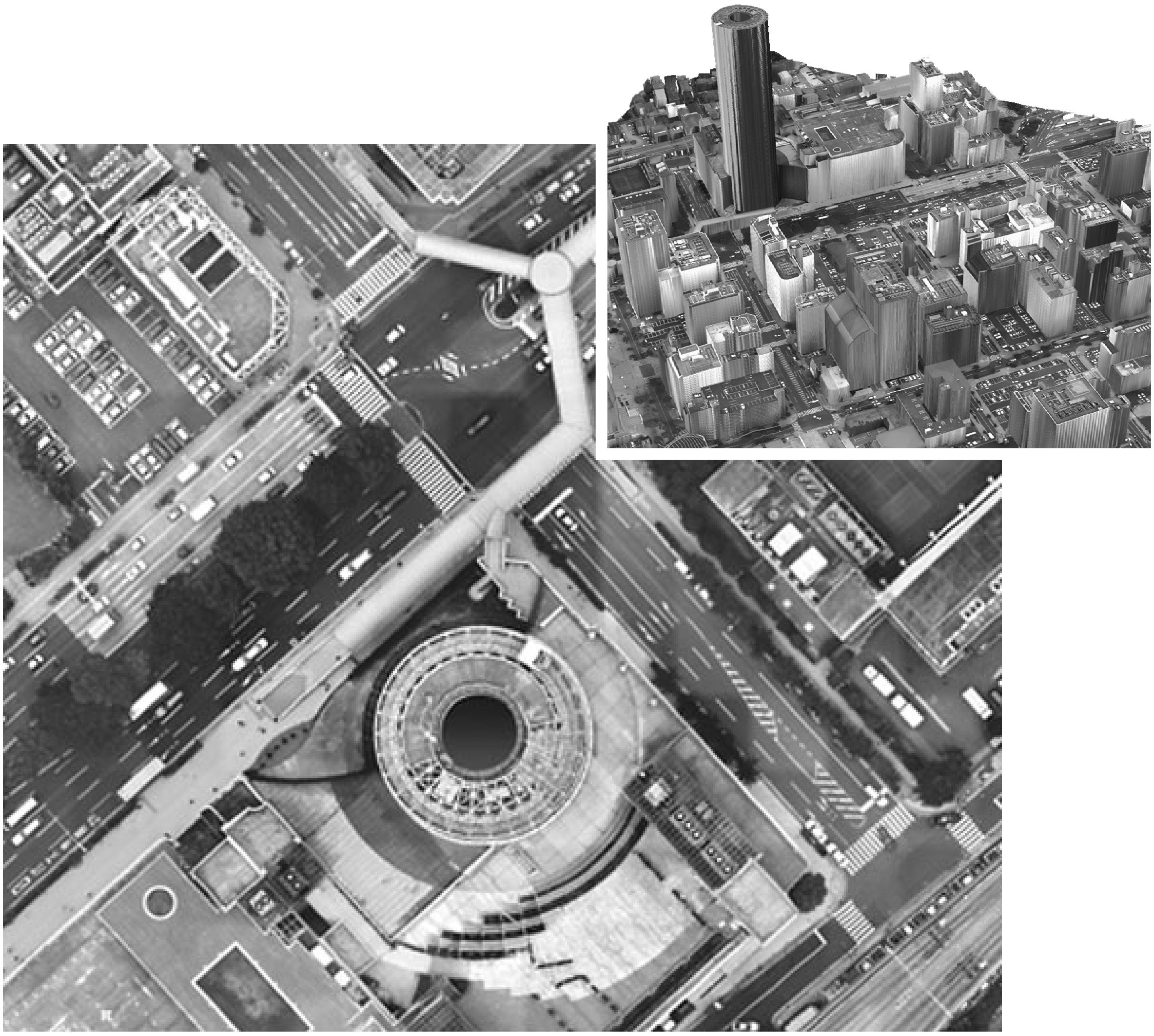

Figure 9: True orthoimage at 6cm GSD and 3D view over Shin-Yokohama, Japan[7]

5. REFERENCES

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[7] Raw imagery copyright STARLABO, Orthoimage made and copyright ISTAR, 2002

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