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D2.4 Prototypal software for Rapid Mosaicking.

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Content

1 Task objective and output indicator 5
2 Archaeological requirement and preliminary choices 6
3 VENUS specific problematic and specific choices 7
4 State of the Art 8
4.1 Free photogrammetric software 9
4.2 Mosaic tools used in earth survey 9
4.2.1 Introduction 9
4.2.2 Visual Mosaic 10
4.2.3 Orthophoto 11
4.2.4 Georeferenced Mosaic 12
4.2.5 Conclusion 15
4.3 Mosaic tools in underwater exploration 16
5 Software component description 18
5.1 Photograph orientation from ROV navigation data 18
5.1.1 Exif metadata format 18
5.1.2 Integration of ROV navigation data in Exif metadata 19
5.2 Georeferrenced images generation 22
5.3 Georeferrenced image formats 22
5.3.1 Geotiff format 22
5.3.2 World file format 24
5.4 Mosaicking algorithm 25
5.4.1 Goal 25
5.4.2 A four step mosaiking process 26
5.4.3 Details 29
5.4.4 Overlapping reduction 29
5.4.5 Filling in holes 29
5.5 Mosaicking interface 30
5.6 VRML export 31
5.7 Connectivity map export 31
5.8 Import/Export data file with ARPENTEUR 31
5.9 Results: close the loop with new wait point for ROV 31
6 Using the mosaic tool during the mission in Marseille 32
6.1 Document produced on board. 33
6.1.1 2D GEOTIFF mosaic. 33
6.1.2 2D VRML mosaic. 36
6.1.3 3D VRML trajectory. 36
6.1.4 Connection Table and overlap check. 38
6.1.5 Archaeologist sketch 40
6.1.6 Full accuracy navigation data 42
7 Rapid Mosaic generator software: user manual 43
7.1 Interface Description 43
7.2 Mosaic generation 45

7.3 Generating and exporting data 49
8 References 49

EXECUTIVE SUMMARY

This report describes the first version of a software producing automatically orthophoto georeferenced from photographs taken by ROV (Remote Operated Vehicles) using the navigation data.

The software allows directly extracting the navigation data embedded in the photographs, rectifying each of them and finally produce a mosaic in Geotiff. (Georeferenced TIFF).

A simple GIS (Geographic Information System) allow the user to display the seabed mosaic and read/store absolute coordinate.

The goal is to be able, a short time after the ROV is picked up from the water, to see if the survey was correct (without not photographs covered zone for example) and to define specific zones to be studied in detail by picking way point on the mosaic.

1 Task objective and output indicator

At the end of the first year of the VENUS project, at the steering committee meeting, it has been agreed to modify the task 2.4 (originally titled *"Absolute underwater photogrammetric orientation"*) in a task titled *"Rapid mosaicking"*, keeping the same men-months and the same financial involvement.

The task 2.4 had been originally defined to ensure that the acoustic and optical data could be expressed within the same reference system. The method initially envisaged was relying on the morphological correlation among the two different terrain representations obtained from the acoustic and optical data, involving the scientific challenge of matching two representations at very different spatial scales (a factor of three orders of magnitude, from the meter to the millimeter).

By means of the integration of both optical and acoustic data acquisition systems within the same localization and tracking system, the work carried out by the partners ISME, COMEX and CNRS during the first year has allowed solving this data-blend problem without having to correlate the two different representations. This development, which was planned in the project proposal stage, has been successfully tested in the field during the Pianosa sea trial.

During the same sea trial, the work between the technological teams and the archaeological teams emphasized specific needs of archeologists. In addition to the precise documentation of the site which is usually available some months after the field trial, archaeologists also need a rapid draft representation of the site in order to adaptively change the survey plan and get a better control of the field activities. These emerging needs are not covered by any of the Venus activities in the original work plan.

As a consequence, the partners have agreed to transfer the efforts of the original Task 2.4 to a method for producing a fast photomosaicking of the surveyed area. This new task will be titled *"Rapid mosaicking"*, and will follow the schedule of the previous Task 2.4 (i.e. should be finalized at month 24). The later will produce a representation of the explored site as a mosaic of still camera images based on:

- The orientation parameters of the camera as read from the ROV navigation system
- The absolute positioning of the ROV as determined from the acoustic navigation

The outcome of the mosaic will then be metric and georeferenced, hence immediately loadable into any GIS system that accepts GEOTIFF images.

The proposed deviation from the original work plan has been discussed and formalized by the partners at the end of year 1, and was discussed with the responsible EU officer at the 1st year revue meeting in September 2007.

2 Archaeological requirement and preliminary choices

In most of cases, information about uninvestigated underwater archeological sites is fuzzy, notably regarding to the nature and the localization of the artifacts to identify. In order to optimize time and mission costs, the construction of a preliminary map of the site turns out to be a crucial task impacting the success of an archaeological mission. Indeed, from a preliminary map analysis, archeologists can define a restricted area of interest, waypoints and eventually identify targets that require special attention.

This deliverable reports a software production developed to answer to an important archaeological need which is to get a draft map of the site at the beginning of a mission in order to start preparing the campaign. We have tried to answer this question by means of an orthophoto at a given scale and a geo-referencing mosaic that allow us to pick point onto the map and compute a road with waypoint for the next ROV or submarine exploration.

The final goal is to produce a fine and accurate digital terrain model of the seabed with measured artefact model but also 2D documents easier to read and often enough definite for assisting archaeologists to analyse the site. The work produced in the WP 2 will answer these questions: deliverable 2.5 we report a 2D GIS tool with accurate position and representation of artefact; deliverable 2.3 report on an accurate and dense could of 3D points with orthophoto production and the work presented here is a non accurate geotiff production (georeferenced orthophoto) with a minimum computing effort.

The first idea was to produce a 2D mosaic using only the image collected by the ROV during the first immersion on the site. A lot of work has been done already on this ([1], [2], [3], [4]), but most of them are done in 2D using homologous points on pairs of photographs. Some of them are close a photogrammetric orientation but this approach is done in deliverable 2.4 and is too much time consuming for the purpose of this task.

We decided to use the on board navigation data without any 3D points or homologous 2D points on photographs. The proposed approach produces a geotiff file of the site, using all the photographs and without any computed points.

The main idea is to use the approximate orientation of the photographs 6 parameters, Translation and three angles, (X, Y, Z, Omega, Phi, and Kappa) and the average depth of the seabed given by the ROV navigation data combined with camera calibration data. (this depth give an approximation of the ROV altitude). First the photographs are projected onto a plane representing the seabed, second a treatment is done to compute polygonal intersection of the projected photographs, third photographs are merged and the complete and absolute perimeter is used to compute the Geotiff parameters.

A set of document are produced (2D and 3D, they will be listed in the next section) in order to check the navigation data as well as produce a georeferenced orthophoto of the site in order to start immediately the archaeological work. In addition the output documents generated by this software will be a considerable help for the photo orientation module developed in Deliverable 2.3 (connectivity table between photographs for example).

3 VENUS specific problematic and specific choices

The particular conditions of the data acquisition in the framework of Venus project makes it difficult to use of existing software to obtain quickly an orthophoto of the site. These conditions are very similar to the initial condition of deliverable 2.3: both mosaicking and photogrammetric process need correct overlap between photographs.

Some of the mains problems and difficulties are:

- ROV guidance is always difficult, even with some automatism and mainly because we have to go slow (we have to fly close to the seabed because of the water opacity and in consequence the speed has to be slow because the flash frequency can't be too high, approximately 1 Hz,). ROV guidance difficulties mean trajectories with permanent changing heading and in these conditions a possible rotation around the axis of view. This means the survey is not organized in regular and linear strip.
- The "flying" altitude of the ROV is difficult to maintain constant, it is easier to maintain depth but that means generally the distance between seabed and ROV will not be constant. The main consequence is a scale variation from a photo to another and this makes the rectification scale not constant. In order to have a relevant rectification we need to associate to each photograph also the altitude.
- The two last problems, uncertain trajectory and altitude, make difficult to have correct overlap between photographs (each point have to be seen on at least 3 photographs with more than 10° intersection angle). The solution used is to increase the number of photographs, more than necessary to be sure to have the mandatory overlap. This produces a huge quantity of photographs which make not easy the management of all these data.
- The need is to produce a 2D site-metric document with qualitative information coming from photographs. Site-metric means the relative position for two photographs on two opposite border of the site have to be determinate with the navigation data accuracy.
- We need also to have short time process in order to obtain an orthophoto in less than one hour to be able to make quickly a complement in case of lack of survey. The ROV is still on board ready to make another dive until the operator have checked the rapid mosaicking generated.
- More generally we need to collect and organise data and knowledge on how the photographs have been taken: overlap, connectivity between them etc…

To solve these problems we use a several point strategy as described below. This show the term of Rapid Mosaicking chosen for this application is a metonymy. In fact the development presented here covers a wide panel of application, from hardware (collecting navigation data and connection with the digital camera), image rectification, 2D/3D visualization, GIS interface to interface for photogrammetric automatic orientation tools developed in Deliverable 2.3.

- For each photograph taken we store the approximate position and orientation given by navigation tools. These data are stored on the fly in the exif field of the photographs. (hardware and software developed to communicate with the digital camera while shooting)
- For each photograph we need also to compute, on the fly, the altitude from the seabed (in addition of standard depth) to compute the local photo scale. This data is also stored inside the exif filed.

- The rotations angle given by navigation data with the computed scale are used to rectify the image and compute an absolute georeference. (image rectification module already exist in the ARPENTEUR package)
- All the rectified image have to be merged in a single frame in order to detect hole or lack of overlap. All this have to express in latitude/longitude as well as in Cartesian system (UTM zone xx) to be coherent with the navigation data (coordinate have to be inserted in the ROV navigation data tool to be able to make complement only of the lack zone) (developing a GIS interface based on JAVA/ Geotool library easily conectable with pre-existing software, ie Arpenteur, or development done in other deliverable as for example D2.3 with the automatic orientation module, yet under development)
- As there is a big overlap and a huge quantity of photographs we need to merge these photographs in order to obtain a clear mosaic. As these photographs are not accurately oriented, (the orientation is only coming from navigation data) a traditional merge process should give non accurate and convenient results. (Because a blend between photographs will show the same detail in different place due to the approximate orientation). The developed merge module compute the final mosaic using always only one photograph for each produced image pixel.
- This final product is able to manage more than 600 hundred photographs, choosing the photo used for the final mosaic, quick overview of the site is offered through a photo mosaic and/or a view of the photo frame projected on the seabed.
- The final product exports the selected photographs as a photogrammetric model which can be used with the software developed in Deliverable 2.3. ie, using SIFT algorithm for homologous point determination, automatic densification and orthophoto and finally automatic orientation.
- The final product exports the selected photographs also in VRML in two different modes: All the photographs are projected on a flat seabed and all the photographs can be seen in 3D space. This gives a very interesting way to check the navigation data and the possible lack of survey.
- Finally the rapid mosaicking software produce a shape file format which allow consultation using common GIS software (GRASS, ARC VIEW, etc..)
- The final product generates two 3D point ASCII file: the first one is the optical center of all the photographs, the second one is a set of point on the seabed directly coming from navigation data: for each photograph X,Y from the optical center and Z is the Z photograph coordinate minus the measured altitude. This last file give immediately and approximation of the seabed.
- Finally the rapid mosaicking software produce two file to manage the connectivity between photo: a JPEG image of the seabed with a color code according to the number of photographs who see the seabed and an ASCII file which describe the connection between photograph (one line by photo, first column the target photo and on the same line all the photo who have and intersection with the target.)

4 State of the Art

According to the VENUS specifications, we had several possibilities for implementing this project: starting from a GIS application and adding some development in photogrammetry (image rectification, connection with Arpenteur framework) or starting from a photogrammetric tool and developing improvement in GIS direction in accordance to the connection with Arpenteur.

We have chosen the second way, starting from the Arpenteur package, to be sure to be fully connected with software developed in WP2 and adding GIS capability using an Open Source library: GeoTools, available in java and so easily mergeable with the existing code.

There is a lot of open source GIS solution, the choice of Geotools, as a low level platform, allow us to use the GIS capabilities inside our already existing development. On the other hand, we don't have a lot of open source photogrammetry software. Some package in Matlab, some code for camera calibration in C++, but not a photogrammetric suite as we are developing.

Finally, the use of Open Gis tools allows us to be also compliant with other existing GIS software.

4.1 Free photogrammetric software

The main axis of this rapid mosaicking software belong to photogrammetry, rectification, metric mosaic and orthophoto are mainly in the field of photogrammetry even if at a small scale, a territorial scale, GIS software are doing similar task.

Indeed there is a lack of Open Source photogrammetric software and this one of our motivation to propose in Open Source our photogrammetric development in Java.

We can therefore mention some existing open source software as The Camera Calibration Toolbox for Matlab: http://vision.caltech.edu/bouguetj/calib_doc/

Or a Bundle adjustment in C/C++ Package Based on the Levenberg-Marquardt Algorithm http://www.ics.forth.gr/~lourakis/sba/ and a wide set of software in the framework of computer vision http://www.cs.cmu.edu/~cil/v-source.html

4.2 Mosaic tools used in earth survey

4.2.1 Introduction

We propose in this section of study of available solutions and software that can be used to generate a photographic overview of a submarine site.

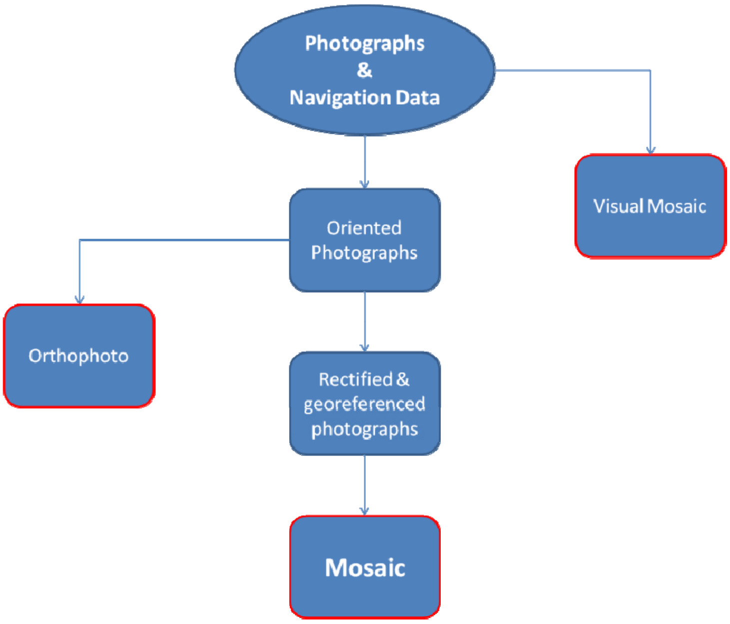


Figure 1 different overview available and the steps to obtain them

As we can see in, the data available in Figure 1 the data available at the end of the underwater photogrammetry acquisition are a set of photographs and a set of navigation data containing photographs orientation given by onboard devices. From this data, three photographic overviews can be generated:

- A visual mosaic and can generated by assembling the photographs by using only images similarity and imagery algorithms. Software like Adobe© Photoshop can make such a visual mosaic.
- An orthophoto can be obtained by orienting the photographs and construct a textured terrain mesh. The orthophoto is an overview of the site where the objects are not submitted to the perspective. Software like PhotoModeler enables to orient photographs and to produce an orthophoto.
- The construction of a Mosaic (metric mosaic) is more complex and requires the orientation of the photographs but also their rectification and georeferencement. There is at this time no solution available to produce a metric mosaic from a set of non oriented photographs. However, GIS systems like ArcGIS or Grass can generate a georeferenced mosaic from a set of rectified and georeferenced photographs.

We now describe the way to obtain the three overviews by using common software. We then discuss the convenience of the three methods.

4.2.2 Visual Mosaic

The construction of a visual mosaic relies only on images algorithm. The software Adobe© Photoshop has a module dedicated to the construction of a visual mosaic. The way to create the mosaic from a set of photographs is given here (we used Adobe© Photoshop CS4):

1. Open the “*File*” menu.
2. Select the sub menu “*Automate*”.
3. Click on the “*Photomerge…*” item.
4. The photo merge dialog appears (Figure 2).

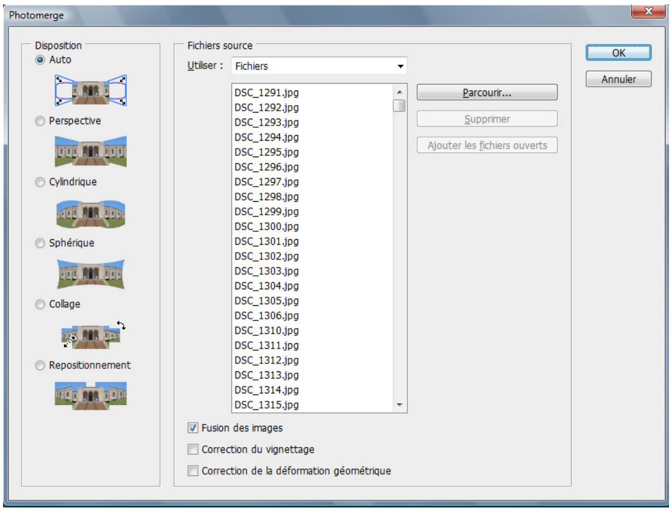


Figure 2 Adobe™ PHotoshop CS4 photo merge dialog

5. In the "*Layout*" panel choose "*Auto*".
6. In the "*Source files*" panel, select "*Files*" for the "*Use*" field.
7. Use the "*Browse…*" button to select the photographs to use for the mosaic process.
8. Click on the "*Ok*" button.

