Some possible protocols of acquisition for optimal use of the “APERO” open source software in automatic orientation and calibration.

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ABSTRACT:

The automatic 3D modelization of scene from an unordered collection of images is now operational in many contexts; several open source software are affordable to people and constitute a cost effective tool for 3D modelization. An originality of IGN’s solution is that it is targeted for scientist who consider the 3D model as a measurement tool rather than a support for communication, this usage require that some minimum protocol are respected during the photo acquisition.

This paper focus on APERO and TAPAS, the calibration-orientation tool of IGN’s photo grammetric suite; we describe the main technical characteristics of APERO and we illustrate, on some case studies, typical acquisition protocol and the main idea of parametrization that will allow their exploitation in TAPAS. These case studies include modelisation of interior scenes using a fish-eye lens, modelisation of distant object using a mix of average and very long (400mm) focal length, sub milimetric resolution modelisation of small objects with macro photography.

# Introduction

The tremendous development of cost effective high quality digital camera and computational power of personnel computers has led, in the past decade, to a very active community of research in photogrammetry and computer vision. Contrarily to what several authors wrote at the beginning of years 2000, the LIDAR has not killed photogrammetry and, in many context, image based solutions are again an effective alternative for 3D modelisation. Several solutions exist now both on the commercial and the open source community.

In this context, IGN has developed a “suite” of free open source photogrammetric software allowing to build 3D models from images. A detailed documentation of these tools can be downloaded on (Micmac 2012). Compared to others open source solutions, like the well known bundler-PMVS pair of tools, the IGN’s tools are currently more complex to use but, we think, also more complete and accurate. Tools targeted for people aim to deal with totally unordered set of image collection, in a push button approach, and consider the 3D model as communication tool that is to be evaluated on the visual aspect. Conversely, our software are targeted for scientific community (architect, archaeologists, geomorphologists ...) who consider the 3D model as a tool to make accurate 3D measurement in a cost effective way.

In this metrologic background, it is necessary that the system can integrate all of the a priori information affordable to the user to maximize the accuracy of the final results. These information can be far more complex than the only tie points between images, non exhaustively it can be : GPS measurements on summit or ground points, acquisition configuration (stereo rig, panoramic images), knowledge on some part of the scene (planes, straight lines) , partial or full knowledge of intrinsic calibration ... Integration of such heterogeneous information require a highly tunable system which lead to some (reasonable) complexity. To take the maximum benefit of these tools, it is also necessary that the user has some very basic notion of photogrammetric constraints so that he can select, for each real scene, an acquisition protocol that will fulfil his objective. But before that, it is also important that the user has some precise objectives, which also one of the main difference between scientifics’ and people’s usage of photogrammetry.

In this paper we describe the main characteristic of APERO, the orientation module of IGN’s pipeline, and we study and several examples how, with a minimum knowledge of the internal organisation, the user can optimize the photo acquisition to fulfil his objective.

# IGN’S pipeline for 3D image based modeling

## Overview of the pipeline.

Like several other solutions (Labatut 2007, Wu 2011, Previtali 2011) IGN’s pipeline for computing 3D models out of an unordered collection of images is made of three main modules. The three modules, common to these pipelines, are:

* First module : computes tie points from non oriented images; it uses algorithm focussing on invariant description of salient points like SIFT, SURF or MSER; when no information on image acquisition is affordable, this computation can be made on all pair of images;
* Second module : computes the orientation of camera, external and internal, compatible with all the observations; these observations can be restricted to tie points outing from the first module, but they can also include many other type of information (GPS, ground control points ...);
* Third module : computes dense matching from images accurately oriented by the second module.

This paper focuses on the second module and on image acquisition protocols that can be used for optimally use this orientation module. The two following section, we describe briefly the first and last module.

