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ROV-3D,
3D underwater survey combining optical and acoustic sensor

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Abstract
ROV 3D project aims at developing innovative tools which link underwater photogrammetry and acoustic measurements from an active underwater sensor. The results will be 3D high resolution surveys of underwater sites. The new means and methods developed aim at reducing the investigation time in situ, and proposing comprehensive and non-intrusive measurement tools for the studied environment.

In this paper, we are presenting a new method of 3D surveys which are dedicated to high resolution modeling of underwater sites. The main met constraints in situ are taken into account and this method leads to a precise 3D reconstruction. Some examples will present both the main obtained results and their limitations. We will end with the perspectives and the necessary improvements to the method, so as to automate the multimodal registration step.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality

1. Introduction and main goals

ROV 3D project, labeled by the competitiveness cluster “Mer PACA”, was chosen during the 10th call for project of the “*Fond Unique Interministériel*” (FUI). It is funded for a three year period by the French ministry of Industry.

The consortium consists of an organization of academic research, LSIS laboratory, and of two industrial partners, COMEX and SETP. COMEX is skilled in underwater scouting and outdoor engineering, whereas SETP is skilled in dimensional control by photogrammetry and topometry.

At the present time, and in the field of high resolution underwater surveys, there is no industrialized automatic treatment. Although, nowadays, certain private businesses propose service charge in underwater sharp metrology by photogrammetry, these offers use traditional methods of close range photogrammetry, based on automatic recognition of coded targets and bundle adjustment. These approaches, precise as they are, need human interference on the object and a site preparation (target laying in the place you want to measure), which, in the underwater context, may be a great handicap.

The project’s goal is to develop automated proceedings of 3D surveys, dedicated to underwater environment, using acoustic and optic sensors. The acoustic sensor will allow acquiring a great amount of low resolution data, whereas the optic sensor (close range photogrammetry) will allow acquiring a low amount of high resolution data. From these two surveys, a high resolution numeric structure build 3D modeling of large complex scenes will be proposed to final users, with the production of different type of outputs (SIG 3D, MNT, Mosaic, …).

In practice, a 3D acoustic scanner will make a large scan of the scene to model, and an optic system will make the high resolution photogrammetric restitution of the different areas in the scene. While our software tools will do the automatic registration of both data sources, other algorithms, developed during the project, will recognize and model objects of interest. Eventually, these data will allow us to establish objects’ symbolic representation and

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their geometry in a precise virtual facsimile, responding to the partners' need in documentation.

The ability to measure and model large underwater sites in a short time opens up many scientific challenges such as image processing, multimodal adjustment, land visualization and offers new opening to marine biology, underwater archaeology and underwater industry (offshore, harbour industry, etc.).

1.1 Underwater Image processing: State of art

The image degradation in underwater environment is often due to imperfections of the sensors, absorption and scattering of artificial light caused by suspended particles known as "marine snow" and the physical properties of the environment.

The image processing can be addressed from two different points of view: as an image restoration technique or as an image enhancement method [SC10].

Image restoration techniques aim to find the image original from an observed image, but these techniques need some parameters such as attenuation and scattering coefficients and also estimate of the depth of the object in a scene. For this reason this part is devoted to image enhancement methods, which do not require a priori knowledge of the environment.

Stéphane Bazeille proposed an algorithm to enhance underwater image, this algorithm is automatic and requires no parameter adjustment. Firstly, it corrects the non-uniform illumination with use of homomorphic filter, then suppress noises with wavelet denoising, enhance edges with anisotropic filtering and finally adjust colors with equalization of histogram to suppress predominant color [BQJ*06].

The use of homomorphic filter will change the geometry of the scene, which will not help us in the use of SURF detector.

Iqbal Kashif et al. have used slide stretching algorithm both on RGB and HIS color models to enhance underwater images [IAO07]. First of all, their method performs contrast stretching on RGB and secondly, it performs saturation and intensity stretching on HIS color model. The advantage of applying two stretching models is that it helps to equalize the color contrast in the image and also addresses the problem of lighting.

Majed Chambah, proposed a method of color correction based on the ACE model. ACE "Automatic Color Equalization" is based on a new calculation approach, which combines the Gray World algorithm with the Patch white algorithm, taking into account the spatial distribution of information color. The ACE is inspired by human visual system, where is able to adapt to highly variable lighting conditions, and extract visual information from the environment [CSR*03].