The creation of such a mosaic is quick and visually efficient. The result can be obtained in a short time but only visual aspects are taken in account, no metric information available.

Of course we have since a few years (since the publication of SIFT algorithm by Lowe) a lot of panorama software (no so much dealing with real mosaic). We can cite for example Hugin (http://hugin.sourceforge.net/tutorials/two-photos/fr.shtml) or Auto pano SIFT (http://user.cs.tu-berlin.de/~nowozin/autopano-sift/) from Sebastian Nowozin.

The problem with this kind of software, every day more powerful, is that most of them are thanked in 2D: the final mosaic is not metric and can't be easily georeferenced.

In fact we use SIFT algorithm in the development of automatic photograph orientation already shawn in Deliverable 2.3.

4.2.3 Orthophoto

An orthophoto is a photograph that has been geometrically corrected. The scale of the photograph is uniform and the photo can be considered equivalent to a map. The strength of an orthophoto or photograph is that it is 'to scale' and can be used for measurement. That is if two objects are the same size in the orthophoto that means they are the same size on the real object (for objects parallel to the projection plane). Orthophotos can be created with a specific scale so an object can be measured in the orthophoto and provide its size in the real world.

An orthophoto is a projection of the 3D model onto a plane using parallel projection. That is, all the rays of projection are parallel to each other and also perpendicular to the plane. The 3D model is assigned photographic data for every part of its surface and it is this photographic data that is projected. The result of this process is an image. Many advanced 3D computer graphic rendering and animation programs accept texture images for mapping onto surfaces. The goal in using textures is to improve the realism of the rendering or animation.

The PhotoModeler software enables to produce an orthophoto from a set of oriented photographs. The orientation phase can be done manually within the software. The generation of is done by following these steps (from an active PhotoModeler project):

1. In the "*File*" menu, select "*Export Ortho Photo…*"
2. The orthophoto dialog box appears (Figure 3)

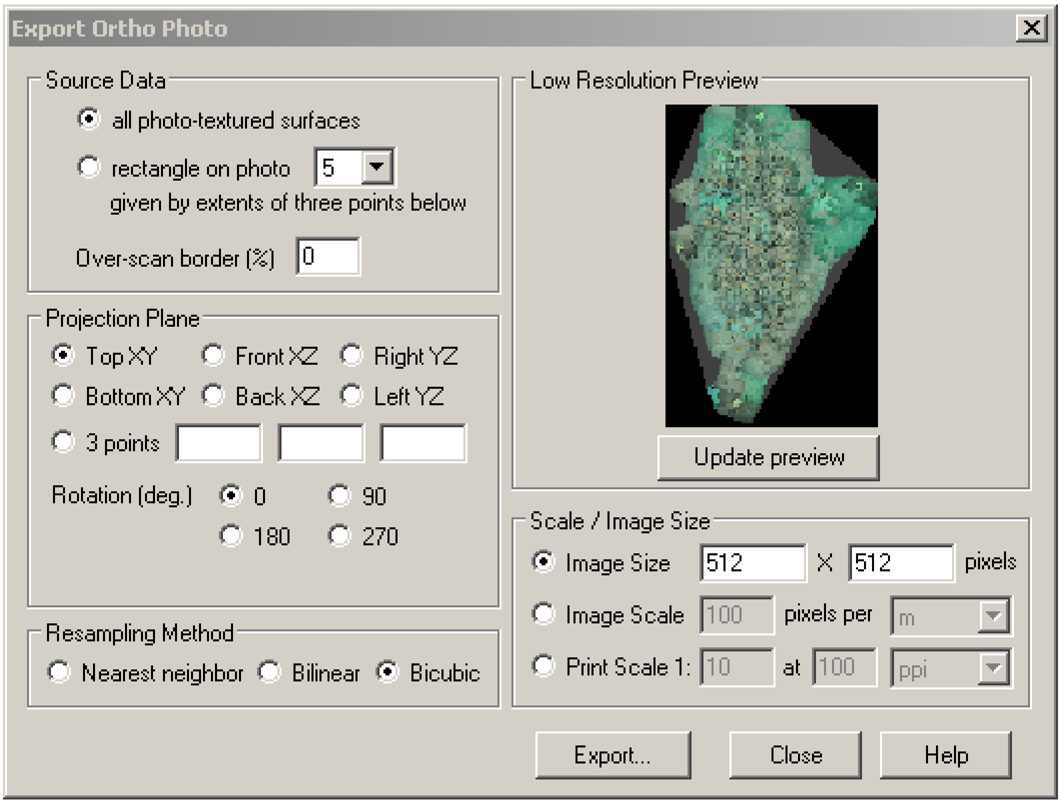


Figure 3 PhotoModeler orthophoto dialog on the Por Miou C survey made during the mission in Marseille.

3. In the panel "*Source Data*", select "All photo-textured surfaces".
4. In the panel "*Projection Plane*", select the wanted plane (by default "*Front XZ*")
5. A rotation can be applied to the orthophoto, by default; no rotation is done (0 deg).
6. In the "*Resampling Method*" panel, choose the method to use:
   - ✓ *Nearest neighbor*: The fastest method with low quality
   - ✓ *Bilinear*: A method providing quality despite a less efficiency in time
   - ✓ *Bicubic*: The best quality but a more expansive processing time.
7. In the "*Scale / Image Size*" panel, specify the wanted orthophoto size in pixel.
8. Click on the "*Export…*" button to launch the process.

The orthophoto is a metric overview of a whole site. However, even if the metric information is correct, the orthophoto is not georeferenced. The generation of the orthophoto relies also on oriented photographs and at this time, there is no software that can orient automatically and efficiently a set of photographs, even with navigation data. The construction of an orthophoto with PhotoModeler needs a manual orientation phase that can take 1 to 2 months long or the development of software that can orient automatically the set of photograph using navigation data and export the oriented photographs in a format that PhotoModeler can handle (the PhotoModeler software cannot be enhanced with plugins or extensions).

4.2.4 Georeferenced Mosaic

The georeferenced mosaic is the most suitable representation for a metric overview of a site. This representation enables to have a visual overview and provide metric and cartographic capabilities. The common GIS systems enables to generate a georeferenced mosaic from a set of georeferenced images.

4.2.4.1 ArcGIS Desktop 9.2

The ArcGIS desktop suite enables to create a georeferenced mosaic from a set of georeferenced raster image. The creation of the georeferenced mosaic is done using ArcCatalog component as follows (source http://webhelp.esri.com/arcgisdesktop/9.2/):

1. Right-click the existing raster dataset that will contain the mosaic, point to "*Load*" menu, then click "*Load Data…*" item. The Mosaic tool dialog box appears (Figure 4).

   OPTIONAL: If the "*Load Data…*" item is not available, the pyramid for selected raster has to be created. For this, right click on the raster dataset and choose "*Build pyramids…*". After that, the "*Load Data…*" item should be available and the step 1 can be performed.

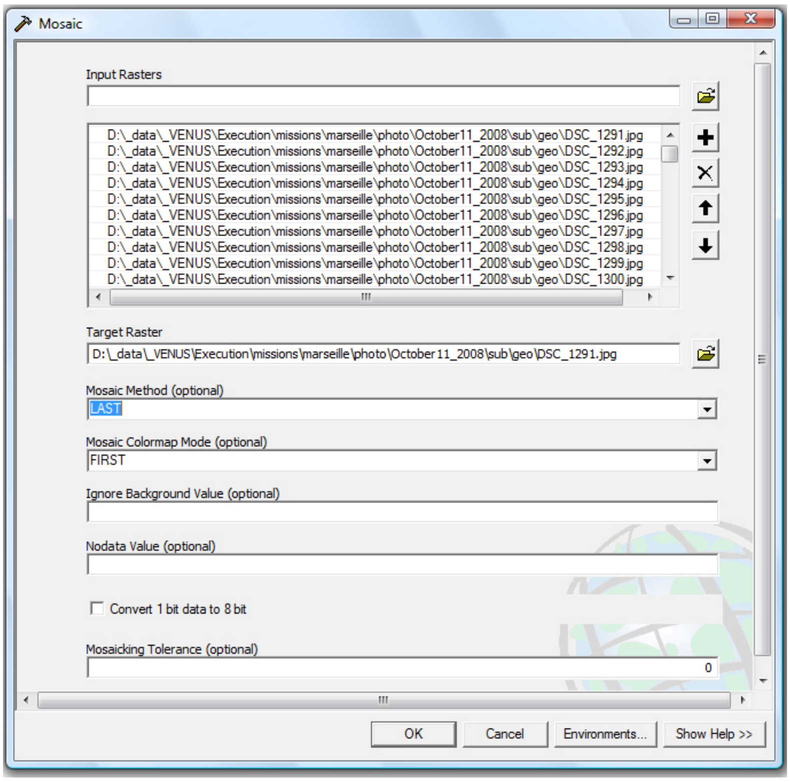


Figure 4 The Mosaic dialog from ArcCatalog

2. In the Input Rasters field, navigate to the raster datasets and choose the rasters to be mosaicked (use the button to add rasters).
3. In the Target Raster text box, confirm that the proper path for the produced mosaic. For example, the mosaic can be named "mosaic.jpg".

   WARNING: By default, the mosaic filename is set to overwrite the first raster in the set.
4. Choose the Mosaic Method to use when adjacent raster datasets are overlapping. There are 6 methods:
   - FIRST: The output cell value of the overlapping areas will be the value from the first raster dataset in the list.
   - LAST: The output cell value of the overlapping areas will be the value from the last raster dataset in the list. This is the default (and is also the fastest mosaic type).

- BLEND: The output cell value of the overlapping areas will be a blend of values that overlap; this blend value is based on an algorithm that is weight based and is dependent on the distance from the pixel to the edge within the overlapping area.
- MEAN: The output cell value of the overlapping areas will be the mean value of the overlapped cells.
- MINIMUM: The output cell value of the overlapping areas will be the minimum value of the overlapped cells.
- MAXIMUM: The output cell value of the overlapping areas will be the maximum value of the overlapped cells.

5. Choose the Mosaic Colormap Mode to use if color maps are present. There is 4 colormap modes available:
    - REJECT: Only the raster datasets that do not have a colormap associated with them will be mosaicked.
    - FIRST: The colormap from the first raster dataset in the list will be applied to the output raster dataset. This is the default.
    - LAST: The colormap from the last raster dataset in the list will be applied to the output raster dataset.
    - MATCH: Makes sure that the colors in the final colormap are all unique.
6. Optionally, you can type a number for the "*Ignore Background Value*" and NoData value. Specifies the pixel value in the raster dataset that would be recognized as a background value, and not a valuable part of the data. The pixel value specified will be set to NoData in the output raster dataset. Use this option after rotating or projecting an image to remove the unwanted values created around the original raster data. Even if this value is not unique in the dataset, it will be distinguished from other valuable data in the raster dataset. For example, a value of zero along the raster dataset's borders will be distinguished from zero values within the raster dataset. The field "*No Data Value*" is such that All the pixels with the specified value will be set to NoData in the output raster dataset
7. Optionally, you can choose whether the input 1-bit raster dataset will be converted to an 8-bit raster dataset. In this conversion the value 1 in the input raster dataset will be changed to 255 in the output raster dataset. This is useful when importing a 1-bit raster dataset to ArcSDE. 1-bit raster datasets have 8-bit pyramid layers when stored in a file system, but in ArcSDE, 1-bit raster datasets can only have 1-bit pyramid layers, which makes the display unpleasant. By converting the data to 8-bit in ArcSDE, the pyramid layers are built as 8-bit instead of 1-bit, resulting in a properly appearing raster dataset in the display. If the box is not checked, no conversion will be done. This is the default. Otherwise, the input raster will be converted
8. Optionally, you can set the Mosaicking Tolerance. When mosaicking takes place, the target and the source pixels do not always line up exactly. When there is a misalignment of pixels, a decision needs to be made whether resampling takes place or whether the data should be shifted. The mosaicking tolerance controls whether resampling of the pixels take place or if the pixels should be shifted.

- If the difference in pixel alignment (of the incoming dataset and the target dataset) is greater than the tolerance, resampling will take place.
- If the difference in pixel alignment (of the incoming dataset and the target dataset) is less than the tolerance, resampling will not take place (instead, a shift is performed).
- The unit of tolerance is a pixel; the valid value range is 0 to 0.9999. The maximum a pixel can be shifted is 0.5, so anything you set that is greater than 0.5 will guaranty a shift takes place. A tolerance of zero guaranty resampling if there is a misalignment in pixels.

For example, the source and target pixels have a misalignment of 0.25. If the mosaicking tolerance is set to 0.2, then resampling will take place since the pixel misalignment is greater than the tolerance. If the mosaicking tolerance is set to 0.3, then the pixels will be shifted.

9. Click OK. To launch the mosaicing process.

4.2.5 Conclusion

As we saw in previous section, there is no software that covers the whole process from a set of photographs with orientation data to a georeferenced mosaic of an underwater site. Specific software can perform a subset of the process (Figure 5).

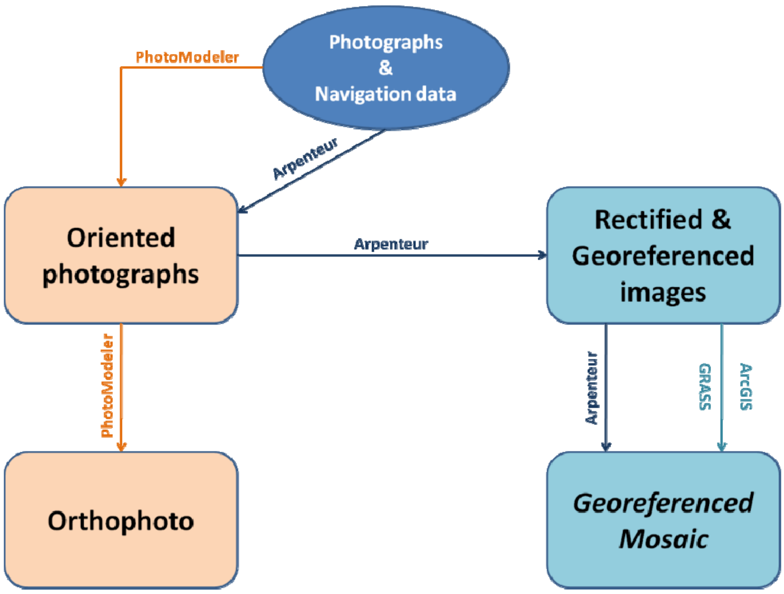


Figure 5 Software coverage of the whole mosaicing process

We have integrated in Figure 5 the planned features to add to Arpenteur for providing an efficient mosaic generation interface.

The PhotoModeler application can create an orthophoto but is limited by the manual orientation phase and the leak of possibility to produce a georeferenced orthophoto. GIS software like ArcGIS or GRASS is effective for a georeferenced mosaic generation but needs a set of rectified and georeferenced photographs in input. Imagery application can only provide a visual representation of a mosaic and are not suitable at all. The following table is a synthetic view of the software capabilities.

Name	Licence	Visual	Orientation	Ortho	Rectification	Mosaic
Photomodeler	Commercial	NO	MANUAL	YES	NO	NO
ArcGIS desktop	Commercial	NO	NO	NO	NO	YES
Photoshop CS4	Commercial	YES	NO	NO	NO	NO
Grass / JGrass	Open Source	NO	NO	NO	NO	YES
Arpenteur	Free	NO	MANUAL / AUTO	YES	YES	YES

Figure 6 Recap of the studied software capabilities

4.3 Mosaic tools in underwater exploration

Over the last ten years, significant study in the development of efficient subsystems for underwater applications has been done by lot of teams coming from institutions and private companies. This research has been specifically driven by the offshore industry and European Commission in term of IT, research and new tools investment. Over the past decade, however, with the growing challenge of reaching deeper sites, human divers are being complemented with or replaced by Remotely Operated Vehicles (ROVs). The ROVs are usually equipped with sonar and vision equipment and, if required, tools to sample the seabed and manipulate artifacts. Regardless of how data are acquired, the crucial problem of overlaying the different data sets to generate composites of the interested site at both large and small scales has not yet been satisfactorily resolved. No off-the-shelf tools are available for these purposes. Several issues have not been satisfactorily addressed in the scientific literature and no efficient software tools are available to solve them. The literature presents lot of studies and examples of efficient way to equip a small class commercial robot in survey, for virtual reconstruction, of a geo-referenced portion of the sea bottom taking care of installation and synchronization of needed commercial and efficient subsystems. Unfortunately no one of them are general purposes and the software can be adopted in other robot structure then the ones taking care on the research used. This reasons justified the work done in the VENUS project to develop an hardware box and a software tools that can easily installed in a general underwater robot as mosaic tool. The tool developed collects all data inside the robot where it is installed and make photos by means of Nikon D300 with all necessary data for mosaicking embedded in the exif area. The system is self contained about data acquisition and archive.

This work relates to the work of a number of other research. The most important differences can be grouped and highlighted as follow:

1) Global tools for mosaic construction: The application of mosaicking techniques for underwater site reconstruction is a topic of increasing research interest both for visualization tool for covering large areas [9], [10], [11], [12] and for spatial representation for underwater robotics [13], [14], [15]. Considering the goal of global site reconstruction, several approaches have been proposed using topology inference of neighboring frames [16], [17], and restricted parameterizations for the projection matrices [18]. Recent methods allow the fast computation of globally consistent linear strips mosaics [19], and use Kalman Filtering for closing the trajectory loops [20].

The main differences of our approach with all of the above are to add to the single image taken during the survey more information as possible about position and attitude of the photographer. This can be used by following mosaicking and photogrammetric tools for reconstruction the 3D scene considering the spatial position of single taken image.