## Tie points module.

For the tie point module, we use the SIFT algorithm (Lowe 2004) and, more precisely the SIFT++ (Vedaldi 2010) implementation that has been tuned to work correctly with large images (Le Bris 2010). In our open source pipeline, the tool to compute the Sift-match is named Tapioca. To limit the computation time, the user can specify the following parameters to Tapioca:

* Parameter specifying a downsizing of images; in fact as colour image acquired by camera using bayer matrix are always somewhat noisy, and as sift currently provide much more tie point than needed, there is few inconvenient to downsize the image from a scale between 2 and 3 (this downsizing has to be made cautiously to avoid aliasing);
* Parameter specifying possible knowledge on the acquisition protocol; this knowledge will be used to limit the number of image pairs on which the SIFT matching will be computed (to avoid a computation time in N2, with N images);

For acquisition protocol, the first parameter is a key word that specifies the strategy that is to be used for restricting the computation time. The possible values of this key word are:

* **All** : this mean that there is no restriction and all the pair have to be matched;
* **Line** : this mean that the acquisition has been made following a linear network, in this configuration image K will be matched with images [K-L,K+L] where L is a parameters;
* **MulScale** : specifies a multi-scale strategy; in a first step, all the pairs are computed at very low resolution; only the pairs giving sufficient matches at low resolution are selected for computation at higher resolution;
* **File** : in this mode the user gives a file containing the explicit list of pairs to match; this will be used for example in aerial acquisition were GPS embedded can have be used to restrict drastically the set of possibly recovering images.

Here is some example of using Tapioca to compute tie points:

* Tapioca All “.\*.CR2” 1500 : for all images terminating by “CR2” compute tie points between all pairs, the 1500 parameter means that after downsizing the images have a width of 1500;
* Tapioca Line “IMG\_[0-9]{4}.CR2” 1500 7 : for all image IMG\_ABCD.CR2, where ABCD are digits, compute tie points with “IMG\_abcd.CR2” where abcd are digits so that abcd are in [ABCD-7,ABCD+7];
* Tapioca MulScale “.\*.CR2” 300 1500 : use a multi scale strategy, the low resolution images have a width of 300 and the higher resolution image a width of 1500;

Figure 1 show some typical results of tie points obtained at the end of this process; although there is no perfect solution for tie points, in our experiment the sift algorithm work pretty well; its only real drawback is lack of affine invariance which make the number of tie points decrease fast when the viewpoints are too different.

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**Figure 1** : *First image : in superposition matched sift point on two close images (40 and 42), from left to right the sift point matched over image 40 for image 42, 44, 46, 48, 50 with acquisition described in 4.1*.

## Dense matching module.

Once the tie points are computed in Tapioca (first module) and the camera poses are estimated in second module , a dense point cloud is extracted using the MicMac software (Pierrot Deseilligny 2006, 2011). MicMac was initially developed to match aerial images and then adapted to convergent terrestrial images. The matching has a multi-scale, multi-resolution, pyramidal approach (Figure 2) and derives a dense point cloud using an energy minimization function. The pyramidal approach speed up the processing time and assures that the matched points extracted in each level are similar. The user selects a subset of “master” images for the correlation procedure. Then for each hypothetic 3D points, a patch in the master image is identified, projected in all the neighborhood images and a global similarity is derived. Finally an energy minimization approach, similar to (Hirschmüller 2008) or (Roy 1998) is applied to enforce surface regularities and avoid undesirable jumps.

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**Figure 2:** *Multi-scale, multi-resolution approach at resolution 128, 64, 32, 16; in foreground the computed depth map, in background the images at same resolution; last image shaded model at resolution 1.*

# Description of orientation module

## Input and output of orientation modules.

The tool for computing orientation is APERO, it is a complete and complex tool; a simplified version, named TAPAS exists and is described at end of this section. Basically, like all orientation software, APERO is a computer program that takes as input a set of redundant, and possibly heterogeneous, observations and produces internal and external calibration that minimize the global incompatibility with these redundant observations. The main possible inputs, or observations, to APERO are:

* Ties points between pair of images;
* Ground control point;
* Initial values of internal calibration, these values may come from *a priori* information (xif data), previous computation or from external software, these value may be frozen or freed according to user’s specifications;
* Known position of image centres (for example when embedded GPS is used);
* Known position of orientation and position of images (or of a subset of images), these information may come from instruments (GPS and IMU) or from previous computations;

The main outputs of Apero are :

* Position and orientation of cameras;
* Values of internal calibration;
* Optionally, the value of 3D point observed as tie points can also be exported (for example to create a sparse 3D point cloud).

