# VISUALLY PLEASANT BLENDING TECHNIQUES IN UNDERWATER MOSAICING

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*Image mosaicing can be defined as the regis-tration (or matching) of two or more images that are then combined into a single and usually larger one. The applications of mosaicing comprehend panoramic photography, super-resolution, virtual environments and vision based navigation systems, as a most relevant exponents. Besides generic camera issues as geometric and chromatic distortions, underwa-ter images are affected by particular factors as non-uniform illumination, caustics, blurring, suspended particles and scattering, making even more difficult the alignment and blend-ing. The aim of this work is to perform a re-view on the existing image blending techniques specially focusing the study on its application on the underwater imaging.*

**1. Introduction**

Underwater photo-mosaics can be used to gain a global perspective of interest sites. Mosaics to be analyzed by underwater biologists or geolo-gists are easier to be interpreted if they are visu-ally pleasant, and should have two desirable properties. Firstly, the mosaic should be geo-metrically and photometrically as similar as possible to the input images. Secondly, the seam between the stitched images has to be invisible.

Image blending is the final step in producing high-quality image mosaics. Radiometric varia-tions in overlapping views and violation of certain scene assumptions such as rigidity, sta-tionary, and (or) planarity, lead to geometric misalignments (e.g. due to the parallax effect) and photometric differences. Upon blending, these mosaics usually result in degrading arti-facts, such as blurry regions or disturbing seams.

Two main seamless blending methods groups have been differentiated. On one hand, transi-tion smoothing techniques concentrate their efforts on combining information of two or more images with a common overlapping region in order to achieve the optimal contribution, minimizing the visibility of the seam in the joining region. Multiresolution Splining in the intensity [1], gradient [2] and wavelet domain [3] and Energy Minimization Multiresolution Splining [4] apply the idea of multilevel blend-ing on different image domains.

On the other hand, optimal seam finding tech-niques are based in the main idea of determining the best boundary (or set of boundaries, if mul-tiple stitching is carried out) that minimizes the visibility of the image seams. Methods based on relative differences [5] in order to find the con-tribution of each image to the final mosaic and methods that find the path with minimal inten-sity difference [6] fall in this category.

Finally, combined methods [7] try to improve the results taking profit of the benefits of both mentioned approaches.

**2. Results and Discussion**

In order to compare and evaluate the behavior of the mentioned approaches, the more repre-sentative methods have been implemented and applied to a set of images showing typical arti-facts in underwater imagery. Two methods have been selected from the transition smoothing approach: Multi-resolution Splining [1] and Energy Minimization Multi-resolution Splining [4]. Graph Cut seam finding based on Water-shed Segmentation [6] have been chosen as a representative of the optimal seam finding ap-proach. Finally, the Interactive Digital Photo-montage method [7] has been considered as a combined method. On the other hand, we pro-pose in this work a hybrid method based on the combination of methods belonging to the first two approaches. It is based on Graph Cut Seam Finding on a Watershed Segmentation and a Gradient Domain Blending on the obtained seam. This new method focuses on solving two main problems of image mosaicing: registration inaccuracies and illumination variations. Fig-ure 1 enables comparison among the different methods.