2) Mosaics for Navigation: Different references are present to the idea of using mosaics as visual maps one of the oldest is the work of Zheng [21], where panoramic representations were applied to route recognition and outdoor navigation. However the visual representations do not preserve geometric characteristics nor correspond to visually correct mosaics. Xu [22] investigated the use of seafloor mosaics, constructed using temporal image gradients, in the context of concurrent mapping and localization, for real-time applications. In the same years Conte and all work on NCG algorithms based on visual feedback [23], [24] and [25].

In the framework of VENUS we try to navigate the ROV combining mosaic with underwater

ROV navigation. In this approach, the navigation system requires additional sensors to provide heading, pitch and yaw information, combining also video with acoustic images. This type of approach coming from different work as [26], [27] and [28].

For the future, the goal is to merge the results coming from mosaic, in term of coordinates of destination points, with the techniques made a station keeping on the recognized objects in the view scene [29] and [30].

5 Software component description

5.1 Photograph orientation from ROV navigation data

The oriented photographs are obtained as JPEG files with Exif metadata.

5.1.1 Exif metadata format

Exchangeable image file format (Exif) is a specification for the image file format used by digital cameras. The specification uses the existing JPEG, TIFF Rev. 6.0, and RIFF WAV file formats, with the addition of specific metadata tags. It is not supported in JPEG 2000, PNG, or GIF [7].

The metadata tags defined in the Exif standard cover a broad spectrum:

- Date and time information. Digital cameras will record the current date and time and save this in the metadata.
- Camera settings. This includes static information such as the camera model and producer, and information that varies with each image such as orientation, aperture, shutter speed, focal length, metering mode, and ISO speed information.
- A thumbnail for previewing the picture on the camera's LCD screen, in file managers, or in photo manipulation software.
- Descriptions and copyright information.

The Exif tag structure is taken from that of TIFF files. On several image specific properties, there is a large overlap between the tags defined in the TIFF, Exif, TIFF/EP and DCF standards. For descriptive metadata, there is an overlap between Exif and IPTC Information Interchange Model info, which also can be embedded in a JPEG file.

When Exif is employed for JPEG files, the Exif data is stored in one of JPEG's defined utility Application Segments, the APP1 (segment marker 0xFFE1), which in effect holds an entire TIFF file within. When Exif is employed in TIFF files (also when used as "an embedded TIFF file" mentioned earlier), the TIFF Private Tag 0x8769 defines a sub-Image File Directory (IFD) that holds the Exif specified TIFF Tags. In addition, Exif also defines a GPS sub-IFD using the TIFF Private Tag 0x8825, obviously holding location information, and a "Interoperability IFD" specified within the Exif sub-IFD, using the Exif tag 0xA005.

The Exif format has standard tags for location information. Currently, only very few cameras, such as the Ricoh 500SE or some higher-end mobile phones, have a built-in GPS receiver and store the location information in the Exif header when the picture is taken. For other cameras, such as Nikon reflex models or Fujifilm S5Pro, a separate GPS receiver that fits into the flash connector is available. Recorded GPS data can also be added to any digital photograph on a computer, either by correlating the time stamps of the photographs with a GPS record from a hand-held GPS receiver or manually using a map or mapping software, e.g. Geoseeker. Photo sharing communities like locr or Flickr equally allow their users to upload geotagged pictures or to add geolocation information online. The process of adding geographic information to a photograph is known as geocoding.

Working with Exif metadata is common on many platforms. In Windows XP and later Microsoft operating systems, a subset of the Exif information may be viewed by right clicking on an image file and clicking properties; from the properties dialog click the Summary tab. However, this can damage certain Exif headers if changes are applied.[4] Other Windows software, lot of them are free available, may be more reliable (i.e. Exif Harvester).

On Mac OS X 10.4 and above, this information may be viewed in the Finder by doing Get Info on a file and expanding the More Info section.

On Unix systems using the GNOME desktop environment, a subset of Exif data can be seen by right clicking the file in the Nautilus file manager and selecting properties. In KDE, it can be seen by right clicking, selecting "Properties" and then "Meta info". Most Unix image viewers give the full set of Exif data.

There are many software tools available which allow both viewing and editing of Exif data. The Opanda IExif Viewer is a free stand-alone application and also a plug-in for MSIE and Firefox on Windows a platform that allows examination of detailed Exif data online by right clicking on an image FxIF and Exif Viewer are multi-platform extensions for Firefox that display Exif data in the image properties dialog. This feature is native in the web browser, Opera under image properties.

Some Java libraries also enable to work with Exif metadata as the "*Metadata-extractor*" library (http://www.drewnoakes.com/code/exif/)

5.1.2 Integration of ROV navigation data in Exif metadata

For what concerns data gathered on the sites the ROV is equipped with a CCD fullHD video camera, a high quality still camera (Nikon D300 with 14 mm Sigma lens) and two flashes (Nikon SB800).

During each launch, the ROV executes a number of transects at the speed of about 1 knot, at an average distance from the sea bottom of about 3m. In this condition, each video frame covers an area of about 3m2 and video stream provides a complete coverage of a 3m wide corridor when the ROV moves along a linear path, assuring an overlap of about 60% between consecutive frames. The video camera takes 25 frames per second and, in order to have a complete documentation, the video stream is recorded by the video camera on a DV tape. The video stream is sampled at a frequency of 5 Hz (getting one frame over 5) by the NGC system of the ROV (implemented on a National Instruments PXI/PC station) and sampled images were digitally recorded. Pictures taken by the still camera covered more or less the same area framed by the video camera (difference was less than 5%) and were recorded on the camera own flash memory. Two different procedures can be adopted for the camera operation. In the first one, shooting is manually commanded by an operator, under the supervision of an archaeologist, from the ROV's supply vessel. Operator and archaeologist can observe the scene framed by the video camera (almost coincident with that framed by the camera) on the ROV's M/M interface. Each command to shoot is recorded as an event by the NGC system of the ROV. In the second procedures, shooting is automatic, with a fixed frequency, chosen according to the flashes' recharging time, to the ROV's speed and to the distance from the sea bottom.

Geo-referencing is obtained by acquiring the position of the ROV with respect to the supply vessel by means of an USBL (Sonardyne Scout USBL system) and by relating this to the DGPS position of the vessel. By keeping the ROV in stationary position on archaeological finds of relevant interest for few minutes, the (absolute) geographic positions of these last can be acquire with high precision.

In every mission, acoustic images of the sea bottom, in addition to optical ones, were acquired by means of the on-board sonar and registered by the NGC system of the ROV at a frequency of 10 Hz.

Data processing, implemented by the NGC system of the ROV, working in cooperation with an additional PC station, exploits a number of specific software procedures. Data collected by different sensors are merged, so that every picture recorded by the NGC system of the ROV is associated with an acoustic image and a set of measures taken by the navigation sensors. In this way, a set of files in JPEG/EXIF format are produced and made directly accessible by the operators. The association process (see scheme in Figure below) is performed accounting for the fact that data are not acquired in a synchronous way.

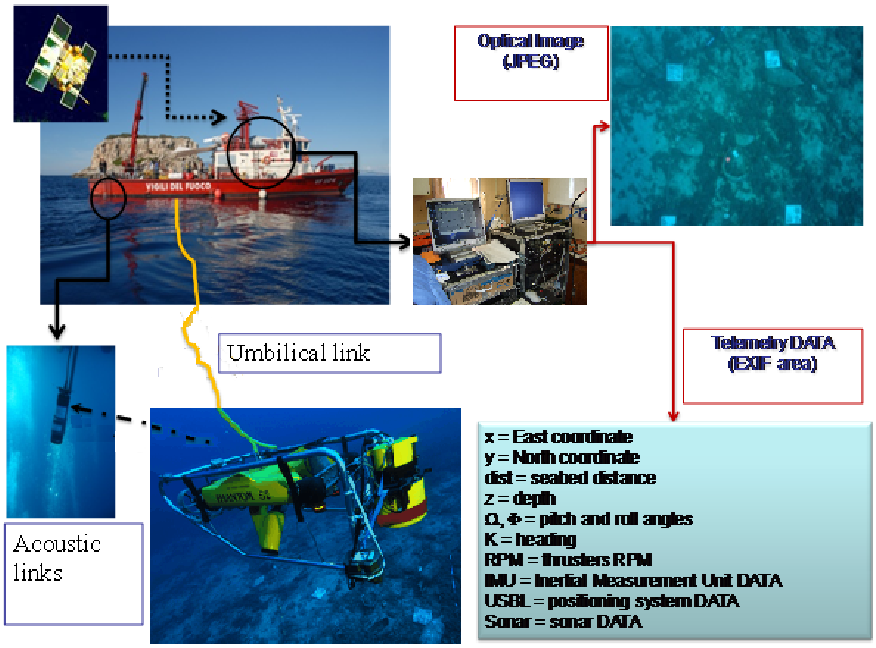


Figure 7Synoptic Schema

In the first (Pianosa Island) and second (Sesimbra) missions every picture sampled from the video stream (relatively low quality picture) was associated with the camera's photo (relatively high quality picture) and with the sonar's acoustic image that exhibited the closest timestamp. The association of the other data, such as geo-referenced coordinates or attitude data, required supplementary calculations, which included averaging, interpolation or filtering procedures, according to the update rate.

The information delivered by the data sets so constructed is richer than that provided separately by individual sensors and it can be said that the procedure actuated a sort of economy of scope, where the whole exhibited more value than the simple union of the parts. For the last mission (Marseille) a new device and logging software have been developed. The device, named NBC01 (Nikon Control Board) acts as an interface between a NIKON Reflex Digital Camera (I.e. NIKON D200, D300) and a remote control unit with a serial RS232 interface. NCB01 receives commands and data from the serial device, unpacks them and sends them to the NIKON camera. The communication is over a simple RS232 protocol with the following hardware settings:

- **BAUD RATE:** 4800 bps
- **DATA BITS:** 8
- **PARITY:** None
- **STOP BITS:** 1
- **FLOW CONTROL:** None

The format of the command string is very strict, i.e. position and length of each field is fixed and unchangeable according with the requested data of Nikon. The following strings must be separated by a comma "**,**" .

Following there's the meaning of the each field present in the command string:

- **"$NIKON"** head ► Each command row must begin with this sequence, otherwise it won't be recognized by the unpacking routine.
- **"210908"** date ► Day **08**, Month **09**, Year **2008**
- **"16563011"** timestamp ► Hour **16**, Min **56**, Sec **30.11**
- **"4338.9061,N"** latitude ► **43° 38.9061' North** of latitude
- **"01320.3933,E"** longitude ► **13° 20.3933' East** of longitude
- **"05620"** depth ► **56.20 meters**, depth from the sea surface
- **"1800"** pitch ► **180.0 degree**
- **"1800"** roll ► **180.0 degree**
- **"1730"** heading ► **173.0 degree**
- **"99"** altitude ► **9.9 m**, altitude from the sea bottom
- **"2"** photo mode ► **"2" continuous**, camera will take one photo automatically every "delay time" seconds

  "1" one shot, camera will take one photo

  "0" stop the continuous mode
- **"200"** msec exp time ► **exposure time**, varying between 1 and 999
- **"02"** delay time ► **delay time**, in the continuous mode, is the time between two consecutive photos
- **"*4D"** checksum ► It's not been implemented yet
- **"END"** tail ► It lets the routine understand that the command string is terminated

When NCB01 receives a new data send them to nikon and command the run of new photograph. At the end of survey on the camera flash memory will be all photos with exif data written by NCB01 regarding position and attitude of the robot photographer.

The data of NCB01 is compiled and sent by logging software that run on the NCG computer of the robot (see D6.5).

Besides the generation of the EXIFs, the images acquired are suitably scaled, oriented and possibly augmented taking into account other sensors' data (e.g. sonar data or sub-bottom profiler data) and finally superimposed on (a portion of) the preliminary map early produced by the broad search. This procedure generates an augmented map of the site that allows to get an overall view of the site.

5.2 Georeferrenced images generation

The first step in the rapid mosaicking process is to generate georeferrenced images from oriented photographs. This work can be done automatically by computing a homographic transformation, as we can see in Figure 8.

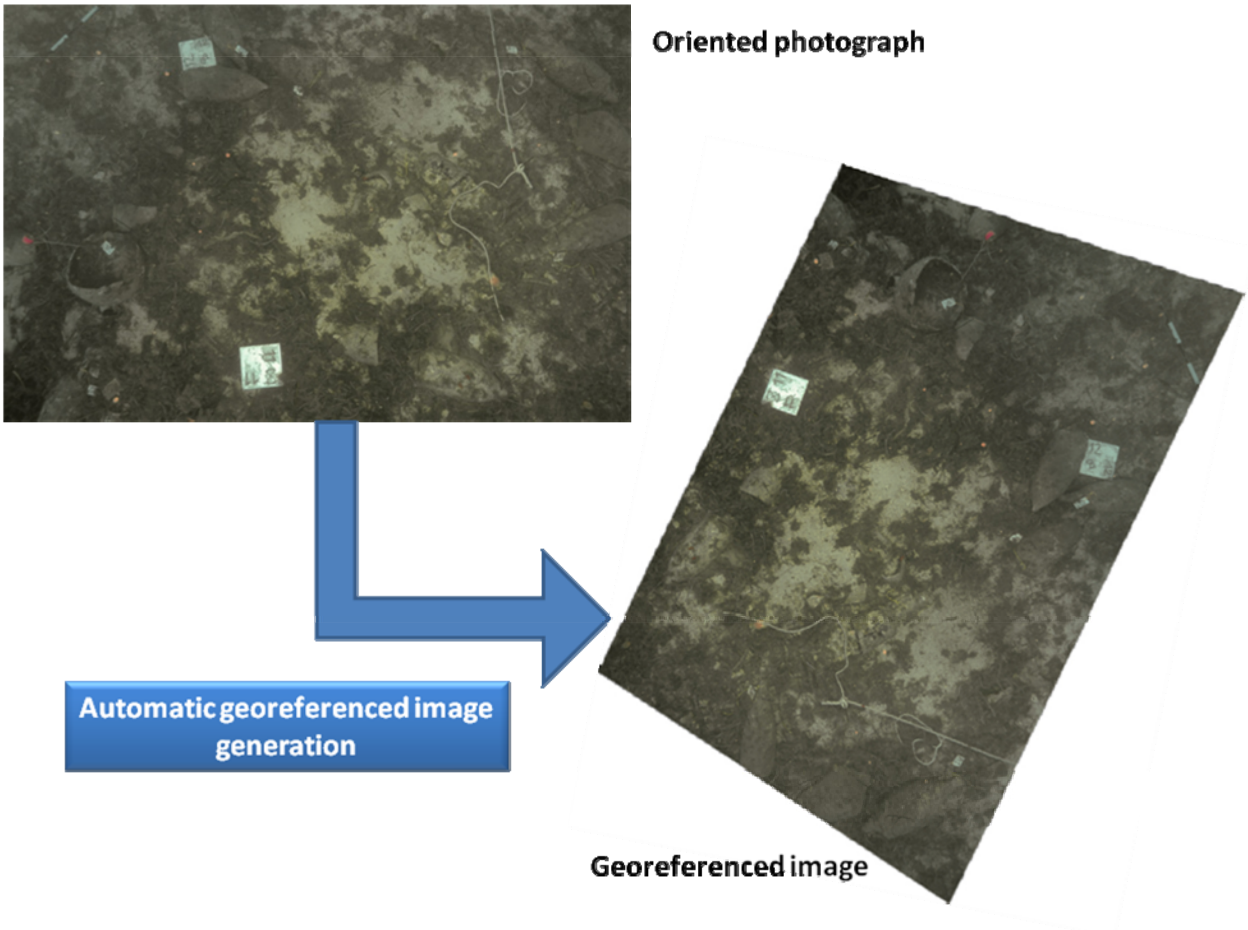


Figure 8 Automatic georeferenced image generation using homographic transformation of oriented photographs

The homography provide a new rastered image deformed to match on a given plane. The transformation of the photograph orientation into plane coordinate is also available. These data enable to generate georeferenced images.

5.3 Georeferrenced image formats

There is two image formats used for georeferencing. The first one is the geotiff format, the second one is the world file format.

5.3.1 Geotiff format

Geotiff [5] has been designed so that standard map coordinate system definitions can be readily stored in a single registered TIFF tag. The TIFF format is the standard in document imaging and document management systems using CCITT Group IV 2D compression, which supports black-and-white (bitonal, monochrome) images. In high-volume storage scanning, documents are scanned in black and white (not in colour or in grayscale) to conserve storage

capacity. This format can save multi-layered documents to a single TIFF file rather than a series of files for each image.
Geotiff has been designed to allow the description of coordinate system definitions which are non-standard, and for the description of transformations between coordinate systems, through the use of three or four additional TIFF tags.

However, in order for the information to be correctly exchanged between various clients and providers of GeoTIFF, it is important to establish a common system for describing map projections.

In the TIFF/GeoTIFF framework, there are essentially three different spaces upon which coordinate systems may be defined. The spaces are:

1. The raster space (Image space) **R**, used to reference the pixel values in an image
2. The Device space **D**
3. The Model space, **M**, used to reference points on the earth.

Raster data consists of spatially coherent, digitally stored numerical data, collected from sensors, scanners, or in other ways numerically derived. The manner in which this storage is implemented in a TIFF file is described in the standard TIFF specification [6].