## Main functionalities and use cases of Apero

The main functionality proposed by Apero are :

* Compute a purely relative initial value to orientation from a set of tie points; this computation is made using the algorithms described in following sections “Tactics” and “strategies” for computing relative orientations;
* Make several steps of compensation, by bundle adjustment, on the current solution to minimize the sum of residuals of all observations; classically, these step are iteration of linearization and weighted least mean square (i.e. Gauss-Newton of Levenberg-Markard descents);
* Use geo-referencing information to globally transform the orientations from relative to absolute; these information can be a set of ground control point (at least 3) or a set of position of camera submit;
* When a physically based orientation is required, but no geo-referencing information is available, use information on the scene; for example use masks specified by the user on a horizontal part of images, to have a orientation where the Oz axis is closed to vertical (see examples on bas relief in next sections); there are also transformation to set the scale of the model.

These basic functionalities can be assembled to fully process the orientation required by application. As example of use case, on can cite:

* 3D modelisation of sculpture for virtual reality application, in this case a purely relative model is sufficient, and the process will only contain initialization and compensation; section 4.1 gives an example of such use case;
* 3D modelization of a globally plane object for measurement, in this case a purely relative model is sufficient provided that it is scaled and that in this model, the Oxy plane coincide the plane of the object. In this case the pipeline will built first a relative orientation, using initialization and compensation; the model will then be rotated and scaled using measurement on the scene; section 4.2 gives an example of such use case;
* Precise 3D geo-referencing using of a large set of images, using ground control point. In this case, after relative orientation as before, the ground control point will be used to transform relative to absolute, then additional steps of compensation will be used mixing all information; section 4.5 gives an example of such use case.

## Some option of APERO and XML interface

APERO aims to be a sufficiently general software for image orientation and there are many options accessible to the user. Among the more frequent options one can cite:

* A wide choice of parametric camera models; for example : radial model, decentric model, Ebner’s and brown model, general polynomial models, specific models adapted to fish eyes (equilinear or equisolid);
* A wide choice of function for weighting the residual during compensation steps;
* The possibility at each step of the compensation to freeze of free each of the unknown;
* The possibility to specify arbitrary groups of images that will share the same calibration unknowns; in particular it is possible that each image has its own unknown of internal calibration; although this possibility is clearly to avoid in general, for obvious accuracy reason, it may be useful when dealing with macro-photo acquisition.

To allow the specification of many bundle adjustment options at each step of the compensation, a hierarchical tree-based format seemed adapted; as we wanted a text-editable format based on existing standards, it was natural to choose the XML format (like with other tools of the pipeline); Figure 3 shows an extract of a very basic parameter file for APERO, used in the example of the documentation. As example of the section present in typical APERO parameter file, on can cite:

* <SectionBDD\_Observation> : in this section all the observation that have to be loaded are described;
* <SectionsInconnues> : this section declare the unknowns and specify the way their initial value must be computed;
* <SectionCompensation> : this section contain the information relative to the weighting of observation during the bundle adjustment.

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| --- | --- |
| <Global >  <ParamApero>  <DicoLoc> <Symb> AeroOut=-Test-0 </Symb></DicoLoc>  <SectionBDD\_Observation>  <BDD\_PtsLiaisons>  <Id> Id\_Pastis\_Hom </Id>  <KeySet> NKS-Set-Homol@@txt </KeySet>  <KeyAssoc> NKS-Assoc-CplIm2Hom@@txt </KeyAssoc>  </BDD\_PtsLiaisons>  </SectionBDD\_Observation>  <SectionInconnues>  <CalibrationCameraInc>  <Name> TheKeyCalib </Name>  <CalValueInit>  <CalFromFileExtern>  <NameFile> Calib-F050.xml </NameFile>  <NameTag> CalibrationInternConique </NameTag>  </CalFromFileExtern>  </CalValueInit>  </CalibrationCameraInc> | ………  </SectionInconnues>  <SectionCompensation>  <EtapeCompensation>  …..  <IterationsCompensation> </IterationsCompensation>  <SectionObservations>  <ObsLiaisons>  <NameRef> Id\_Pastis\_Hom </NameRef>  <Pond>  <EcartMesureIndiv> 1.0 </EcartMesureIndiv>  <Show> eNSM\_Paquet </Show>  <EcartMax> 100 </EcartMax>  <SigmaPond> 5 </SigmaPond>  <ModePonderation> eL1Secured </ModePonderation>  </Pond>  </ObsLiaisons>  </SectionObservations>  …..    </ParamApero>  </Global> |

