



**LAPM: a tool for
underwater
Large-Area
Photo-Mosaicking**

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LAPM: a tool for underwater Large-Area Photo-Mosaicking

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This is the first article to present and to provide a finished and functional program to construct large geo-referenced photo-mosaics of the seafloor using feature detection and matching techniques. It also presents concrete examples of photo-mosaics produced with the LAPM tool.

2 Computer requirements

The LAPM tool was developed and compiled in Matlab, and is able to run on Windows, MacOS and Linux operating systems. No particular computer requirements other than those of the Matlab runtime are necessary. Currently the program does not implement any multicore parallelization. Nevertheless, it worked flawlessly on a 64 bit Windows 7 platform running on a 1.30 GHz Dual-Core Processor with 4 GB RAM, which is the minimum configuration the LAPM tool was tested with.

3 Mosaicking with the LAPM tool

3.1 Background

During the photo-mosaicking process, images are aligned together onto a single 2-D plane of the mosaic. The projection and alignment of an image onto the 2-D plane of the mosaic is called image registration (Zitová and Flusser, 2003). For underwater applications, images can be registered in different ways. First by geo-referencing each individual photograph based on navigation (easting, northing, and altitude) and attitude (pitch, roll, and yaw) data of a remotely operated vehicle (ROV) or autonomous underwater vehicle (AUV). The method is fast and low demanding in terms of computing resources, but the quality of the mosaic suffers from the inaccuracies of the navigation data (Fig. 1a). Another method consists in using pictorial information to infer the motion between two images. Such feature-based method requires each image to overlap with the next and has higher computing requirements, but it generally yields more accurate

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results (Fig. 1b). However, it may not be able to register images if the overlap area is too small, if the scene is featureless, or if the relief is too sharp.

A robust underwater mosaicking tool should rely on feature tracking methods to ensure best registration accuracy. However, it should also be able to use navigation data in areas where feature tracking fails or is not possible. With the LAPM tool (Fig. 2), mosaics can be constructed in three different ways, depending on the user requirements and on the data available: with feature tracking and navigation data, with feature tracking only, or with navigation data only.

3.2 Feature tracking

If used, feature tracking is the first step of the mosaicking process. It consists in detecting and matching features within each consecutive pair of the image sequence. The feature tracking is based on the VLFeat toolbox (Vedaldi and Fulkerson, 2008, 2010), which includes an open-source implementation of the Scale Invariant Feature Transform (SIFT) method (Lowe, 1999, 2004). With this method, a set of features is computed for every image and tracked onto the next consecutive image in order to compute the transform matrix, or homography, that explains the motion. In addition, an outlier rejection (Pizarro and Singh, 2003) is performed in order to remove erroneous matches (outliers) from the set of positive matches (inliers), which ensures that the best possible homography is computed.

In some cases, the feature tracking may also fail to compute matches. This happens generally if the overlap between the images is insufficient, if the scene is featureless, or if the relief causes perspective distortions. Such failure can be overcome by user intervention, i.e. by creating a few links between the unmatched images (Fig. 3). Alternatively, navigation data can be used to estimate the motion between unmatched images.

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3.3 Initial topology and crossover

In mosaicking terms, the topology is the estimation of the position and orientation of every image onto the 2D plane of the mosaic (Gracias and Negahdaripour, 2005). Computing the topology is the next main step of the mosaicking process and a prerequisite for the actual construction of the mosaic. The ‘initial topology’ step of the LAPM tool consists in estimating the position of each image onto the mosaic plane from the homographies (Fig. 4). In this step, the image registration is done successively from the first image to the last in the order of the image sequence.

In such context, minor registration errors tend to add up from a pair to the next and to lead to a larger global error. The use of overlaps between non-consecutive images can help limiting the error by providing additional positioning constraints (Fig. 5), also known as crossover points (Fleischer et al., 1996, 1997; Fleischer and Rock, 1998). Crossover points are used in the computation of the initial topology after the pairwise registration of all images has been estimated. Starting again from the first image, whenever a crossover point is found, the registration parameters of all images within the loop are recalculated backward until the beginning of the loop or until the previous crossover point. The principle of this technique is comparable to the smoother-follower technique described by Fleischer et al. (1996).