In standard TIFF 6.0 there are tags which relate raster space **R** with device space **D**, such as monitors. The list of such tags consists of the following:

- ResolutionUnit
- XResolution
- YResolution
- Orientation
- XPosition
- YPosition

In Geotiff, provision is made to identify earth-referenced coordinate systems (model space **M**) and to relate **M** space with **R** space. This provision is independent of and can co-exist with the relationship between raster and device spaces.

The following methods of describing spatial model locations (as opposed to raster) are recognized in Geotiff:

- Geographic coordinates
- Geocentric coordinates
- Projected coordinates
- Vertical coordinates

Geographic, geocentric and projected coordinates are all imposed on models of the earth. To describe a location uniquely, a coordinate set must be referenced to an adequately defined coordinate system. If a coordinate system is from the Geotiff standard definitions, the only reference required is the standard coordinate system code/name. If the coordinate system is non-standard, it must be defined. Projected coordinates, local grid coordinates, and geographical coordinates, form two dimensional horizontal coordinate systems (i.e., horizontal with respect to the earth's surface). Height is not part of these systems. To describe a position in three dimensions it is necessary to consider height as a second one dimensional vertical coordinate system.

To georeference an image in GeoTIFF, it must be specified:

- a Raster Space coordinate system
- a horizontal model coordinate system,
- a transformation between Raster Space coordinate system and horizontal model coordinate system

These three requirements are available at the end of the automatic homographic process. The raster space coordinate system is the standard image raster coordinate system, the horizontal model is arbitrary defined as a standard Cartesian 2D and the transformation between these two is given by the projection of the oriented photograph onto the reference plane.

5.3.2 World file format

The world file format consists in a couple of files. The first file is a standard raster image file. The second file contains the transformation between raster and a horizontal model coordinate system. The file used by geographic information systems to coordinate raster map images is called “World files”. The file specification was introduced by ESRI (Inc)

A rectangular raster image can have an associated world file which describes the location, scale and rotation of the pixels of the raster to match a point on the terrain. These world files are six-line files with decimal numbers on each line. The name of the file is modeled after the associated raster file. The name of the world file is formed by appending the letter "w" to the end of the raster filename. An alternative naming convention is also honored, and in fact is more widespread. This convention was developed for filenames that need to conform to the 8.3 file naming convention. The three letters of the filename extension are altered thus: the second letter of the original filename extension is replaced with the last letter, and, the third letter is replaced with the letter "w." If the map files end in .jpg or .tif -- then the separate world file ends in .jgw or .tfw for example.

World files do not specify a coordinate system, so the generic meaning of world file parameters are stated on each line of the file as follow:

1. **A**: pixel size in the x-direction in map units/pixel
2. **D**: rotation about y-axis
3. **B**: rotation about x-axis
4. **E**: pixel size in the y-direction in map units, almost always negative[3]
5. **C**: x-coordinate of the center of the upper left pixel
6. **F**: y-coordinate of the center of the upper left pixel

The **E** parameter is often a negative number because most image files store data from top to bottom, while the software utilizes traditional Cartesian coordinates with the origin in the conventional lower-left corner.

In a world file using a Universal Transverse Mercator coordinate system (UTM) constantly use:

- **D** and **B** are always 0

- **C** is the Easting UTM coordinate
- **F** is the Northing UTM coordinate
- Units are always metres per pixel

The above description applies also to a rectangular, non-rotated image which might be, for example, overlaid on an orthogonally projected map. If the world file describes an image that is rotated from the axis of the target projection however, then **A**,**D**,**B** and **E** must be derived from the required affine transformation. Specifically, **A** and **E** will no longer be the meter/pixel measurement on their respective axes.

The world file 6 values are used in a six-parameter affine transformation:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} A & B \\ D & E \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} C \\ F \end{bmatrix}$$

Where

- x' is calculated UTM Easting coordinate of the point on terrain
- y' is calculated UTM Northing coordinate of point on terrain
- (x, y) is the couple of coordinate for a pixel in the image raster

The affine transformation can be written as this set of equations:

$$x' = Ax + By + C$$
$$y' = Dx + Ey + F$$

The generation of a world file format from an oriented photograph is similar to the generation of a geotiff file. A Raster image file can be generated by the homographic transformation and an attached world file is wrote by using the parameters of the projection of an oriented photograph onto a given plane

5.4 Mosaicking algorithm

A Mosaic is constructed with an array of georeferenced images. For the sake of simplicity, we can consider this kind of image as a 2D polygon expected to be quadrilaterals. In our framework, a java class named Polygon2D represents a polygon. The interesting limits on the original 'images' of a polygon can be obtained by calling getROI(index) for each of the original Polygon2D. The 'index' parameter is the index of the polygon in the array of Polygon2D given as input. This method returns an array of Polygon2D, so that each polygon given as input can produce several polygons needed to create the final mosaic.

5.4.1 Goal

The underlying algorithm assumes that all polygons given as input to the constructor are quadrilaterals, i.e. polygons with four sides. These quadrilaterals taken all together form a 'mosaic' of a greater area and the purpose of the algorithm is to have this area covered completely by the polygons, with one single participating polygon covering each part of the area, except on the edges of the polygons where some overlapping is desired.

Translated in the real world, each quadrilateral represents an image and the result is an image of the full area where each part of the area is covered by a single image except on the edges of the images where a small overlapping is required.

5.4.2 A four step mosaiking process

The algorithm relies on four steps. The first step selects among the input quadrilaterals, those that will best cover the full area and unselect the redundant ones. The Figure 9 shows the original set of polygon representing the georeferenced images for all oriented photographs.

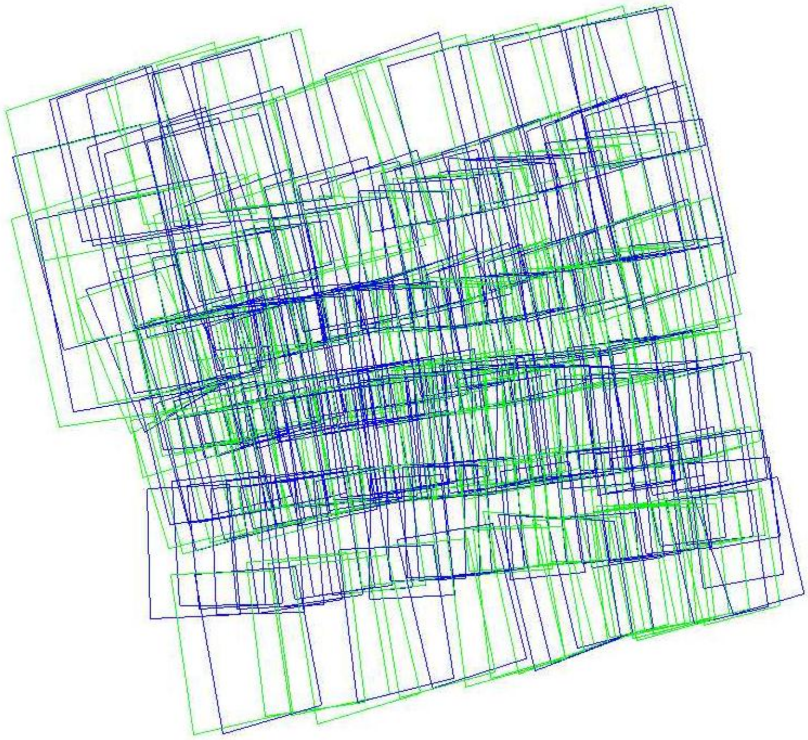


Figure 9 the original polygon set

The Figure 3 shows a first set of polygon filtered from the original set. The polygons that are the most involved in overlapping are removed. The technique used is to reduce the overlapping between adjacent quadrilaterals to a predefined limit given as input.

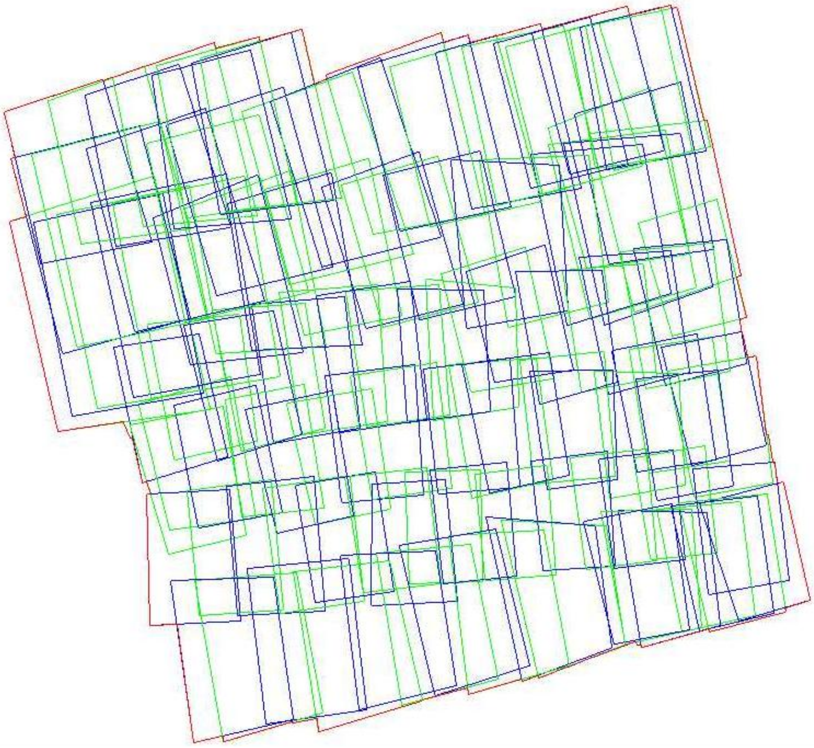


Figure 10 first filtered polygon set

The overlapping reduction is repeated until overlap limit is reached. This process can provide some polygons set with holes, as we can see in Figure 11.

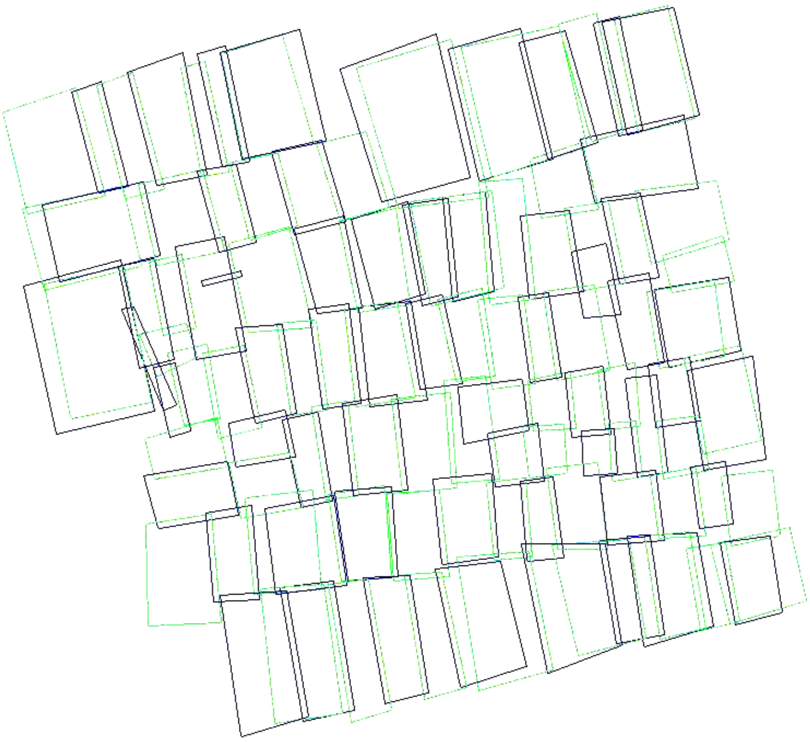


Figure 11 last filtered polygon set, with holes

As the previous step may lead to create holes in the coverage of the area, we select the quadrilaterals where these holes are and compute an additional inner zone in the quadrilateral. Each input quadrilateral may therefore give birth to more than one polygon in the result

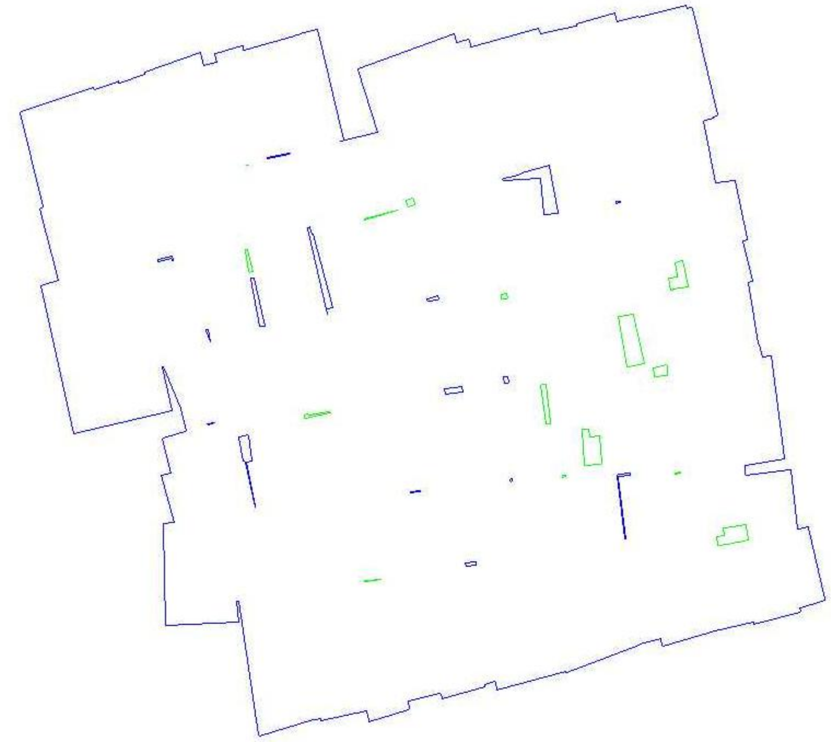


Figure 12 Final polygon set

The resulting mosaic image is build thanks to the computed polygons ()

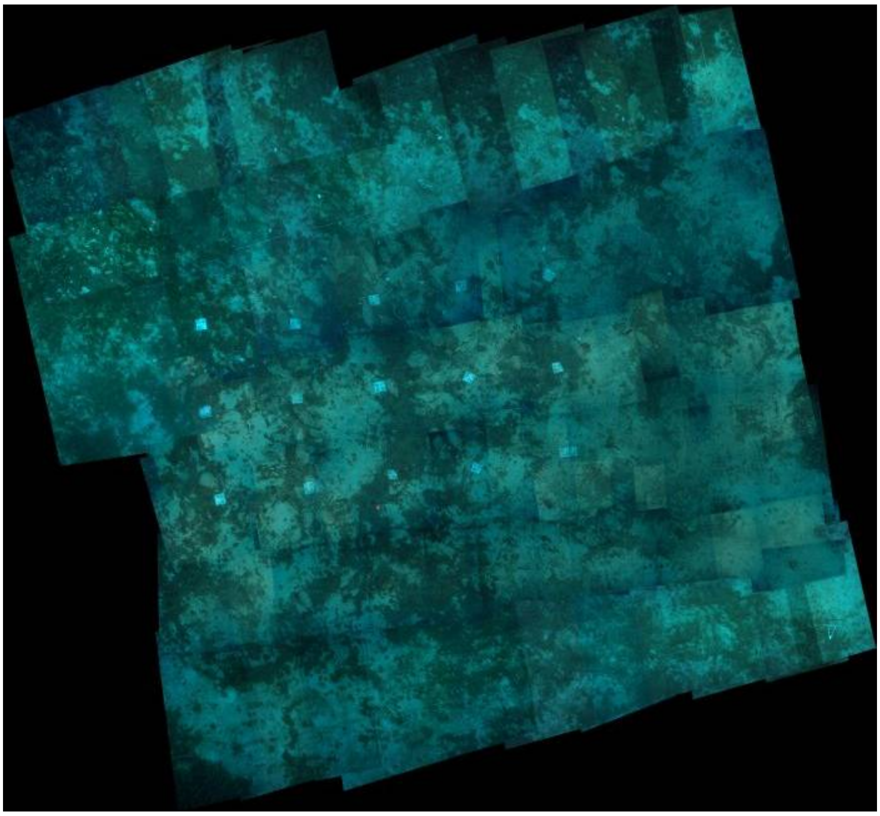


Figure 13 Image mosaic

5.4.3 Details

Selecting the quads for coverage

Selecting between the input quadrilaterals those that will remain to form the final mosaic is made in 5 steps:

compute the global bounding box of the whole area. While doing this, remember the smallest side length between all quadrilaterals.

divide the resulting bounding box into squares with a side length of half the above 'smallest side length': this forms a pavement.

go through each square in the pavement and compute its intersection with all input polygons. For each square in the pavement, the selected quadrilateral is the one that has the greatest intersection with the square.

If the square is included in several quadrilateral, then these quadrilaterals are all possible candidates.

when all intersection have been computed and all possible candidates have been 'marked' as such, each quadrilateral is given a 'score' (or 'weight') which is the number of time where it has been selected as a possible candidate.

the finally selected quadrilaterals are those detected as 'selectable' in step 2 and have the greatest score attributed in step 3 (meaning the algorithm attempts to select the quads that cover the greatest number of squares). If several are still possible, then the first in the input array is preferred (quad index).

Note that unselected polygons have their area reduced to zero (they are modified in the input array).

5.4.4 Overlapping reduction

The algorithm works on the polygons (output of the selection step) as follow:

- for all polygons, create a Quadrilateral2D and add it in a queue
- compute all polygons that are intersections between these quadrilateral2D
- sort these intersections by surface size
- beginning with the intersection with the greatest surface, try to move
- the two sides 'of interest' of the intersected polygons
- For a given Intersection, the sides of the intersected polygons that are 'of interest' are the sides cut by a line between the 'center' of the polygon and the center of the intersection.
- Sides are moved toward each other symetrically to their median line.