**Figure 3:** *An extract of a very basic APERO parameter file.*

## “Tactics” for additional relative orientations

One of the critical steps of automatic orientation is the computation of initial value of camera poses. In this computation, a crucial and atomic problem is : “Given a set of already oriented images, use the tie points to compute the initial orientation of a new image in the same coordinate system”. For this first step APERO use three possible algorithms:

* A classical algorithm, based on essential matrix, to orientate pair of images; if the image to orientate is the second image, the scale is set to an arbitrary value, else it is computed using the global set of already oriented images,
* A variant of previous algorithm that work only when the scene is planar; as the standard first algorithm fails in this case, these two algorithms are complementary for the orientation of the first pair of images;
* An algorithm based on space resection that can be used when there are already more than two oriented images; for the multiple tie points of the new image, that are seen in more than two already oriented images, it is possible to compute, by bundle intersection, their “ground position”, in the relative model being built; so using non linear method it is possible to compute the orientation of the new image with only three such multiple tie points; this algorithm is generally much more robust than the two previous one when there are sufficient number of multiple tie points to use it in a robust canvas like RANSAC; it is particularly advantageous with long focal length for which the algorithms based on orientation of pair of images have been proved for long times to be ill-posed and intrinsically unstable (Arthur 1962).

These three algorithms are complementary; as generally it is not possible to evaluate *a priori* which one will give the more reliable solution, APERO test the three solutions given by these algorithm and select *a posteriori* the best solution on robust criteria (based on L1 norms of the angular residual).

## “Strategy” of relative orientation

Using this atomic solution, the standard strategy used by APERO to make a fully automatic global relative orientation is:

* Choice a first image which will arbitrarily fix the orientation and origin of coordinates;
* As long as there remains no oriented images:
  + Select the next image, according to an a priori estimator of the stability that will result from the orientation computation;
  + Compute the orientation of this image relatively to already oriented images, using algorithm leading to direct solutions;
  + Regularly make bundle adjustment on the already oriented image to limit the probability of divergence.

As an estimator of the stability, we analyse for each image the cloud of tie points with already oriented images. We want to select an image where the tie points are numerous and homogeneously spread. The estimator we use is the smallest value of the inertial matrix of this point cloud.

## TAPAS, a simplified interface to APERO

Inside APERO the user can largely modify the previous strategy when required. However, for many applications, if the images have been acquired respecting basic photogrammetric protocols, this strategy can be used without modification. The photogrammetric protocols include :

* Sufficient overlap;
* When using long focal, add sufficiently wide angle overlapping images to stabilize the equations;
* Is the scene is plane, or if the acquisition may have insufficient overlap, make a pre-calibration of the camera.

When the standard strategy is usable, TAPAS is a simplified tool that allows using APERO in a very simplified way; it’s a command line program that takes few arguments. Here are some examples of using TAPAS:

* Tapas RadialExtended "IMGP[0-9]{4}.JPG Out=Init" : compute the orientation of all jpeg images using a radial model for distortion, save the result in Init directory;
* Tapas FishEyeEqui "IMGP41([0-9]{2}).JPG" InCal=Tmp1 Out=all : compute the orientation of jpeg images between 4100 and 4199, using a linear fish eye model, for the initial value of calibration import the results stored in Tmp1 directory.

# Some protocols

All the images illustrating this section have been acquired with a canon EOS 5 D Mark II camera (21 M pixel, 24x36 mm sensor); various lenses have used, they were all fixed focal length (no zoom); the images come from different sites in Luxor; generally for these close range application in cultural heritage, the focus has to be adapted to each site, consequently it is not possible to use a laboratory calibration.

## Acquisition for 3D models of sculpture.

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**Figure 4** :  *Head of Ramses II acquired in Ramesseum : 35 image acquired with a 50 mm, position of camera, and point cloud of full 3d model.*

Figure 4, present the 35 images acquired for the 3D modelisation of the ramses II head (head is around 2.5 meter high); the protocol is very basic, it can be summarized by “turn around the object and take regularly sufficiently many picture”, to fix thing, taking a picture approximately each 10 degree is sufficient ; Figure 5 present the position of the camera (as computed with APERO) and the final result of 3D model; the requirement to use this protocol is :

* It’s possible to make a circle around the object;
* The level of detail given by a single image is sufficient (else some panoramic with long focal will be required as in 4.3);

To make the orientation of this object, we have used the commands:

* Tapioca Line “.\*.CR2” 1500 5 Circ=1 : for computing tie pointts;
* Tapas RadialExtended "IMG\_023[3-9].CR2 Out=CalibInit" :
* Tapas RadialExtended "IMGP[0-9]{4}.CR2 InCal=CalibInit Out=Init"

The first call to Tapas, is made with a small group of 7 images (0233 to 0239 here); this group is chosen to be favourable to internal calibration : having sufficient depth (for focal and principal point estimation) and texture in all image (for distortion estimation); the computed internal calibration is then used as an initial value in the second call to Tapas. If one does not use this two step procedure, the error accumulation in orientation estimation along long chain of image can be high (due to bad estimation of internal parameters); this can lead to divergence, especially when closing the loop.

## Acquisition for bas-relief modelization

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| D:\EuroCow\ImBasRelief\AperiCloudSnap00.png |

**Figure 6** : *Acquisition for bas relief: two of the parallel image, one of the oblique images, position of camera and the depth map.*

Figure 6 present some images acquired for a bas-relief modelisation. For this kind of object the “optimal” configuration of image for the matching step is very similar to those used in aerial photogrammetry :

* A set of 60x60 overlapping images, parallel to principal plane of the bas relief;

There is no problem for computing the orientation of such scenes, due existence of algorithm specialized for planar scene. The possible difficulty comes from the following conflict:

* On one hand, if the images are taken “too” parallel to the scene, the focal and principal point can be set free : it is well known that the focal length cannot be computed; so letting the focal free, would lead to a divergence;
* On the other hand, if the images are not exactly parallel to the plane, and the focal is not precisely known, it must be re-estimated; else the orientation will not be suitable for matching.

The protocol we use to solve this conflict is to add several oblique images of the bas relief. These images will be used for the orientation step (but generally not the matching step), they create depth in scene and allow to free all the internal parameters.

To make an optimal matching of these image, it is preferable to orientate the images in system where the plane of the bas relief coincide with plan Oxy; once a first relative, orientation has been done, these can be done accurately by fitting the plane on 3D estimation of tie points. The auxiliary program Bascule, furnished in the open source distribution, can be used for this.

## Acquisition for 3D model using long focal lenses.

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| D:\EuroCow\ImPilier\TIMG_0220Detail.JPG |

**Figure 7** :  *Pillar in ramessum : a 35 mm image, a 100 mm image of the capital and a detail of this image, two view of camera position.*

Often it is impossible to take image sufficiently close to the object to get the desired resolution; in this case, long focal can be a good solution. The basic idea is simply to take some approximate panoramic photo from different view point; each set of panoramic will add the information equivalent to a very high resolution wide angle camera. However, using only long focal can lead to several problems:

* With narrow angle camera there is higher correlation between internal parameter (Stamatopoulos 2011) and the relative orientation of two camera by essential matrix is quite instable; in fact it is known from long time that the problem is intrinsically ill posed (Arthur 1962) and that in the limit case of infinite focal one angle can be determined;
* Taking the image a panoramic each 10 degree to assure of having a converging orientation, would lead to huge set of images.

To avoid these difficulties the protocol we use is:

* Acquire a first set of images with a wide angle lens using the protocol described in 4.1, these images will be used only to facilitate and stabilize orientation;
* Acquire only the pseudo panoramic images that will be used for matching.

With such a protocol, the orientation is made in two step, for example with Tapas on can type :

* Tapas RadialExtended ".\*.CR2” Out=Init Focs=[35,35];
* Tapas RadialExtended ".\*.CR2” InOri=Init Out=All;

In the first step, only the image acquired with the 35 mm lens are oriented; as it is a wide angle camera and the canvas is sufficiently dense, this works well. In the second step all the images are oriented, for the 35mm we start from the previous solution; so the orientation of 100mm is facilitate because generally there is sufficiently multiple tie points with 35mm to compute the initial value of orientation using space resection. Figure 8 present the 3D model of the capital computed from 100mm images.