The aim of improving the color is not only for better quality images, but also to see the effects of these methods on the SURF in terms of its feature points detection.

Kalia et al.[KLB11] investigate the effects of different image preprocessing techniques which can affect or improve the performance of the SURF detector. And they propose new method named IACE 'Image Adaptive Contrast Enhancement'. They modify this technique of contrast enhancement by adapting it according to the statistics of the image intensity levels.

If P_{in} is the intensity level of an image, we can calculate the modified intensity level P_{out} from equation (1).

$$P_{out} = \frac{(P_{in} - c)}{(d - c)} \times (b - a) \quad (1)$$

Where, a is the lowest intensity level in the image and equal to 0, b is its corresponding counterpart and equal to 255 and c is the lower threshold intensity level in the original image for which the number of pixels in the image is lower than 4% and d is the upper threshold intensity level for which the number of pixels is cumulatively more than 96%. These thresholds are used to eliminate the effect of outliers, and improve the intrinsic details in the image while keeping the relative contrast.

The result of this algorithm is very interesting. They observe that the relative performance of *IACE* method is better than the histogram equalization method, in terms of time taken for the complete detection and matching process.

1.2 Underwater object recognition

Pattern recognition process is complex and approaches to solve it are very different, depending on whether we have an a priori knowledge of the object or not, depending on the type and the number of used sensors (one or more 2D cameras, 3D cameras, telemeter, etc.), depending on the type of object to be detected (2D, 3D, random form, ect.). Nevertheless, there are two main family of methods to build a pattern recognition system: structural methods and statistic methods.

The first application related to our project is red coral monitoring. From its tentacular form, we are aiming at developing a structural approach which uses the objects' median (skeleton) axis as form descriptor.

There are many applications for 2D and 3D objects' skeletons in image processing (encoding, compression,...) and in vision in general [MDS06]. Indeed, we retrieve in the object's skeleton its topological structure; moreover, most of the informations which are contained in the form's silhouette can be retrieved in the skeleton. Another advantage that cannot be denied is the fact that, by nature, skeleton have a graph structure. Hence, after the encoding of the coral's form under a graph structure through a 3D skeletisation process, we are going to use powerful skills from the graph theory so as to complete the matching [SMZ*05].

The second application consists in archaeologist objects recognition on an underwater site. Because of the a priori informations we have, such as the type of the object (amphora, bottle, etc...), we will choose a statistic recognition method [BR05].

In an environment like wreck in 40 meters deep, the vision conditions are strongly damaged. It is then necessary to free ourselves from preliminary treatments such as edge detection, line detection and other structural primitive.

Recent works showed the interest in using learning methods like *adaboost*, see [FS97]. The advantage of this king of methods is to only need low level descriptors such as pixels'[BR05]. LBP's [AHP06], Haar's [VJ01], etc...

For our problem, we are going to implement an Adaboost classifier ; SIFT [LOW04] and/or SURF [BET*08] will stand for weak learners. We will check the relevancy of this method by comparing its results to other standard classifiers'.

1.3 Merging optical and acoustic data: State of art

Optic and acoustic data fusion is an extremely promising technique for underwater object mapping that has been receiving increasing attention over the past few years [FM04] [PES09]. Generally, bathymetry obtained with underwater sonar is done at a certain distance from the measured object (generally the seabed) and the obtained cloud point density is rather low in comparison with the one obtained by optical means [DDP*05].

Since photogrammetry requires working on a large scale, therefore it makes it possible to obtain dense 3D models. The merging of photogrammetric and acoustic models is similar to the fusion of data gathered by a terrestrial laser and photogrammetry. The fusion of optical and acoustic data involves the fusion of 3D models of very different densities – a task which requires specific precautions [HCS10].

1.4 Terrain visualisation

In volume's visualisation domain, we can find many tools for exploring data, especially those applied to review volumetric ones. To render these data, Indirect Volume Rendering techniques (IVM) are the most used, and the Marching Cubes algorithm (MC) (Lorensen & Cline, 1987) is one of the most popular and latest algorithms of surface construction with a constant density from 3D scalar field employed in a very wide range of applications.

Marching Cubes method creates a triangulated mesh of polygonized iso-surface extracted from the 3D scalar field. Considering the space like an imaginary 3D regular grid, every eight adjacent vertices, called "corners", define a voxel (cube). The reconstruction is made by a local processing of each cell (cube) independently. All corners have a value which will be compared with the value characterizing the iso-surface. If it's equal that means the corner is inside the object to reconstruct (below the iso-surface), otherwise it's outside the solid space (above the iso-surface).