Concretely, implementing crossover points consists in computing or manually adding additional matches between pairs of adjacent (but non-consecutive) images. Crossover points have been used in previous mosaicking efforts, and in some cases in a fully automatized and iterative fashion (Pizarro and Singh, 2003). In contrast, the LAPM tool gives to the user full control over crossover matches. It includes graphical interfaces to display all existing matches and to identify potential crossover points.

The use of crossover points can significantly improve the quality of the topology and of the final mosaic (Fig. 6). Crossover points can also be used to compensate for inaccuracies in the navigation data. However, to take advantage of crossover points,

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overlaps between non-consecutive images must be planned at the image acquisition stage, by preparing an adequate trajectory (Fig. 7).

3.4 Global registration

The global registration consists in computing for each image the optimal transformation matrix in order to obtain the smallest possible global error at the scale of the mosaic. This operation, also known as bundle adjustment (Pizarro et al., 2004), is done by minimizing a cost function, which simultaneously takes into account all matches from every matched pair of images.

The LAPM tool uses the cost function presented by Pizarro and Singh (2003) to compute homographies. It is solved in one iteration by linear least squares and presents the advantage of computing the global minimum. The global registration solves for affine (i.e. 6 degrees of freedom) homographies; hence, it results in a finer estimation than the initial topology.

3.5 Mosaic construction

After all images have been registered, they are merged together to build the actual mosaic. Several methods exist to optimize the rendering of the overlaps, which can be divided in two categories: clipping and blending methods (Burt and Adelson, 1983; Marks et al., 1994; Eustice et al., 2002; Pizarro and Singh, 2003; Ferrer et al., 2007; Lirman et al., 2007; Gracias et al., 2009). Clipping methods consist in taking into account the pixels from one image only out of all overlapping images; they are usually fast but clear seams are visible at the intersection between overlapping images. Conversely, blending methods combine pixels from the overlapping images; depending on the blending type, such technique can better render the mosaic, although at a higher computing cost.

Two rendering methods are available with the LAPM tool: a clipping method, in which the pixels that are closest to the center of their image are chosen (Lirman et al., 2007),

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and a blending method, known as multi-resolution pyramidal blending (Eustice et al., 2002; Pizarro and Singh, 2003). The latter method is significantly slower but produces a quasi-seamless mosaic (Fig. 8).

4 LAPM tool: functionalities

5 The LAPM tool was developed specifically for the purpose of underwater mosaicking, and its main functions were designed to meet the needs of an end-user scientist interested in building visual maps of the seafloor. Therefore, it has a graphical user interface (GUI) to ensure ease of use without requiring prior knowledge of the techniques involved (Fig. 2). Other main requirements included the abilities (1) to assemble large
10 high-resolution image datasets on any regular computer, (2) to produce geo-referenced mosaics, (3) to give the user full control over feature matches, and (4) to produce mosaics in different resolutions.

4.1 Tiling the mosaic

15 Due to limited field of view in the deep sea, mosaicking large areas commonly requires hundreds to thousands of images. Most panorama-dedicated programs were usually not designed to cope with such large datasets, and computer resources are often exceeded. For instance, a photo-mosaic image from a set of several thousand high-resolution photographs can easily reach a few hundred million pixels. Most computers and operating systems cannot cope with such large files.

20 The LAPM tool can generate photo-mosaics of any size and on any recent computer. To achieve such capability, large mosaics are automatically tiled in several square image files (Fig. 9), which are then constructed successively and independently. The size of individual tiles can be defined by the user and is limited by the computing resources available. Therefore, lower computing capabilities result in smaller tiles.

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However, because the amount of tiles is unlimited, photo-mosaics of any size can be constructed on any computer.