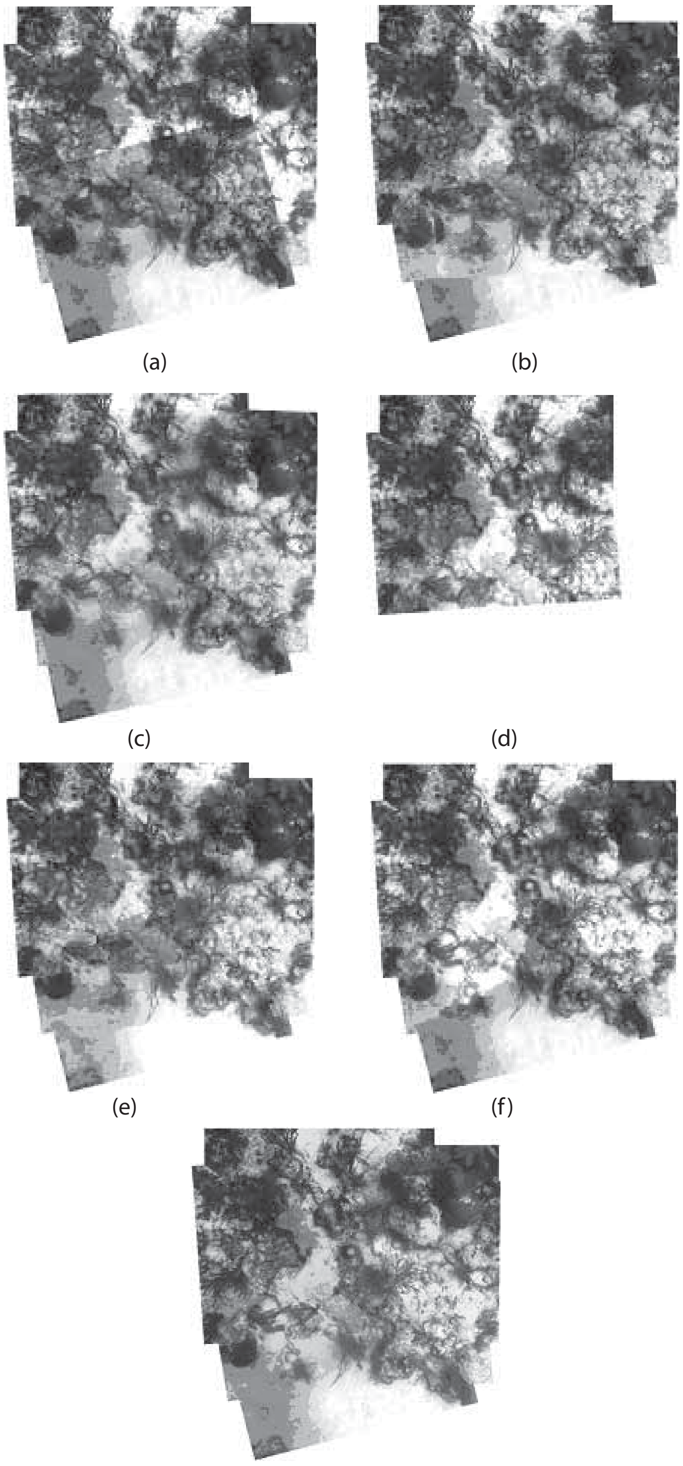


***Figure 1. (a) and (b) show a small mosaic ren-dered without any blending, using (a) "Last Image In" and (b) "First Image In" ap-***

***proaches. (c)-(g) show blending results using (c) Multi-resolution Splining, (d) Energy Minimization Multi-resoltion Splining (applied only on straight lines), (e) Interactive Digital Photomontage, (f) Graph Cut Seam based on Watershed Segmentation, (g) proposed hybrid method.***

**3. Conclusions**

The reviewed and obtained results demonstrate that transition smoothing methods are adequate for image mosaicing presenting an accurate registration, when moving objects or significant geometrical inconsistencies do not appear in the scene. The vignetting problem is well solved. Energy Minimization Multiresolution Splining is especially valuable to reduce the perception of large photometric inconsistencies Neverthe-less, the blurring on the overlapping region stills being sometimes noticeable.

Finding the optimal seam allows reducing the visibility of misalignment problems in the regis-tration. These methods are not able to solve by themselves the photometric inconsistencies, but actually reduce their visibility.

In the proposed hybrid method, Graph Cut based seam estimation allows to reduce the visibility of geometrical misalignments, while the application of this method on the Watershed segmentation increases the speed of the whole process, making it feasible for large images. Gradient Domain Image Blending, based on the imposition of boundary conditions to the gradi-ent belonging to the seams boundary, allows recovering the images through the Poisson equations, forcing the intensity of differently exposed mosaic areas to have the same lumi-nance level.

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# CREATING LARGE AND ACCURATE MOSAICS OF THE MID-ATLANTIC RIDGE

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**1. Introduction**

Seafloor imagery is a rich source of data for the study of biological and geological processes. Among several applications, sea-floor imagery can be used to construct image composites referred to as photo-mosaics. Photo-mosaics provide a wide-area visual representation of the benthos, and find applications as diverse as geological surveys, mapping and detection of temporal changes in the morphology of biodiversity and autonomous vehicle navigation.

The characteristics of the underwater environment offer several challenges for image mosaicing, mainly due to the significant attenuation and scattering of visible light. Moreover, light attenuation does not allow images to be taken from a large distance. Therefore, in order to gain global perspective of the surveyed area, mosaicing techniques are needed to compose a large number of images into a single one. Obtaining high quality mosaics requires a good harmony of the different steps, namely: motion estimation between overlapping images, detection of the non-consecutive overlapping image pairs, and global alignment. We present an approach for creating image mosaics using navigation data consisting on 3D position estimates provided by sensors such as LBL available in deep water surveys. A central issue with acoustic 3D positioning is that the accuracy is far too low compositing the images within reasonable accuracy.

**2. Approach**

We parameterize the camera trajectory in the most general terms using 6-DOFs (3D position and orientation), using unitary quaternions to represent the camera rotation in order to prevent singularities. The bundle adjustment step will optimize these poses to minimize a defined cost function.

As an input, we consider an image sequence captured at close range above the sea-floor, with sufficient overlap to allow automatic pairwise registration, plus its corresponding navigation data. Image-to-ground plane mappings are used to estimate planar homographies which allow for a simple definition of the error terms [1].

The algorithm starts with a coarse estimate of the trajectory given by the navigation data. This estimation allows detecting loops in the trajectory, and defining which sets of nonconsecutive images are likely to overlap.

Planar motion between consecutive and nonconsecutive image pairs is estimated using SURF [2] matches. Every pair of images is locally aligned according to the SURF result. Then, we extract Harris corners [3] in one of the images, and their correspondences are detected through correlation in the other image. If correspondences are not found, this motion is rejected. The new correspondences and the LBL camera readings are used as input observations for the minimization algorithm.

An initial 3D camera trajectory is computed from the navigation data and then used as the starting point for the non-linear minimization. The minimized cost function is defined as the weighted squared sum of the point-match and the LBL reading residuals:

$$\min \left( W_{PM} \sum_{k=1}^{n} \left( {}^{k}r_{ij}{}^{2} + {}^{k}r_{ji}{}^{2} \right) + W_{LBL} \sum_{k=1}^{n} {}^{k}r_{LBL}{}^{2} \right)$$

where ${}^{k}r_{ij}$ r is the difference between the point ${}^{k}x_{i}$ and the projection of its match ${}^{k}x_{j}$ in the image frame $i$ , ${}^{k}r_{ji}$ is the difference between the