If a cell has both "inside" and "outside" corners, it determines that the iso-surfec passes through it. The polygonizing process concatenates intersection's vertices (the intersection between the iso-surface and the cube's edges); the coordinates of these vertices are computed by an interpolation process using the coordinates of cell corners.

Technically there are 2^8 possible configurations of triangulation of the iso-surface's part extracted within a cube (see Figure 1), organized in 15 equivalence classes depending on the number of internal/external corners and symmetries as shown in Table 1.

The original Marching Cubes algorithm has a well-known defect in the involving called ambiguous cases, which related to the organisation of equivalence classes. first identified by Dürst [DÜR88]. To resolve these problem others classifications appeared, like 33 equivalence classes of [CHE95] and 20 equivalence classes of [TMC01].

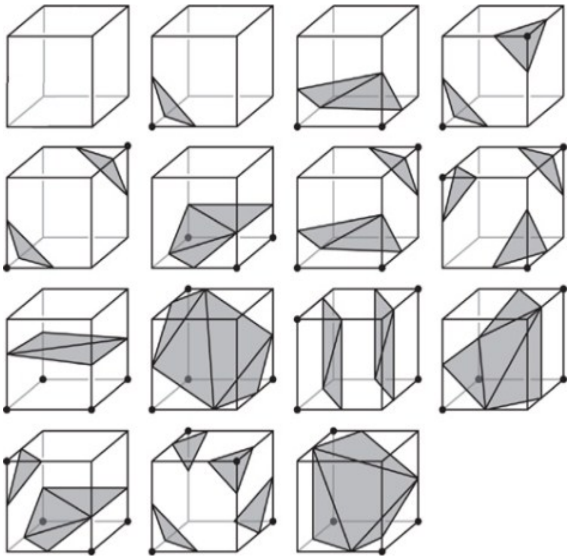

Figure 1. 15 equivalence classes of the 256 possible configurations, ranked by [LH87] black corners are below iso-surface.

Symmetry used	*Equivalence classes*
None	256
Reflection	128
Rotation	23
Rotation + mirror	22
Rotation + reflection	15
Rotation + reflection + mirror	14

Table 1. Symmetry equivalence classes [RH99].

The advantage of Marching Cubes is to process in each cell (cube) independently, and all intersections in a cell are computed once.

We presented the principle of Marching Cubes Algorithms, and we recommend [NY06] for more information. However, we propose a new method for modelling and visualizing grounds with specific annotations, allowing the representation of caves, and over all using data coming from different sensors and measuring tool (as multibeam, photogrammetry at several scales …).

Like Marching Cubes algorithm, our approach is based on a regular tiling of the space's representation and a set of allowed configurations of triangles for each relevant tile. But, instead of triangulating intersection's vertices, we approximate points cloud inside a cube to the most appropriate existing configuration, and we'll consider the adjacent cubes of the Voxel map to ensure continuity (water-tight surface).

In the other hand, whereas Marching Cubes uses only scalar field data, our technique considering a points cloud in each voxel permits to use data of various origins and resolutions. We will employ only point clouds to build the model. This is particularly relevant in the case of multi resolution point clouds.

By pre-computing a model at various resolution levels, we can use them at a low cost, i.e. with very little computation for visualization.

The accuracy is strongly linked with both the tilling option taken and the point cloud density, consequently no relevant measures are possible inside a tile.

An important step in the project will be the choice of an optimization method that leads to a proper ground model.

The proposed visualization, mainly focused on a qualitative aspect, will be enriched with textures using the camera orientation when the seabed is visible on photographs or video.

In addition it will be possible, using annotation, georeferencing artefacts or local flora implantation. These external data will be stored and accessed through external storages.

Nevertheless, in a real time visualization context, we will need to generate models at different resolution levels in order to get a complete multi-scale representation. The choice of a suitable scale level for visualizations will depend, for instance, on the distance to the observer.

This approach will be extending to allow time change visualization. The temporal evolution will be stored at the tile level every time it is needed

2. Photogrammetry: Dense map

To model the environment by photogrammetry in an unsupervised way it is first necessary to automatically orient a set of unordered images. This orientation phase, which is crucial in photogrammetry, as computer vision, has seen the past three years a great boom. The problem was first solved in the case of ordered series of photographs, for example, made a circle around an object and recently in the case of photographs unordered [BSR10] [SRZ07]. Once all the photographs are oriented several methods are proposed for producing a dense cloud of 3D points to represent the area photographed.