For instance, computers equipped with 4 GB and 64 GB RAM could build blended mosaic tiles with up to 100×10^6 pixels ($10\,000 \times 10\,000$) and 1.6×10^9 pixels ($40\,000 \times 40\,000$) respectively. Even larger tile sizes can be constructed if the blending option is not used.

4.2 Geo-referencing the mosaic

If the navigation data is used, photo-mosaics can be geo-referenced. The geo-referencing data is written in a world file, which allows mosaics to be imported into a geographic information system (GIS) such as ArcGIS directly. A world file is created for every tile of the mosaic. The global photo-mosaic can be visualized entirely by loading each tile into GIS (Fig. 9). Therefore, spatial analyses can be performed directly on the entire mosaic, instead of separately on each individual tiles.

A world file can also be produced when full navigation data is not available. In such case, the geo-referencing information is estimated from the position and orientation of the first image of the mosaic, as well as from the average field of view of one image. Therefore, such method only gives a crude approximation of the true geographical data; its accuracy depends strongly on the morphology of the surveyed area and on the motion of the camera.

4.3 Editing feature matches

Although robust, feature tracking methods are not foolproof and they sometimes fail to detect matches between overlapping images. This is generally the case if the overlap is too small, the mapped area featureless or the perspective distortions too strong.

Therefore, the LAPM tool includes graphical interfaces that provide the possibility to visualize current matches (Fig. 10) and to manually edit them (Fig. 3). If necessary, the user can select and delete individual links, or create new ones between any pair of

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images. This function is particularly useful when reliable navigation data is not available and that feature tracking fails. It is also very efficient to force the implementation of crossover points even between very low overlapping images.

4.4 Lowering the resolution

5 The LAPM tool can produce the final mosaics at several different resolutions. Lowering the resolution reduces computing times significantly. Indeed, the construction of a high-resolution photo-mosaic can be a very computer-intensive and slow process, and it may sometimes be advantageous to lower the resolution in order to speed up the process. For instance, building large and accurate photo-mosaics can be an iterative process,
10 for which the construction of low-resolution intermediary mosaics may be beneficial; a preliminary mosaic is indeed an efficient way of identifying crossover points in a set of images.

For example, the construction of a 5.7 billion pixel mosaic, on a computer equipped with a 3 GHz CPU, required computing times of about 24 h without blending and about
15 4 days with multifrequency blending option. Dividing two times the resolution allowed constructing a fully blended mosaic within a day.

5 Results

The LAPM tool was used to create maps of several deep-sea features. In particular, it produced photo-mosaics with images datasets from different underwater vehicles
20 (ROV and AUV) and from both video- and photo-cameras.

5.1 Helgoland mud volcano

The Helgoland mud volcano, in the Back Sea, was visited in 2010 during the MSM15/2 cruise (Bohrmann et al., 2011). High-resolution images of the volcano center were acquired with a Canon Powershot G10 camera mounted on the MARUM ROV

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Quest 4000. The surveyed areas included both sharp topography and featureless areas, and reliable ROV-navigation data was not available. Nevertheless, photo-mosaics could be successfully constructed with the LAPM tool. The results include in particular a 400 m²-large photo-mosaic of the center of the volcano (Fig. 11). The perfect alignment of linear features (mud flows) indicates that the images were accurately registered.

5.2 Regab pockmark

The Regab pockmark is a cold seep structure located at 3160 m water depth in the Congo deep-sea fan. It was intensively studied during the WACS cruise (2011) and large video and photo surveys were conducted with the Ifremer ROV Victor 6000 (Marcon et al., 2013b). Datasets also contain hybrid navigation information from both Doppler Velocity Log (DVL) and ultra-short baseline (USBL) sensors.