Note that sides are only moved one time, so sides that could be moved because of several intersections are actually only moved for the intersection with the greatest surface.

5.4.5 Filling in holes

This is made iteratively by computing a XOR between the union of all the polygons before the 'overlap reduction' step and the union of all the 'reduced' polygons.

For each polygon in XOR that has an area greater than a minimum value get the Quadrilateral that best cover the zone, i.e. has the greatest intersection with it: this intersection must be:

- Added to the ROI corresponding to the chosen quad.
- Added to the area defined by 'the union of all the 'reduced' polygons'.

This calculus is repeated *until no more change is observed.*

5.5 Mosaicking interface

The mosaicking process relies on a selection of georeferenced image to use by an automatic overlap computation. We have developed an interface for the mosaicking process that enable to select manually images we want to use for the process.

This interface provides the view of all images and a list of all selected images. When the interface is opened, it shows all available georeferenced images, as we can see in Figure 14.

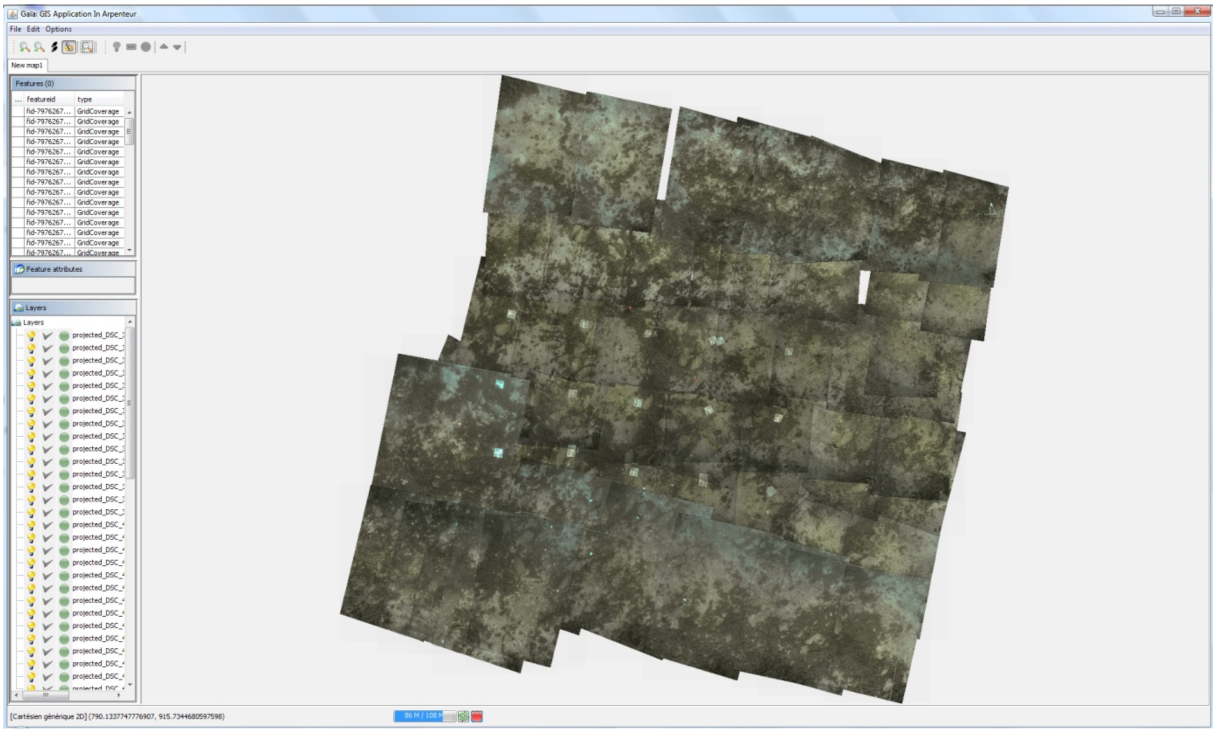


Figure 14 Interface showing all available georeferenced images

User can easily select or unselect images before the launch of the mosaicking process. The Figure 15 shows a subset of images selected by user. This subset is used as entry of the mosaicking process.

This interface relies on the Geotools library, already integrated in the Arpenteur framework. A description of geotools is available in available in the Venus deliverable 2.5 “Prototypal software for automatic digitalization method”

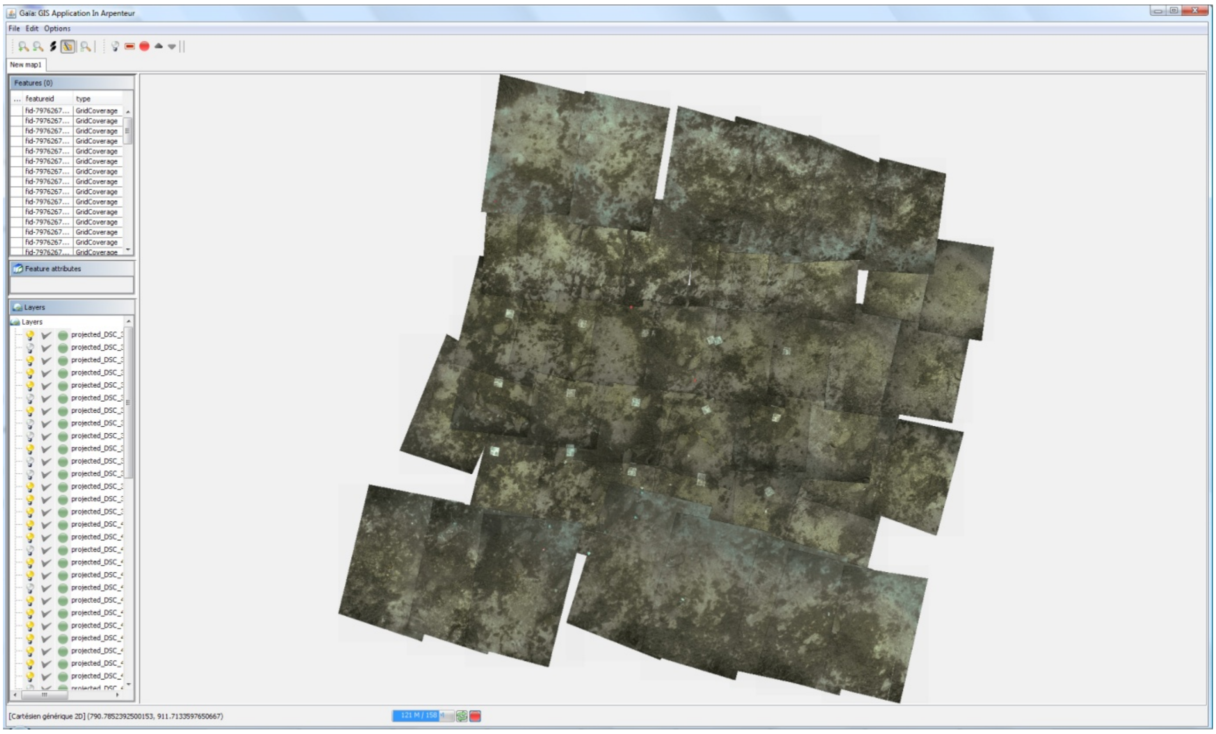


Figure 15 Interface with user selected georeferenced images

5.6 VRML export

As we have seen in the result produced during the use of this software for the mission in Marseille, in addition of Georeferenced orthophoto, this software produce VRML files.

The idea is always the same: giving tools to understand the navigation and the photographic survey.A VRML file with all the photo oriented in the space and with textured DTM of the seabed allows to understand better the navigation error or the sensor surveys.

5.7 Connectivity map export

The second tool, far from Geotiff, produced is a map reflecting the photograph overlaps. This is a great of interest to have a quick understand on how relevant was the navigation and if we can stop the survey photographic phases.

A specific connectivity map, georeferenced, allow to geolocalize precisely the lack zone of the survey.

5.8 Import/Export data file with ARPENTEUR

Finnaly the software produce Arpenteur XML model file to allows us to work fully with the other software already present in the Arpenteur project as well as new development made and presented in Deliverable 2.3.

5.9 Results: close the loop with new wait point for ROV

In traditional marine archaeological surveys, data gathering procedures involve divers for taking photos and measures, whose correlation and interpretation is facilitated by structuring the area of interest by means of frames and landmarks. Structuring the area is a hard and invasive work, that put divers and equipment at risk, as well as the manual collection of data.

In order to accomplish the job in a satisfactory and exhaustive way, investigators have to return repeatedly to the same location and the whole process is cumbersome and time consuming.

The problem considered in the present task concerns the design, testing and development of a set of procedures and best practices for collecting data from underwater archaeological sites by employing robotic vehicles and automatic devices under the supervision of archaeologists and engineers, possibly in cooperation, under some circumstances, with divers. Essentially, robotic vehicles are used to carry cameras, video-cameras and acoustic sensors in order to collect optical and acoustic images of the site. These are transmitted to a supply vessel and, together with navigation data, can be automatically processed in real time or post-processed by means of suitable software tools during the mission time.

In the proposed methodology, the introduction of one or more robotic vehicles in substitutions of divers is intended to speed up the exploration of the site, while allowing for possible on-line rescheduling of the mission or parameters adjusting. This is obtained by implementing a sort of logic feedback loop, based on the possibility of constructing in real time, with respect to the whole process, a map of the explored site by means of photomosaicking techniques. The fact of making the output of the survey process, namely the map, available - although in a preliminary form - in real time is one of the key advantages gained by collecting data (in this case, photos and video frames) in automatic way by means of sensors installed on robotic vehicles like ROVs. This characteristic is crucial for implementing a feedback loop and it cannot be obtained using traditional techniques based on manual data acquisition. The feedback mechanism allows the archeologists to modify some of the survey parameters (e.g. area coverage, point of sight, data density and so on) during operation, saving time and reducing costs.

Other important advantages of using robotic vehicles for collecting data are, obviously, the fact of avoiding the risks of diving and the possibility of working at high depth for long time. At the same time, the quantity and the density of data are greatly increased. Navigation data, in addition, allow to obtain strong correlation between photos and to construct geo-referenced maps of photogrammetric quality, augmented by information acquired by means of sonar, sub-bottom profiler and magnetometer, if available. Maps obtained in this way can be accurate enough to allow a satisfactory virtual reconstruction of the site at specified levels of precision.

6 Using the mosaic tool during the mission in Marseille

The main goal of the mission in Marseille was to obtain the photographic survey with a good approximation of the photo orientation parameters for all the photographs.

Rapid mosaic software has several goals:

- to be used on board as soon as the submarine or ROV is taken off the water in order to have a good idea of how the survey was done (overlap, navigation etc)
- to produce a draft mosaic to help the archaeologist to start designing a sketch of the site
- To produce data in order to fed the automatic photogrammetric orientation module.

One month after the mission we can give an overview on the document produced by this software during the mission and during the three after.

6.1 Document produced on board.

The rapid mosaic software input data are the photographs, taken by the submarine, with navigation data embedded in the EXIF field.

These data were available on October 11th.

The photographs were taken from 9:07 AM to 10:33 AM with the submarine. The mission, this day was successful all the navigation data were logged into the photographs and the site was correctly covered.

After the return of the submarine on board we transfer the data on several computer and Hard Disk to archive a copy.

We start using rapid mosaic software at 11:45AM.

The main goal here was to check if the survey was complete and if we didn't need to dive another time. This information was very important because if the whether was fine on the morning wind from Est was arriving and another dive had to be done very quickly.

6.1.1 2D GEOTIFF mosaic.

After downloading the image from the digital camera the rapid mosaic software read the exif field for each image and allows a quick visualization of the photographs after rectification and scale according to camera orientation and the altitude.

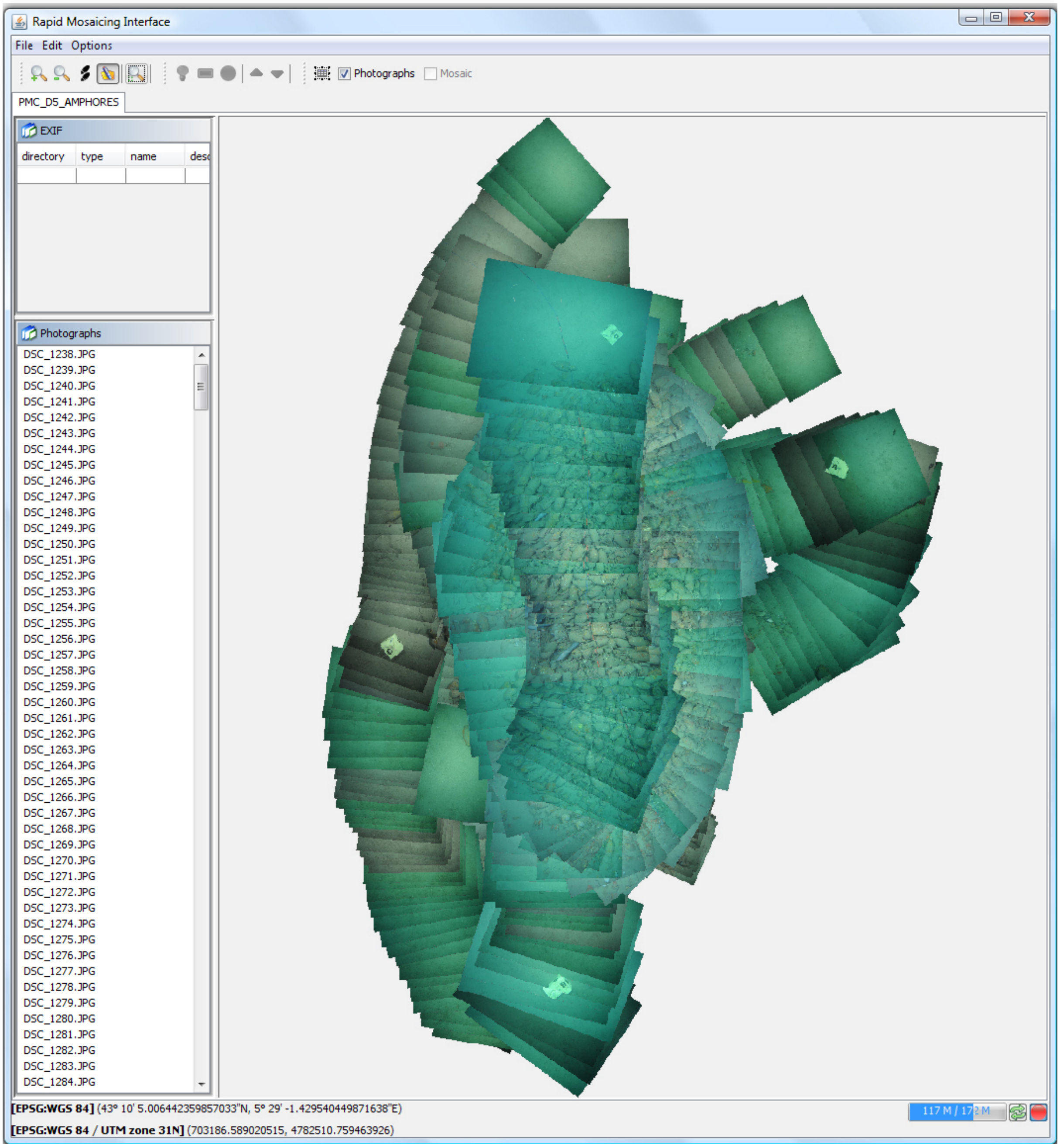


Figure 16. View of all the photographs georeferenced by navigation data, one hour after the diving.

This first visualization shows quickly the vehicle trajectory and the photograph dominant color give an idea of the 'flying' altitude of the vehicle.

This window allows selecting dynamically a subset of the photographs to generate the mosaic.