Two major families of methods exist. Those that use solid models as the voxels [FP10] [GPQ*05] are based on the discretization of space into cells and the goal is to discriminate between full and empty cells to define the boundary between them. The advantage of this method is to use lots of photographs taken from arbitrary viewpoints. In contrast the delicacy of the final model depends on the resolution of the voxel grid can be RAM consuming. On the other hand methods using meshes could adapt their resolution to better reconstruct the details of the scene [MK00].

Since 2007 IGN (InstitutGéographique National, in France) has decided to publish in open source the APERO MICMAC software, dedicated to the automatic orientation of an unordered set of photographs and the calculation of the automatic mapping on a set of photographs oriented. (Http://www.micmac.ign.fr) [PC11].

Also the work of Furukawa and Ponce on the dense map generation [AFC*10] [FP10] have also resulted in open source publications. We use this work for several months and some examples are presented in this paper.

These developments were coupled with a software bundle adjustment of operating on an unordered set of photographs are based on an implementation of SIFT on GPU due to Changchang Wu, University of Washington (http://cs.unc.edu/ccwu / siftgpu) and implantation of developments PhotoTourism [AFC*10] [SSG10]. The bundle adjustment used is based on the Sparse Bundle Adjustment of Lourakis [LA09].

3. Acoustic survey

The acoustic survey is mainly useful to produce a 3D model of the complete submarine site with a good precision in an absolute coordinate system.

To perform this survey an acoustic scanner 3D is used which can produce multiple 3D points with a same couple (x,y) coordinates, in opposite of standards bathymetric echo sounder.

This particularity is a essential to create a model of complex structures like walls, caves, overhangs…

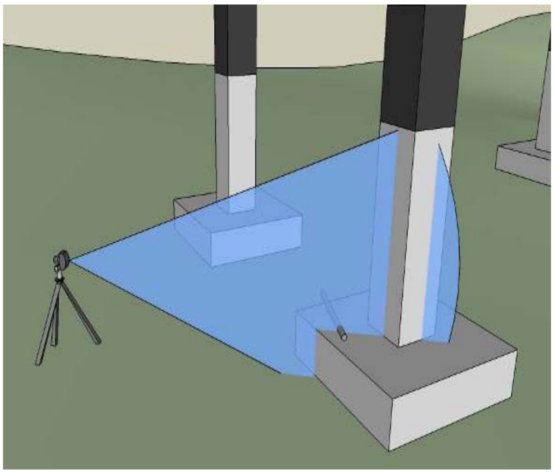

Figure 2. Acoustic scanner schema of use.

The *BlueView BV5000* system used is composed of a high frequency sonar (1,35MHz), mounted on a pan & tilt system. Both Sonar and pan & tilt are managed from the surface by the dedicated software.

The system works by mechanically scanning a thin vertical sonar slice around the selected area. At each direction, a profile of the surface is taken and added to the other direction profiles to create a final 3D point cloud.

Through mechanical rotation of the sonar head, the BV5000 is capable of producing 3D points from a stationary location

To cover all the structure with enough density of points, multiple stations can be realized around the site and merged after by algorithms like ICP (iterative closest points).

Some reference points can be located with high accuracy in absolute coordinate system to georeferenced the final model.

The sonar head is composed of 256 beams for an aperture of 45°. The beam width is 1° per 1° and time resolution is 3cm. The maximum range is 30m to be optimal between 1 and 20m.

4. Experimentations

We present here the first experimentations of the ROV-3D project. The first one is merging acoustic data with photogrammetry in a cave close to Marseille (Figure 4). And the second one is a survey of a modern wreck, “le Liban” also close to Marseille. This second survey is done only with photogrammetry with more than 1000 photographs.

4.1 Close range acoustic and optical survey

Under the ROV-3D project we experimented with the fusion of acoustic data from two sensors, high precision, high frequency acoustic camera sold by Blue View and the photogrammetry system automatically MENCI society (see Figure 5). An experiment was done on the Cave of the Imperial land in Marseilles.

The 3D scanner is a BlueView BV5000 of active acoustic system that provides a point cloud of 3D high-resolution imagery of underwater sites, see Figure 5.