Results include notably a 105 000 m²-large photo-mosaic of the most active area of the pockmark (Fig. 9). Photos were obtained with the high-sensitivity OTUS camera (Simeoni et al., 2007) from an altitude of 8 m above seafloor. Further photo-mosaics could also be constructed from the video materials. To do so, individual frames were extracted at regular interval (1 s) from the video files. Video images are usually of lower quality than photos from still cameras; however, the high frequency of frames (25 fps for PAL cameras) ensured large overlap areas between consecutive images. Therefore, two very high-definition mosaics could be constructed, with areas of 14 000 and 5800 m² (Fig. 12). All mosaics were geo-referenced and could be imported into ArcGIS for spatial analyses.

5.3 Håkon-Mosby Mud Volcano

The Håkon-Mosby Mud Volcano (HMMV) is a 1.4 km-wide circular structure located at about 1250 m water depth in the Barents Sea (Jerosch et al., 2006). The HMMV has been intensively surveyed since its discovery, and high-resolution micro-bathymetry and transects of video-mosaics are already available (Jerosch et al., 2006, 2007).

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not include multicore parallel computing capability and cannot make full use of recent processors. Nevertheless, not all applications require full-resolution blended mosaics, and processing times can be greatly speeded-up by deactivating the blending option or by reducing the resolution.

7 Conclusions

The large-area photo-mosaicking tool was presented in this work. It allows end-users to effectively construct large geo-referenced photo-mosaics without requiring in-depth knowledge of the technical aspect of the mosaicking process. The tool can be used with any imagery data, but its interface and functions were tailored specifically for the purpose of underwater mosaicking. Although based on the current state-of-the-art feature tracking algorithms and on some commonly-used registration techniques, the LAPM tool does not claim to compete with all other photo-mosaicking techniques. The development of this tool was instead motivated by the current lack of end-user underwater photo-mosaicking tools freely available to deep-sea scientists interested in seafloor mapping.

It is fully functional and has already been used successfully with photo and video material from several scientific cruises for the production of high quality and high-resolution photo-mosaics. However, given the absence of similar end-user tools, the quality and accuracy of the results could not be compared. The LAPM tool is available for download in its current version at <http://doi.pangaea.de/10.1594/PANGAEA.808960> (DOI registration in progress). It will be subject to continuous improvements with notably the ability to correct images for geometric distortions, to solve homographies with 8 degrees of freedom (projective transformations), and to use multicore parallel computing.

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References

Allais, A. G., Borgetto, M., Opderbecke, J., Pessel, N., and Rigaud, V.: Seabed video mosaicking with MATISSE: a technical overview and cruise results, in: Proceedings of The Fourteenth International Offshore and Polar Engineering Conference, Toulon, France, 2004.

Boetius, A., De Beer, D., Felden, J., Viehweger, M., Asendorf, V., Weiz, E., Stiens, R., Eicken, G., Wetzel, G., Harmegnies, F., Dussud, L., Ferré, B., Van Campenhout, J., Albrecht, S., German, C. R., Camilli, R., Billings, A., Kinsey, J. C., Duester, A., Yoerger, D. R., Versteeg, W., Vercruysse, J., and De Rycker, K.: Short Cruise Report – MERIAN MSM16/2 – “LOOME” – Long Term Observatory of Mud Volcano Eruptions (Cruise report), Alfred Wegener Institut für Polar und Meeresforschung, Bremerhaven, 2010.

Bohrmann, G., Blinova, V., Dehning, K., Evtushenko, D., Friese, C., Hiruta, A., Hüttich, D., Ivanov, M., Klapp, S. A., Körber, J. H., Komakhidze, G., Kopiske, E., Lange, K., Mai, H. A., Malakhova, T., Marcon, Y., Meinecke, G., Pape, T., Ratmeyer, V., Rehage, R., Renken, J., Reuter, C., Reuter, M., Römer, M., Sahling, H., Sakvarelidze, E., Wintersteller, P., and Zarrouk, M.: Report and preliminary results of RV MARIA S. MERIAN Cruise MSM 15/2, Istanbul (Turkey) – Piraeus (Greece), 10 May–2 June 2010, Origin and structure of methane, gas hydrates and fluid flows in the Black Sea, Cruise report No. 278, Berichte aus dem Fachbereich Geowissenschaften, Geowissenschaften, Universität Bremen, Bremen, 2011.