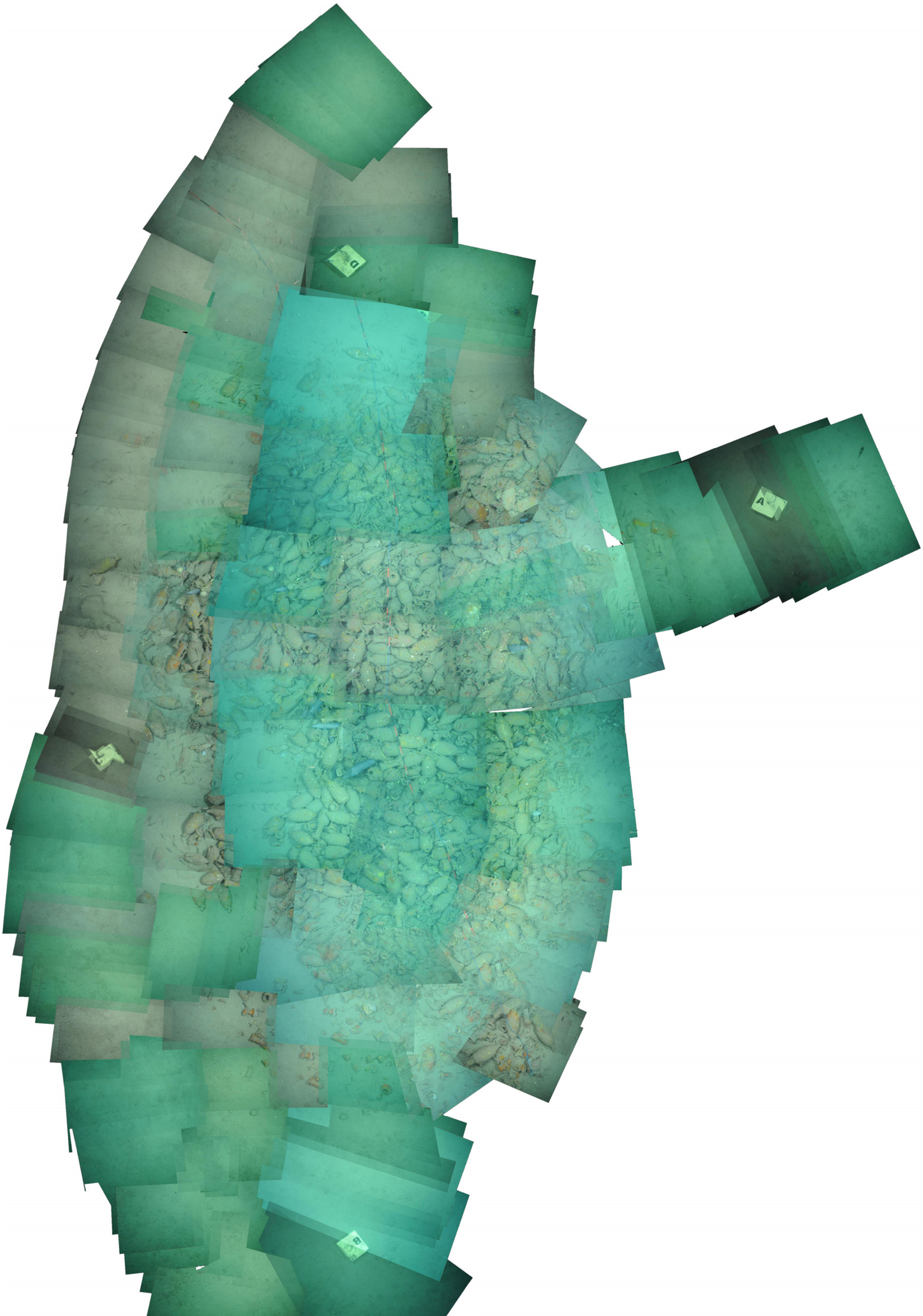


Figure 17. Geotiff generated with a subset of the photograph.

After a visualisation of all the rectified photographs the operator can choose a subset of them or start computing the mosaic with these options. The above image show the full mosaic computed on October 11th after two hours computations (mainly due to rectification in full resolution of 600 photographs).

6.1.2 2D VRML mosaic.

In the same time The rapid mosaic software produce thumbnail a several resolution and VRML file to allow a 3D/2D quick visualisation of the photographs and of the vehicle trajectory.

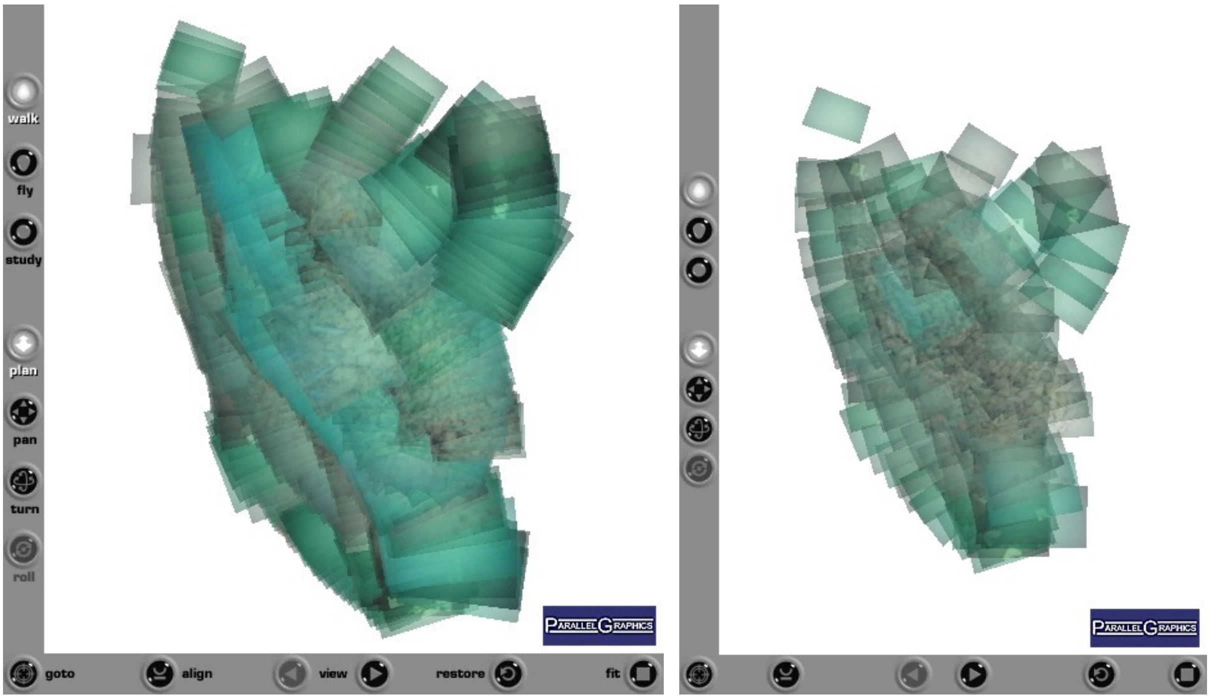


Figure 18. VRML 2D: Projection onto a plane of photographs with transparencies to estimate visually the overlap. Left: all the photographs, right only the subset already seen in the last image.

The last figure shows the photographs projected onto a horizontal plane with transparency. This allows checking qualitatively the overlap between photographs.

6.1.3 3D VRML trajectory.

Using a similar method rapid mosaic software produces 3D VRML files showing the vehicle trajectory. This is of great interest and this file is a very convenient way to control the trajectory and the navigation sensor registration.

This file was generated immediately and was used on board one hour after the end of the dive mission. The journalist from Euronews, present this day (October 11th) have integrated some images of this VRML file in their movies (see images below).

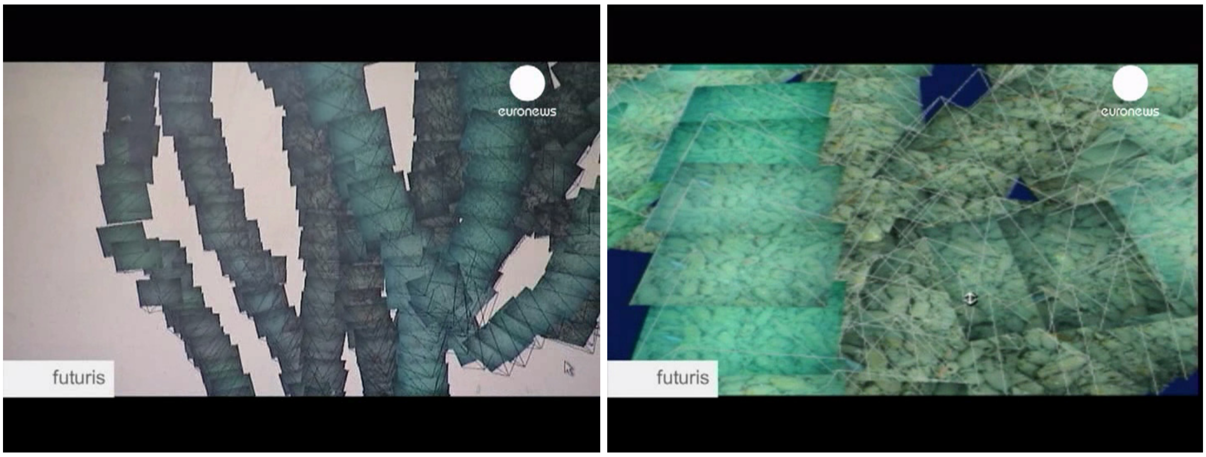


Figure 19. VRML file of the photo trajectory, made on October 11th, and filmed by Euroneuws.

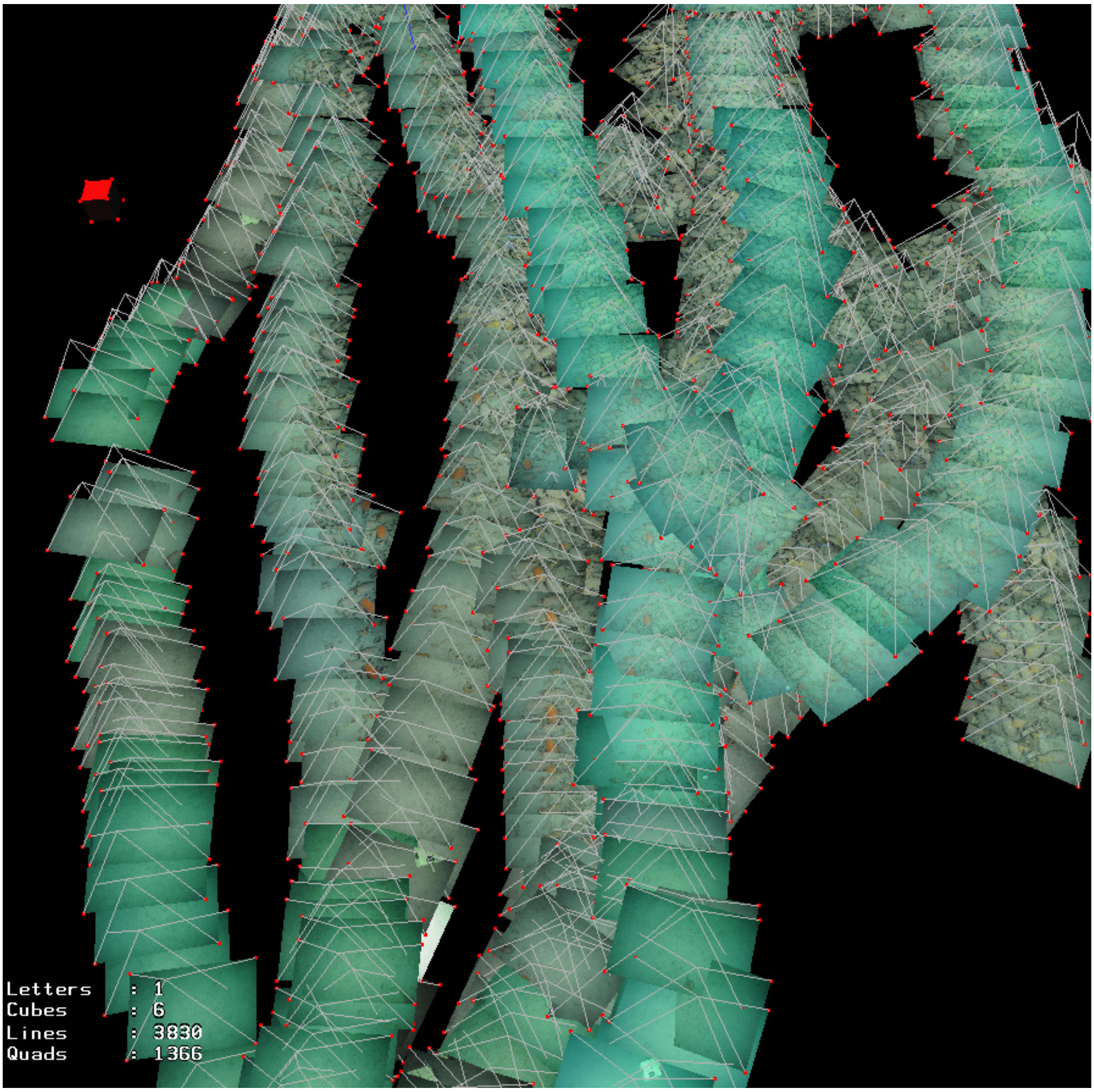


Figure 20. VRML of all the photograph, projected one meter from the optical center.

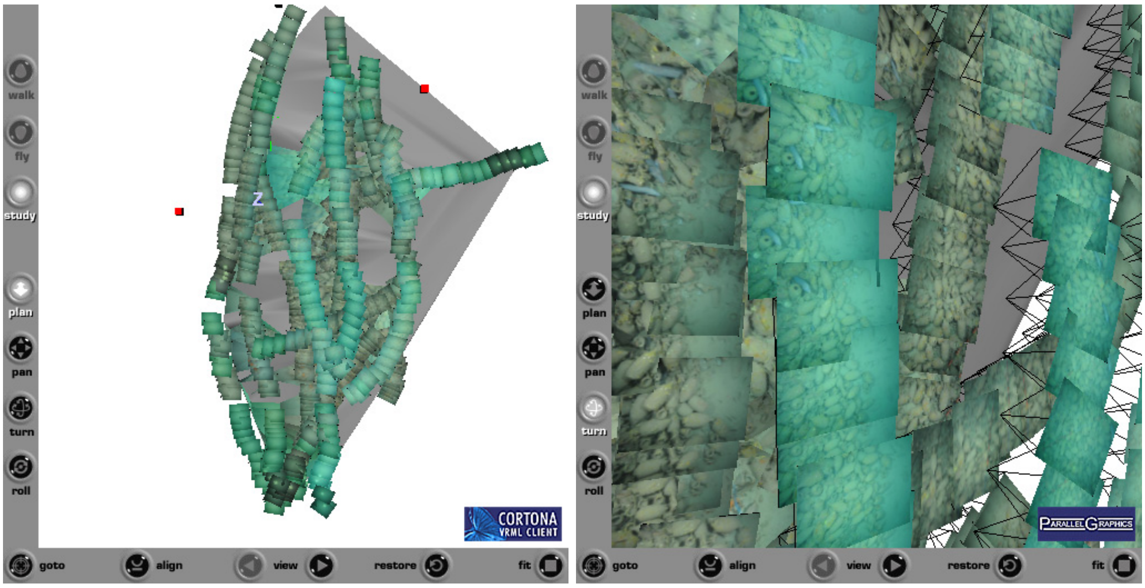


Figure 21. 3D VRML visualisation using the full accuracy EXIF field.

The image above shows the photographs represented in VRML. On the left one the seabed is represented by a set of points (optical center of each photograph with the Z coordinate corrected by the photo altitude). On the right image we see clearly the two passages: the first one flying at 2m height the second one at 3m. In the second one the flashes illumination if more weak and the general color is affected by the ambient illumination.

6.1.4 Connection Table and overlap check.

The mosaic generated give information of the overlap in the absolute reference system. The VRML file gives also information about overlap and trajectory but only qualitative. We can get the information visually and a click on the image refers to the photograph and gives an access to the EXIF data.

We need indeed more quantitative information about the photograph configuration. To obtain these data we have three other file generated:

- An image of the seabed, georeferenced in GEOTIFF, with a resolution of 2cm, with a code color in accordance to the number of photograph in which these 2 square centimetres are seen.
- An ASCII table which say for each photograph all the photograph who have an overlap with it.
- And finally a ShapeFile which allows to visualise and analyse these data in a common or commercial GIS software.

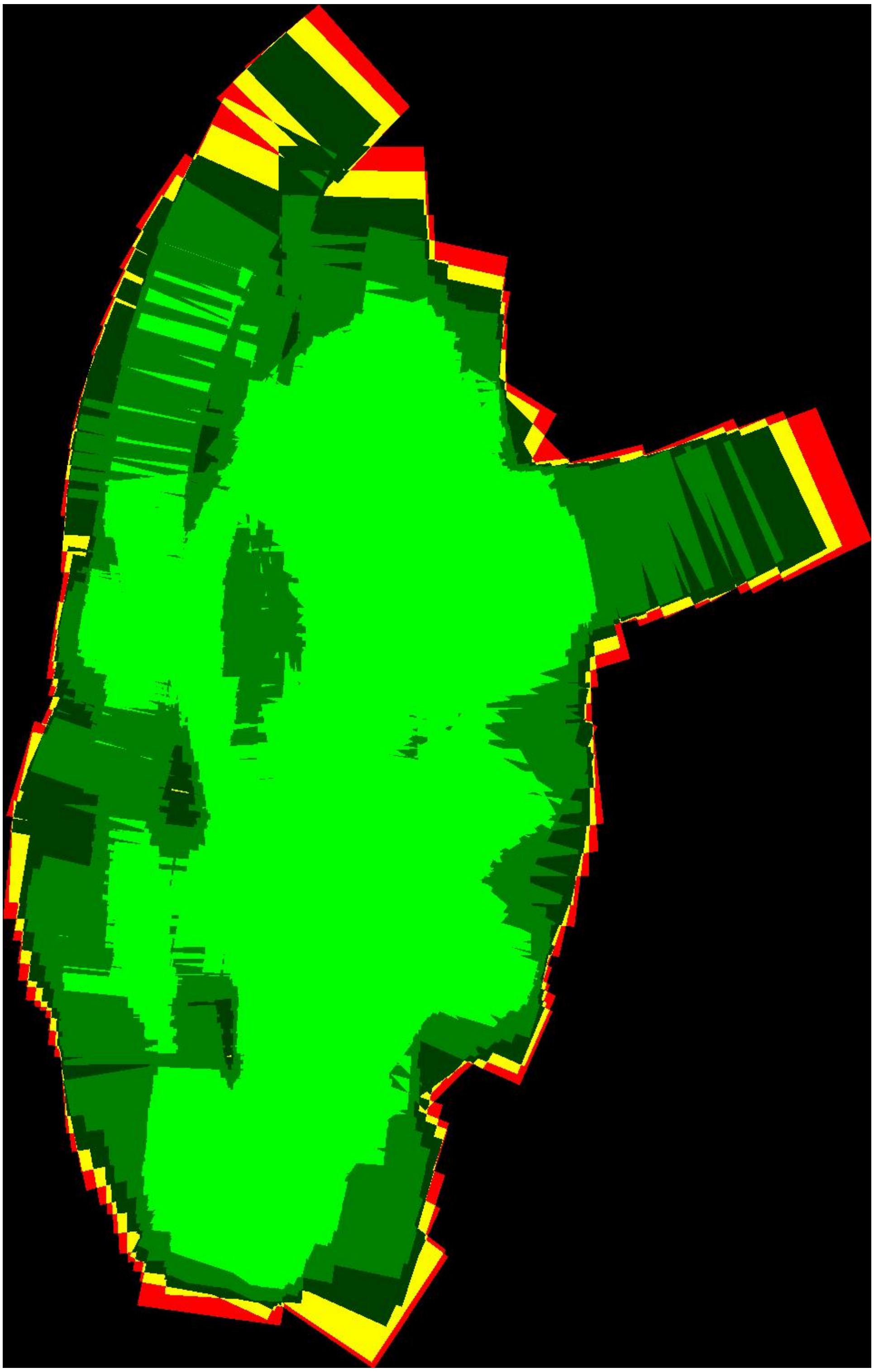


Figure 22. Geotiff Connection Map: 1 pixel = 2cm.