Unlike conventional bathymetric measurement systems that retain only the high points, the 3D sonar, installed near the bottom, can acquire and maintain multiple points of elevation Z for a given pair of coordinates (X, Y).

This system "Scanner" opens up new possibilities for constructing 3D models of complex structures such as drop offs, overhangs, or even caves see Figure 6.

Figure 3. *The acoustic camera in situ, just in front of the cave (see next image).*

The "3D scanner is mounted on a hinged support along 2 axes (horizontal and vertical) allowing rotation from top to bottom and from right to left.

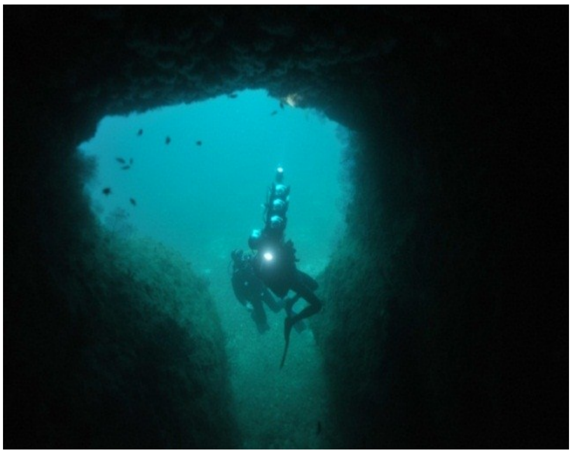

Figure 4. *The underwater cave close to Marseille, “L’Impérial de terre” 30m depth.*

With an acoustic aperture of 45 ° of the scanner itself and the system is capable of measuring an area of 45 ° or 360° on a spherical surface comprising the whole environment surrounding it on the scanner and a range up to 30m. In the latter case, the rotation along the vertical axis that accumulated along the horizontal axis allows 4 or 5 scans cover the entire hemisphere to be measured.

Each scan or set of scans are performed in a fixed position and using such a tripod. To obtain a sufficiently dense cloud of points on the stage and studied by size, and multiple stations can be performed and the results merged.

Figure 5. *The photogrammetric survey with the Menci approach (Three synchronized digital camera).*

Point clouds generated that were acquired from fixed stations, algorithms such as ICP (Iterative Closest Point) can assemble the sets of points against each other. It then remains to position the merged point cloud in an absolute reference, using reference points whose coordinates can be determined by acoustic positioning systems such USBL (Ultra Short Baseline).

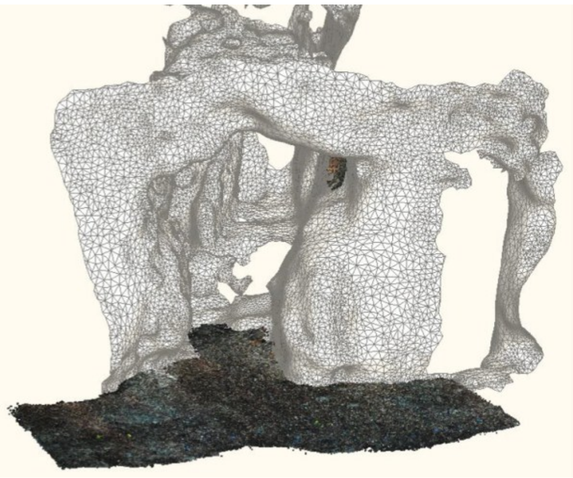

Figure 6. *Merging optical and acoustic underwater data.*

Two dives were devoted to the acquisition of 3D data with the scanner noise.

Two more dives were used to record by using the photogrammetry system MENCI see Figure 5. This system consists of a hardware part, three cameras on a linear, calibrated. The shots are processed by a synchronous software house, which on one hand trying to calculate beam by adjusting the largest block possible, i.e. the block containing the most triples as possible, then once the block is calculated, the triplets are used to obtain a depth map of the central apparatus producing a dense cloud of 3D point. The adjustment of the beam is therefore only there to ensure the cohesion of these triplets, the 3D points to them being calculated using a single triplet.

4.2 Large scale detail by photogrammetry

We also tested as part of this mission approach automatic mapping proposed by Furukawa and Ponce [FP10]. We tested this approach on large-scale details, Gorgonaria whose ends were slightly in motion because of the current, see the two figures below.