Brandou, V., Allais, A. G., Perrier, M., Malis, E., Rives, P., Sarrazin, J., and Sarradin, P. M.: 3D reconstruction of natural underwater scenes using the stereovision system IRIS, in: Proceedings of the MTS/IEEE Oceans 2007 Conference, Vancouver, British Columbia, Canada, 1–6, 2007.

Burt, P. J. and Adelson, E. H.: A multiresolution spline with application to image mosaics, ACM Trans. Graph., 2, 217–236, 1983.

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- Escartín, J., García, R., Delaunoy, O., Ferrer, J., Gracias, N., Elibol, A., Cufi, X., Neumann, L., Fornari, D. J., Humphris, S. E., and Renard, J.: Globally aligned photomosaic of the Lucky Strike hydrothermal vent field (Mid-Atlantic Ridge, 37°8.5'N): Release of georeferenced data, mosaic construction, and viewing software, *Geochem. Geophys. Geosy.*, 9, doi:10.1029/2008GC002204, 2008.
- Eustice, R., Pizarro, O., Singh, H., and Howland, J.: UWIT: Underwater Image Toolbox for optical image processing and mosaicking in MATLAB, in: *Proceedings of the 2002 International Symposium on Underwater Technology*, Tokyo, Japan, 141–145, 2002.
- Ferrer, J., Elibol, A., Delaunoy, O., Gracias, N., and Garcia, R.: Large-area photo-mosaics using global alignment and navigation data, in: *Proceedings of the MTS/IEEE Oceans 2007 Conference*, Vancouver, British Columbia, Canada, 1–9, 2007.
- Fleischer, S. D. and Rock, S. M.: Experimental validation of a real-time vision sensor and navigation system for intelligent underwater vehicles, in: *IEEE International Conference on Intelligent Vehicles*, Stuttgart, Germany, 1998.
- Fleischer, S. D., Wang, H. H., Rock, S. M., and Lee, M. J.: Video mosaicking along arbitrary vehicle paths, in: *Proceedings of the 1996 Symposium on Autonomous Underwater Vehicle Technology*, AUV'96, Monterey, CA, 293–299, 1996.
- Fleischer, S. D., Rock, S. M., and Burton, R.: Global position determination and vehicle path estimation from a vision sensor for real-time video mosaicking and navigation, in: *OCEANS'97, MTS/IEEE Conference Proceedings*, Halifax, Nova Scotia, 641–647, 1997.
- Gracias, N. and Santos-Victor, J.: Underwater mosaicing and trajectory reconstruction using global alignment, in: *Proceedings of the MTS/IEEE Oceans 2001 Conference*, Honolulu, Hawaii, USA, 7 pp., 2001.
- Gracias, N., Mahoor, M., Negahdaripour, S., and Gleason, A.: Fast image blending using watersheds and graph cuts, *Image Vision Comput.*, 27, 597–607, 2009.
- Gracias, X. and Negahdaripour, S.: Underwater mosaic creation using video sequences from different altitudes, in: *Proceedings of the MTS/IEEE Oceans 2005 Conference*, Washington, DC, 1295–1300, 2005.
- Jerosch, K., Schlüter, M., and Pesch, R.: Spatial analysis of marine categorical information using indicator kriging applied to georeferenced video mosaics of the deep-sea Håkon Mosby Mud Volcano, *Ecol. Inform.*, 1, 391–406, 2006.