- No coverage
- Covered by 1 photograph
- Covered by 2 photographs
- Covered by 3 to 4 photographs
- Covered by 5 to 9 photographs
- Covered by at least 10 photographs

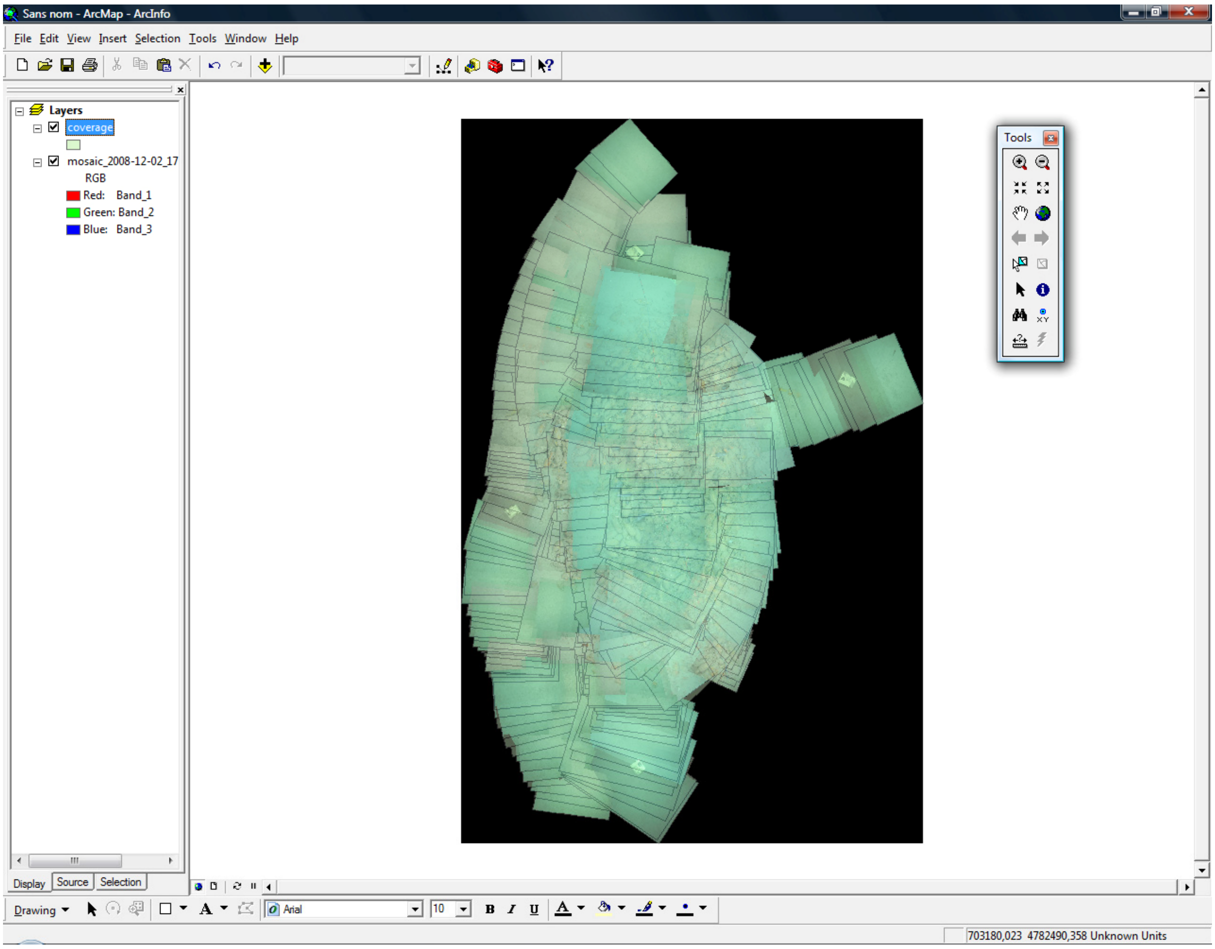
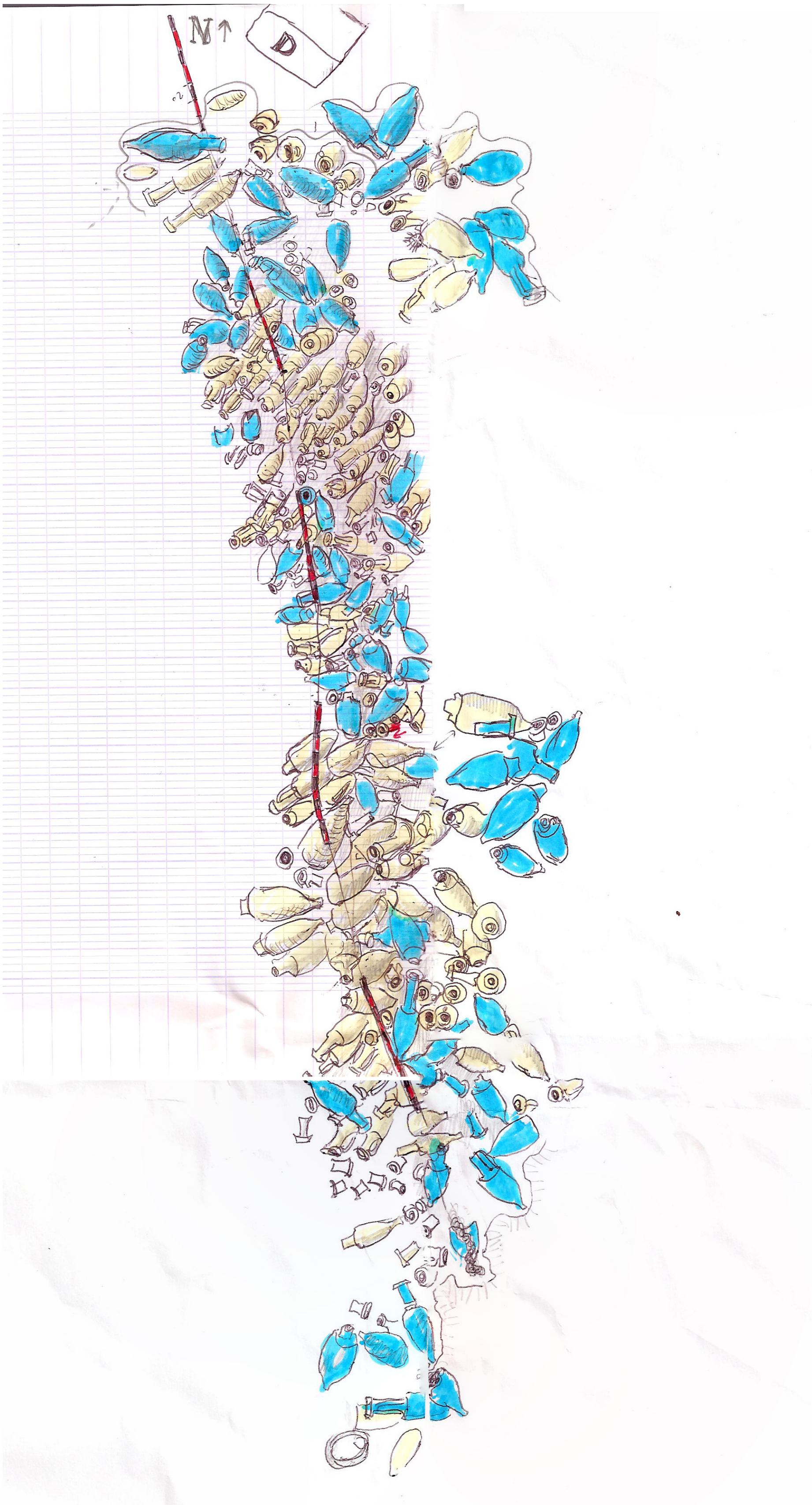


Figure 23. Exported ShapeFile visualized with ArcGis.

6.1.5 Archaeologist sketch

Since we were on site and making photograph Luc Long and Pamela Gambogi start to study and trying to design the site. At the beginning only with individual photograph, looking at them on the computer screen. Finally on October 11th, the navigation data were stored correctly and the rapid mosaic was generated.

This mosaic, generated on October 11th was printed and Luc Long can continue the site sketch with a complete document. Figure below show the central strip of the wreck redesigned by Luc Long with already a color code for an interpretation: in blue the amphorae which are not yet in their original place, probably moved by trawlers from fish boat, the amphorae without special color are interpreted as still in their original place.



175 amphorae, central strip
Cargo estimation (surface) 1000 amphorae

6.1.6 *Full accuracy navigation data*

During the mission, on October 11th, the navigation, position and attitude data are registered on the fly in the EXIF field directly by the Nikon D300 digital camera by means of the ISME software and hardware tools (see NikonControlSw and NCB01 description on D6.5). This is done using the GPS entry facility of the camera.

This way to do allow a registration in each photograph but the data to be registered has a predefined format. Our first problem is to synchronize all data inside the submarine taking care of the different refresh time of each installed sensor. Other solved problem is to store all the data we need in the exif area: we had to split the data in order to fill all the room available.

This solution has an inconvenient: we loose one digit on latitude/longitude and so we loose accuracy.

The lost is, of course, not definitive because future development of the digital cameras on the market naturally fix this problem. We temporarily solve the problem storing all the data also on external ASCII files by NikonControlSw tool.

That means that the data found on the EXIF field on October 11th at 11h45AM were truncated and the result obtained a bit more inaccurate than the real navigation data given by the sensors.

We need to run an external procedure, after recovering all the log files, to recomputed the entire data belonging to latitude/longitude.

After some days we obtain these data and the results, with the full accuracy on the data and the final result are presented in the next section. The different results between truncated en entire coordinate are not graphically significant but the entire data will be use in the work developed in Deliverable 2.3 regarding the automatic photo orientation.

Figure 24. Rectified Photo on the seabed. On the left with truncated data, on the right with complete data.

7 Rapid Mosaic generator software: user manual

7.1 Interface Description

The Rapid Mosaicing Interface relies on one frame as we can see in Figure 25.

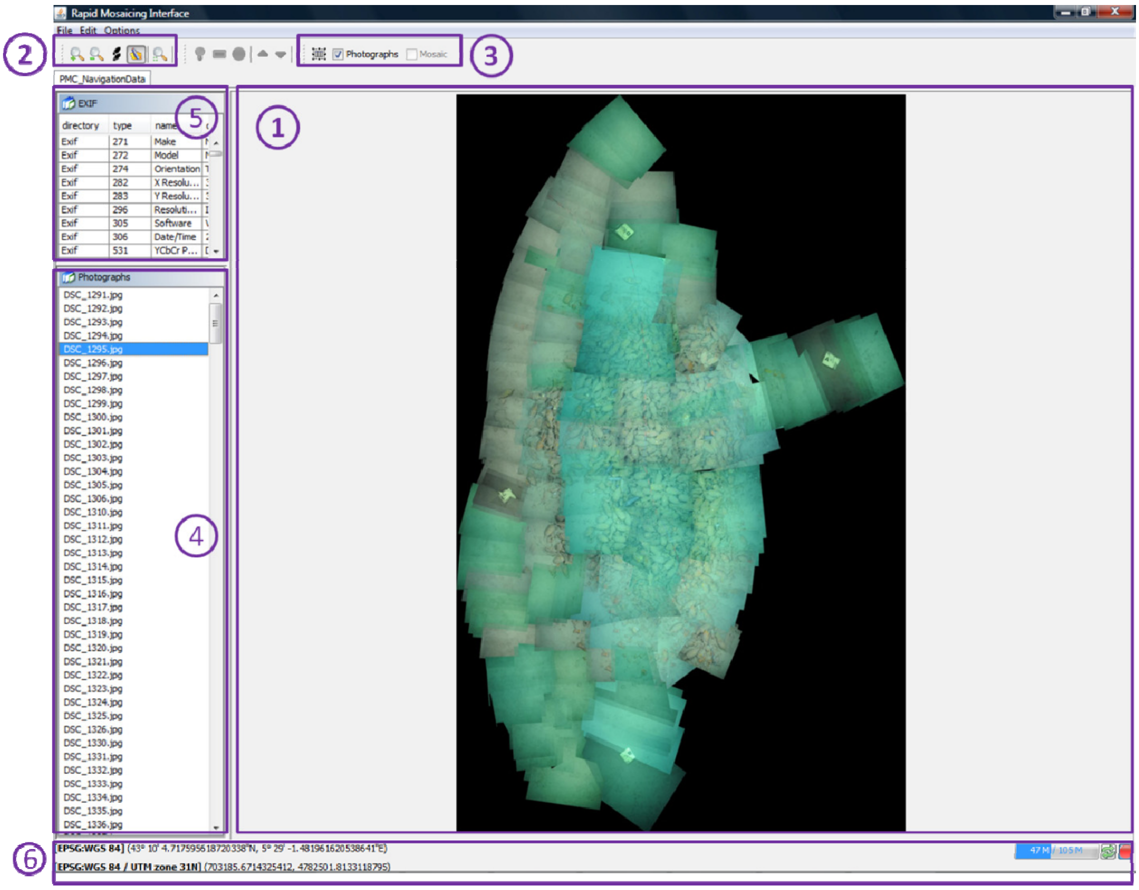


Figure 25 Overview of the Rapid Mosaicing Interface

The window is divided in 6 components:

1) The master view is dedicated to the display of georeferenced photographs rasters, photograph frames projected on ground (in red) and the mosaic itself.
2) The master view control bar enables to control the display provided by the master view (1). Controls are:
   - Zoom plus.
   - Zoom minus.
   - Pan (move the view).
   - Fit (zoom to display the entire site).
3) The photographs / mosaic tool bar provide the mosaic creation button ( ) and two checkboxes for a switch between photographs or mosaic display.
4) The photograph list display the name of the photographs currently displayed. A simple click on a photograph name selects its raster and its frame in the master view (1). A double click enables / disables the photograph take in account in the mosaic generation. A disabled photograph is not displayed in the master view (1) and is stated in red in the photograph list (2).
5) The Exif information panel specifies the available Exif metadata in the selected photograph. If several photograph are selected, only the metadata of the first photograph of the selection are displayed. This panel is purely informative; no modification can be done from it.

6) The state panel displays the coordinates of the cursor in the master view. The coordinate are expressed in WSG84 global system and in a site specific coordinate system (for example UTM31).

7.2 Mosaic generation

The mosaic generation from a set of photographs associated with navigation data is described here. The user has to follow these steps:

1) In the File menu, choose "Open Exifed Photographs…"
2) The dialog of the Figure 26 opens.

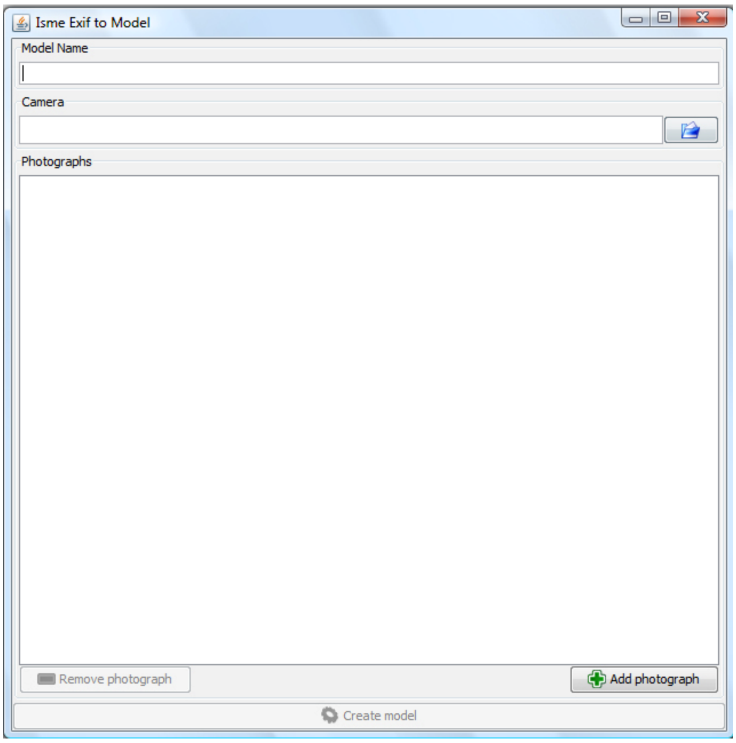
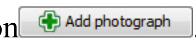


Figure 26 Exif to Model dialog

This dialog enables to automatically create an Arpenteur photogrammetric model from a set of photographs tagged with Exif metadata. In this dialog:

- Field "Model Name" is used for storing the model. The model name enable to identify other data files. In this document, we denote by **<model_name>** the name set up in this field.
- The field camera has to point on the Arpenteur XML description of the camera used for making of the photographs (if available, this field is read from Exif metadata).
- The list of photographs has to be filled by clicking the button 

. A file chooser appears to select the photographs to use.