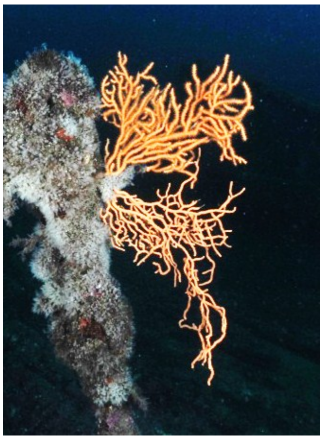

Figure 7a. *One of the 64 digital photographs taken.on the gorgonaria.*

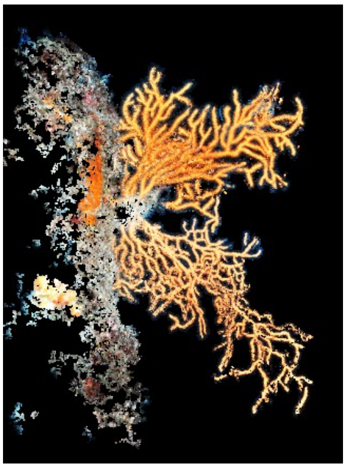

Figure 8b. *The point cloud automatically computed on the 64 photographs by the Furukawa method.*

One camera was used and sixty photographs were taken for each of the tests that follow. The study of the accuracy and the percentage of coverage was not yet done, that the study dating from April 2011.

4.3 The “Liban” wreck

The “Liban” is a ship built in 1882 in Glasgow (Scotland), measuring 91 meters long and 11 wide. It was equipped with a steam engine. On June 7, 1903 at noon, The “Liban” left the port of Marseille and less than one hour later sinks after a big collision with another ship see the two next figure..

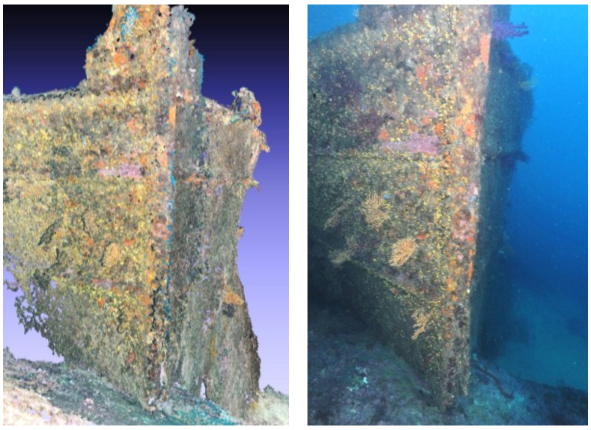

Figure 9. *On the right, one of the 1221 digital photographs took, on the left, The "Liban" wreck. : Cloud of 3D points measured by photogrammetry using Furukawa method.*

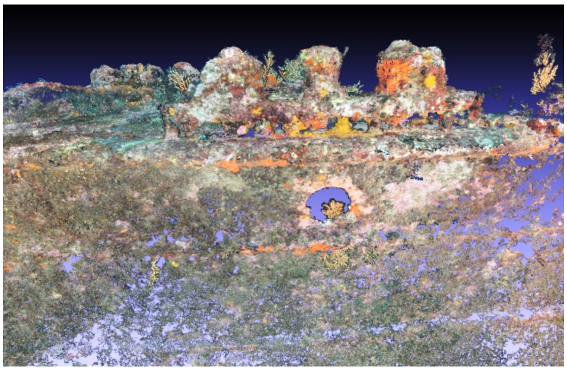

Figure 10. *Below, one of the 1221 digital photographs took, on the top, The "Liban" wreck.: Cloud of 3D points measured by photogrammetry using Furukawa method.*

5. Conclusion

The ROV3D is young and ambitious project, funded by the French ministry of Industry. It takes benefit from a strong collaboration between a research laboratory and two private companies in order to be able to test and improve methods and algorithms.

The project aims to produce a complete set of tools and methods for underwater survey in complex and varied environment, for example, real 3D sites as caves, wrecks, walls where a simple type of terrain modelling as DTM is not enough.

Moreover the interest of this project is to produce accurate 3D models with texture information and thanks to the combination between the acoustic and the optical approaches developing specific image processing filters in order to correct photo illumination in underwater conditions.

In addition, we want to add knowledge in the final survey and the 3D model produced will support link and database connection in order to offer GIS capabilities for the end user. The final 3D model will be an interface to the end-user data and will be able to offer several type of visualisation, founded in the same 3D measured data, according to the needs of the experts.

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