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**Figure 8** :  *3D model of the capital computed from 100 mm images : point cloud and shading.*

## Acquisition for photo rectification

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| D:\EuroCow\ImKOrtho\Planche.jpg | | | |

**Figure 9** :  *Up a 35 mm image, two 100 mm images forming one the 100mm panoramic, camera position; bottom the 23 images used for the 400 mm pyramid.*

In architectural context, one of the main products of photogrammetry is mosaic of rectified images. It often happens that the object is globally flat, but not sufficiently to make a simple rectification on a global plane. In this case, a good quality-time compromise to make a rigorous rectification is to compute a DTM at relatively low resolution, and to rectify the high resolution images on this low resolution DTM. Figure 9 shows some image of an acquisition made in Karnak temple to create a very high resolution ortho mosaic of the pylon. Three focal lengths have been used:

* A 35 mm focal length has been used for acquiring five convergent images, these image give some photogrammetric solidity to the bloc
* A 100mm focal length has been used to create the digital elevation model; four panoramic have been acquired, each contains only two images;
* A 400mm focal length has been used to create the texture of the ortho photo; a single panoramic of 23 image has been acquired.

The orientation is made in three steps, in a way similar to example 4.3 : first orientate only the 35 mm, then orientate the 35mm and the 100mm, finally orientate all the images. Figure 9, show some images and resulting orientation, figure 10 show a global view of the 400 ortho mosaic.

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**Figure 10** :  *Orthomosaic with 400 mm images.*

## Acquisition for interior scene modelization

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| D:\EuroCow\ImGlob\TIMG_4858_GlobPartC.JPG | D:\EuroCow\ImGlob\TIMG_4859_GlobPartC.JPG |

**Figure 11** :  *Meremptah tomb : a Map and four consecutive fish eye images.*

For the global modelization of interior scene, it is generally more convenient to use wide angle lenses because:

* It decrease the number of images to acquire and process;
* The block are more solid as the correlation between internal and external parameters decrease when the angle increase; furthermore, it allows wide overlap between images which also consolidate the block;

Fish-eye lenses are the extreme case of wide angle lenses as their opening is currently 180 degrees in the diagonal. Fish eye are rarely used in traditional photgrammetry because of their high distortion; however this distortion can be modelized with a physical model in arctangent combined with classical polynomial model as (Fraser 1997); in our experiment, with this model the orientation of images can be done with residuals comparable to classical lenses.

The meremtpah tomb is a typical Egyptian tomb, its general form is a corridor of 150 m length and 3 meter width with several room (see figure 11 for a map); we needed a global 3D model of the tomb as a canvas to reference the detailed ortho photo acquired for the archaeologists. For the corridor we have acquired more than 300 photo with a 15mm diagonal fish eye (see figure 11), regularly spaced; the command to generate the orientation was :

* Tapioca Line “IMG\_[0-9]{4}.CR2” 1500 7
* Tapas FishEyeEqui “IMG\_041[0-9].CR2” Out=Calib
* Tapas FishEyeEqui “.\*.CR2” InOri=Calib Out=All

The first line compute the tie point and exploit the linear structure of the acquisition canvas to limit the number of pair tested; the second line compute an initial calibration with a small subset; the last line compute all the orientation; the FishEyeEqui means that we select an equilinear (in arctangent) fish eye model as first approximation.

When required, this fish eye acquisition can also be used to compute dense 3D models. Figure 12 some result of this orientation and a small example of dense match.

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| D:\EuroCow\ImGlob\AperiCloudSnap01.png | | D:\EuroCow\ImGlob\NuageImProf_Geom-Im-5081_Etape_6Snap00.jpg |

**Figure 12** :  *Orientation of fish eyes in Meremptah tomb; up: two views of the point cloud, bottom: view of the camera canvas and dense 3D model on a part of a room.*

# Conclusion

This paper has described some aspects of IGN’s open source photogrammetric suite with a special emphasize on APERO and TAPAS the orientation software. An originality of IGN’s suite, compared to other open source solution, is that it is intended for professional; we believe that, such audience can accept a limited complexity in these tools if they satisfy their professional requirement in term of accuracy and density of information.

To take a real benefit of any image based modelization tool, it is essential that the user optimizes the acquisition protocol according to his objective and some “fundamental” rule of photogrammetry. In this paper, we have presented on some case studies the typical precautions that should be observed during photo acquisition to assure a good orientation with our tools; this case studies includes : long focal lenses for long distance high resolution acquisition, orientation of plane scenes and usage of fish eye lenses for interior modelization. A complete documentation of these tools can be downloaded on (Micmac 2012) and more detailed case studies can be found on (Tapenade 2012).

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