3) A filled model creation dialog should be like the one in Figure 27.

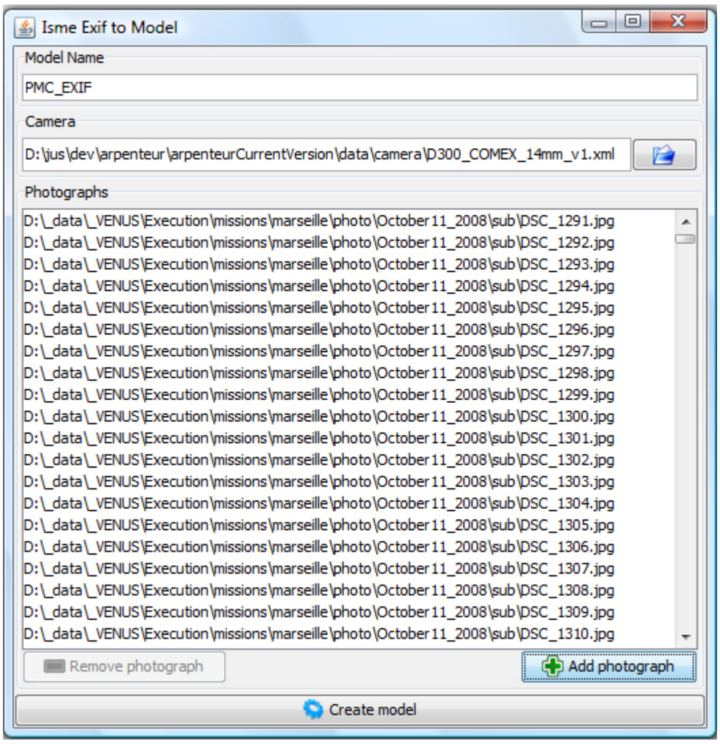


Figure 27 Full Exif to model dialog

From the filled dialog, the activation of the 

button launch the model generation.

4) When the model is generated, it is stored as an XML file in the "model" directory of Arpenteur workspace and can be used by other applications. The rapid mosaic interface shows a new dialog box dedicated to the automatic photograph rectification, as we can see in Figure 28.

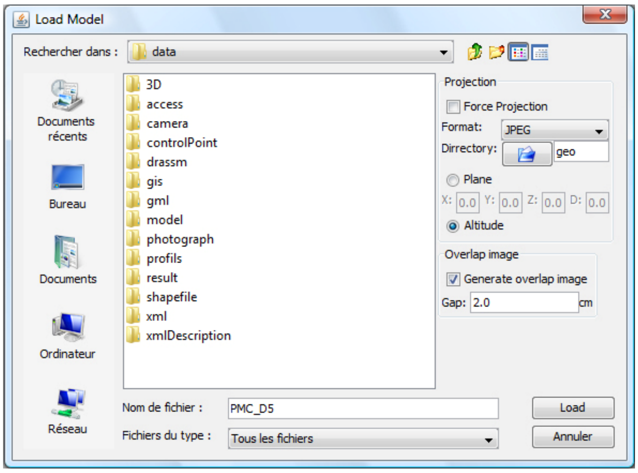


Figure 28 Model loading and photograph rectification parameters dialog

5) In the model loading dialog, a model XML file has to be chosen (if the dialog appears after a model generation from Exif, the file is already chosen). The right pane of the dialog is dedicated to the rectification parameters:
   - The "Force Projection" checkbox has to be checked if the photograph rectification is wanted. *By default (and for a first time use of the model) this checkbox has to be selected.*

- The “Format” combo box specifies the format of the worlds referenced images produced by the rectification process. *By default, the JPEG/JGW format is used*.
- The “Directory” field points the directory where the world referenced images are stored. The directory can be changed using the button. *By default, rectified photographs are stored is a sub-directory of the photograph files root called “geo”*.
- The “Plane” radio button has to be selected for a rectification using a constant plane to project the photographs. In this case, the plane equation is provided using the X, Y, Z and D fields.
- The “Altitude” radio button is selected if the rectification process uses the depth (Z) and the altitude from the sea bottom of each photograph. *This radio button is selected by default if the model used provides an altitude for each photograph. The altitude and plane radio button are exclusive*.
- The overlap image control enable (if checked) to generate a raster representation of the site photographic overlap. The gap between two points on the site has to be specified, in cm in the appropriate field. By default, the overlap image is activated with a gap of 2cm.
- When all parameters are specified, the activation of the button “Load” launches the rectification process.

6) When the rectification process is finished, the master interface opens. If the photographs are not visible, a click on the fit button will make it appear. The master view is now like in Figure 29.

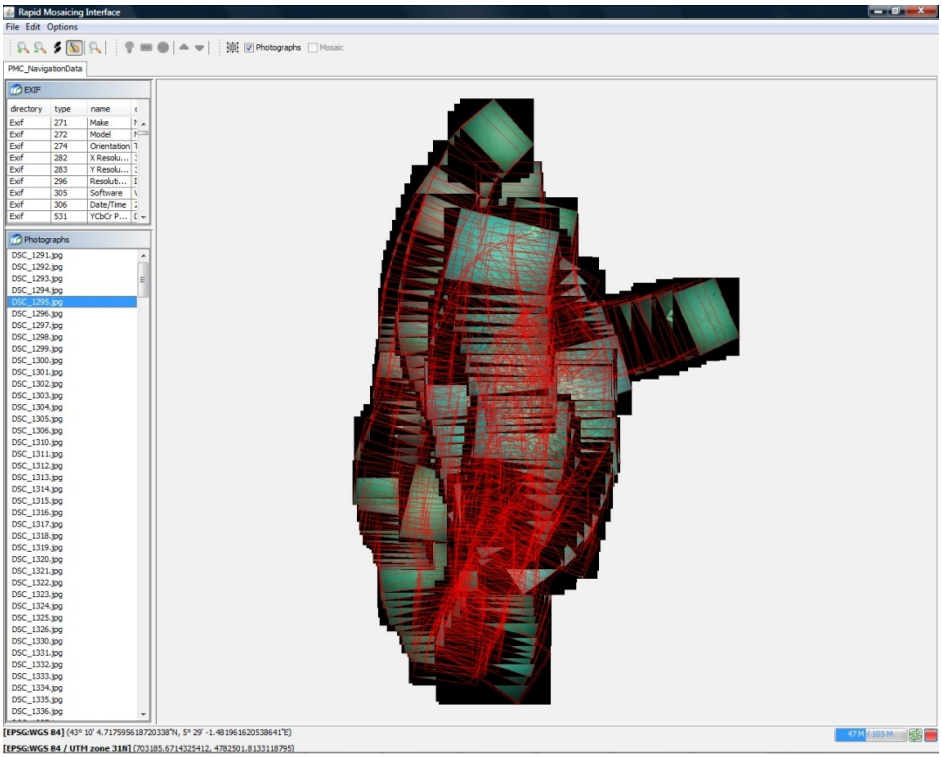


Figure 29 Rapid Mosaicing Interface

The rectification process has created some files that can be used in standard GIS software. These files are:

- A set of world referenced images representing the rectified photographs (*available by default in the "geo" subdirectory for each photograph directory*)
- A representation of the photographs frames projected on terrain (*by default in the "geo" subdirectory, the file is called "<model_name>_coverage.shp"*)
- A graphic representation of the terrain photographic overlap (*available by default in the "geo" subdirectory and called "<model_name>_overlap.jpg"*). The Figure 30 is an example of the coverage graphic representation.
- A connectivity graph representing the overlap between photograph (*stored by default as a tabular text file named "<model_name>_connectivity.txt"*)

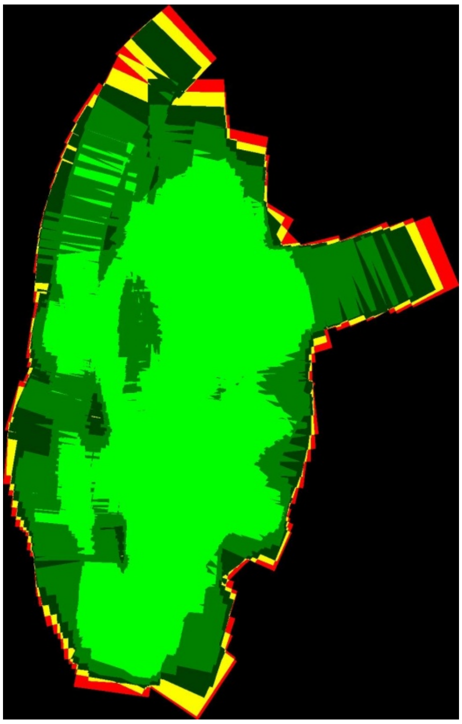


Figure 30 Graphic representation of the photogrammetric coverage of the site

All these files can be used in GIS systems such as ArcMap, Grass, JGrass or others.

7) The the master interface (Figure 29), provide simple controls to select the photographs involved in the mosaicing process. A photograph can be added / removed to the process by double clicking on its image within the master view or on its name in the photograph lists. *By default all photographs are selected.*
8) The mosaic automatic generation is performed by activating the button . The mosaic process creates a mosaic, display it in the master interface and store it as a world reference file. The default directory of the mosaic file is the directory "geo" and the name of the file is "*<model_name>_mosaic.jpg*".

At the end of the process, the main interface display the mosaic created and the original photographs frames. The mosaic generation process can be performed yet with a new set of photographs.

7.3 Generating and exporting data

The mosaic creation process follows different steps and can be retrieved from a previous session with available data. The rapid mosaicing interface enables also to export data in different ways. The export commands are grouped in the menu File (Figure 31).

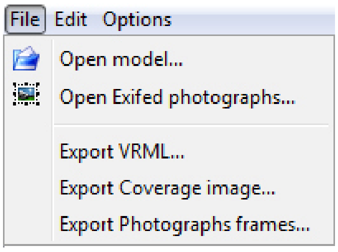


Figure 31 File menu of the main interface

The three main exports commands are available from the following items:

- The “Export VRML” item enables to create two VRML files one representing the oriented photographs projected on space the second one all the photograph are projected onto a horizontal plane, with transparencies, to visually check the overlaps.
- The “Export overlap image…” item is dedicated to the export of world referenced image file describing the coverage of the site by a set of photographs and shows the overlap.
- The “Export photographs frames” item enables to the export of an ESRI Shapefile formatted file describing the rectified photographs frame (photographic coverage)

8 References

[1] Allais A.G., Borgetto M., Opderbecke J., Pessel N., Rigaud V., « Seabed vidéo mosaicking with MATISSE: a technical overview and cruise results », Proc. of 14th Internadonal Offshore and Polar Engineering Conférence, ISOPE-2004, vol. 2 pp 417-421, Toulon, France, 23-28 Mai 2004.

[2] Garcia, R.; Batlle, J.; Cufi, X.; Amat, J Positioning an underwater vehicle through image mosaicking.Robotics and Automation, 2001. Proceedings 2001 ICRA. IEEE International Conference onVolume 3, Issue , 2001 Page(s): 2779 - 2784 vol.3Digital Object Identifier 10.1109/ROBOT.2001.933043

[3] T. Nicosevici, R. Garcia, S. Negahdaripour, M. Kudzinava and J. Ferrer. "Identification of Suitable Interest Points Using Geometric Photometric Cues in Motion Video for Efficient 3-D Environmental Modeling", IEEE International Conference on Robotics and Automation (ICRA), Rome, Italy, pp. 4969-4974, 2007

[4] J. Ferrer, A. Elibol, O. Delaunoy, N. Gracias, R. Garcia, Large-Area Photo-Mosaics Using Global Alignment and Navigation Data, MTS/IEEE OCEANS, Vancouver (Canada), Nov. 2007.

[5] Geotiff Specification, http://www.remotesensing.org/geotiff/spec, Remote sensing GeoTIFF consortium.

[6] TIFF Specification, http://partners.adobe.com/public/developer/en/tiff/TIFF6.pdf, Adobe

System Incorporated.

[7] Exif format 2.2 specification, http://www.exif.org/specifications.html, Exif.org consortium.

[8] S. Sotoodeh, D. Novàk, M. Sauerbier, D. Scaradozzi, A. Caiti, G. Conte, S. M. Zanoli, P. Drap, P. Chapman, A. M. Pascoal, "UPGRADE and IMODELASER: Tools and Best Practice for 3D Data Acquisition and Processing for CH in Different Environments", EPOCH Conference on Open Digital Cultural Heritage Systems (2008)

[9] R. Eustice, H. Singh, and J. Howland, "Image registration underwater for fluid flow measurements and photomosaicking," in Proc. of the Oceans 2000 Conference, Providence, Rhode Island, USA, September 2000.

[10] E. Trucco, A. Doull, F. Odone, A. Fusiello, and D. M. Lane, "Dynamic video mosaics and augmented reality for subsea inspection and monitoring," in Proc. of the Oceanology International Conference 2000, Brighton, England, March 2000.

[11] E. Trucco, Y. Petillot, I. T. Ruiz, C. Plakas, and D. M. Lane, "Feature tracking in video and sonar subsea sequences with applications," Computer Vision and Image Understanding, vol. 79, no. 1, pp. 92–122, July 2000.

[12] H. Singh, J. Howland, L. Whitcomb, and D. Yoerger, "Quantitative mosaicking of underwater imagery," in Proc. of the IEEE Oceans 98 Conference, Nice, France, September 1998.

[13] S. Negahdaripour, X. Xu, A. Khamene, and Z. Awan, "3D motion and depth estimation from sea-floor images for mosaic-based positioning, station keeping and navigation of ROVs/AUVs and high resolution sea–floor mapping," in Proc. IEEE/OES Workshop on AUV Navigation,Cambridge, MA, USA, August 1998.

[14] S. Fleischer, "Bounded–error vision–based navigation of autonomous underwater vehicles," Ph.D. dissertation, Stanford University, California, USA, May 2000.

[15] X. Xu and S. Negahdaripour, "Application of extended covariance intersection principle for mosaic-based optical positioning and navigation of underwater vehicles," in Proc. International Conference on Robotics and Automation (ICRA2001), Seoul, Korea, May 2001, pp. 2759–2766.

[16] H. Sawhney, S. Hsu, and R. Kumar, "Robust video mosaicing through topology inference and local to global alignment," in Proc. European Conference on Computer Vision. Springer-Verlag, June 1998.

[17] E. Kang, I. Cohen, and G. Medioni, "A graph–based global registration for 2D mosaics," in Proc. of the 15th International Conference on Pattern Recognition, Barcelona, Spain, 2000.

[18] K. Duffin and W. Barrett, "Globally optimal image mosaics," in Graphics Interface, 1998, pp. 217–222.

[19] R. Unnikrishnan and A. Kelly, "Mosaicing large cyclic environments for visual navigation in autonomous vehicles," in Proc. International Conference on Robotics and Automation (ICRA2002), Washington DC, USA, May 2002, pp. 4299–4306.

[20] R. Garcia, J. Puig, P. Ridao, and X. Cufi, "Augmented state Kalman filtering for AUV navigation," in Proc. International Conference on Robotics and Automation (ICRA2002), Washington DC, USA, May 2002, pp. 4010–4015.

[21] J. Zheng and S. Tsuji, "Panoramic representation for route recognition by a mobile robot," International Journal of Computer Vision, vol. 9, no. 1, pp. 55–76, October 1992.

[22] X. Xu, “Vision–based ROV system,” Ph.D. dissertation, University of Miami, Coral Gables, Miami, May 2000.

[23] G. Conte - S. M. Zanoli - D. Scaradozzi ,”Guide and control of an unmanned underwater vehicle by visual-feedback techniques”, in IARP International Workshop on Underwater Robotics for Sea Exploitation and Environmental Monitoring, Rio de Janeiro, Brasil, 2001.

[24] G. Conte - S. Zanoli - D. Scaradozzi, Barcellona, “An automatic guidance system for a small work-class ROV”, in 15th IFAC World Congress, Spain, 2002.

[25] G. Conte - S. Zanoli - D. Scaradozzi, “An Automatic Guidance System for an Underwater Remotely Operated Vehicles”, in Proceedings NiWeek2002, Austin, TX, 2002.

[26] G. Conte - S. Zanoli - L. Gambella ,”On the Problem of Underwater Simultaneous Localization and Mapping using Mechanical Scanning Sonar”, in Proceedings of The 2nd International Symposium on Control, Communications and Signal Processing, Marrakech, Morocco, 2006.

[27] G. Conte - L. Gambella - D. Scaradozzi - S. M. Zanoli, “Acoustic Mapping and Localization of an ROV”, Proc. 14th Mediterranean Conference on Control and Automation, Ancona, Italy, 2006.

[28] G. Conte - L. Gambella - D. Scaradozzi - S. M. Zanoli , “An Approach to Underwater SLAM using Mechanical Scanning Sonar”, Proc. 7th IFAC Conference on Manoeuvring and control of Craft, Lisbon Purtugal, 2006.

[29] G. Conte, S. M. Zanoli, D. Scaradozzi, S. Maiolatesi, “Visual-feedback Positioning of an ROV”, in Proceedings of The IFAC Conference on Control Applications in Marine Systems 2004, Ancona, Italia, 2004.

[30] G. Conte, S. M. Zanoli, D. Scaradozzi, S. Maiolatesi, “Visual-feedback Positioning of an ROV” , in Proceedings of The IFAC Conference on Control Applications in Marine Systems CAMS 2004, Ancona, Italy, 2004.