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- Jerosch, K., Schlüter, M., Foucher, J. P., Allais, A. G., Klages, M., and Edy, C.: Spatial distribution of mud flows, chemoautotrophic communities, and biogeochemical habitats at Håkon Mosby Mud Volcano, *Mar. Geol.*, 243, 1–17, 2007.
- Lirman, D., Gracias, N., Gintert, B. R., Gleason, A. C., Reid, R. P., Negahdaripour, S., and Kramer, P.: Development and application of a video-mosaic survey technology to document the status of coral reef communities, *Environ. Monit. Assess.*, 125, 59–73, 2007.
- Lowe, D. G.: Object recognition from local scale-invariant features, in: *The Proceedings of the Seventh IEEE International Conference on Computer Vision 1999*, Corfu, Greece, 1150–1157, 1999.
- Lowe, D. G.: Distinctive image features from scale-invariant keypoints, *Int. J. Comput. Vision*, 60, 91–110, 2004.
- Marcon, Y., Sahling, H., Borowski, C., Dos Santos Ferreira, C., Thal, J., and Bohrmann, G.: Megafaunal distribution and assessment of total methane and sulfide consumption by mussel beds at Menez Gwen hydrothermal vent, based on geo-referenced photomosaics, *Deep-Sea Res. Pt. I*, 75, 93–109, 2013a.
- Marcon, Y., Sahling, H., Allais, A. G., Bohrmann, G., and Olu-Le Roy, K.: Distribution and temporal variation of mega-fauna at the Regab pockmark (Northern Congo Fan), based on a comparison of videomosaics and GIS analyses, *Mar. Ecol.*, accepted, 2013b.
- Marks, R. L., Rock, S. M., and Lee, M. J.: Real-time video mosaicking of the ocean floor, in: *Proceedings of the 1994 Symposium on Autonomous Underwater Vehicle Technology, AUV'94*, Brest, France, 21–27, 1994.
- Nicosevici, T., Negahdaripour, S., and Garcia, R.: Monocular-based 3-D seafloor reconstruction and ortho-mosaicing by piecewise planar representation, in: *Proceedings of the MTS/IEEE Oceans 2005 Conference*, Washington, DC, 1279–1286, 2006.
- Nicosevici, T., Gracias, N., Negahdaripour, S., and Garcia, R.: Efficient three-dimensional scene modeling and mosaicing, *J. Field Robot.*, 26, 759–788, 2009.
- Pizarro, O. and Singh, H.: Toward large-area mosaicing for underwater scientific applications, *IEEE J. Ocean. Eng.*, 28, 651–672, 2003.
- Pizarro, O., Eustice, R., and Singh, H.: Large area 3D reconstructions from underwater surveys, in: *Proceedings of the MTS/IEEE Oceans 2004 Conference*, Kobe, Japan, 678–687, 2004.
- Pizarro, O., Eustice, R., and Singh, H.: Large area 3D reconstructions from underwater surveys, *IEEE J. Ocean. Eng.*, 34, 150–169, 2009.

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- Simeoni, P., Sarrazin, J., Nouze, H., Sarradin, P. M., Ondréas, H., Scalabrin, C., and Sinquin, J. M.: Victor 6000: new high resolution tools for deep sea research, “Module de Mesures en Route”, in: Proceedings of the MTS/IEEE Oceans 2007 Conference, Vancouver, British Columbia, Canada, 6 pp., 2007.
- 5 Vedaldi, A. and Fulkerson, B.: VLFeat: An open and portable library of computer vision algorithms, www.vlfeat.org (last access: 18 March 2013), 2008.
- Vedaldi, A. and Fulkerson, B.: VLFeat: An open and portable library of computer vision algorithms, in: Proceedings of the International Conference on Multimedia, Firenze, Italy, 1469–1472, 2010.
- 10 Vincent, A. G., Pessel, N., Borgetto, M., Jouffroy, J., Opderbecke, J., and Rigaud, V.: Real-time geo-referenced video mosaicking with the MATISSE system, in: Proceedings of the MTS/IEEE Oceans 2003 Conference, San Diego, USA, 2319–2324, 2003.
- Zitová, B. and Flusser, J.: Image registration methods: a survey, *Image Vision Comput.*, 21, 977–1000, 2003.

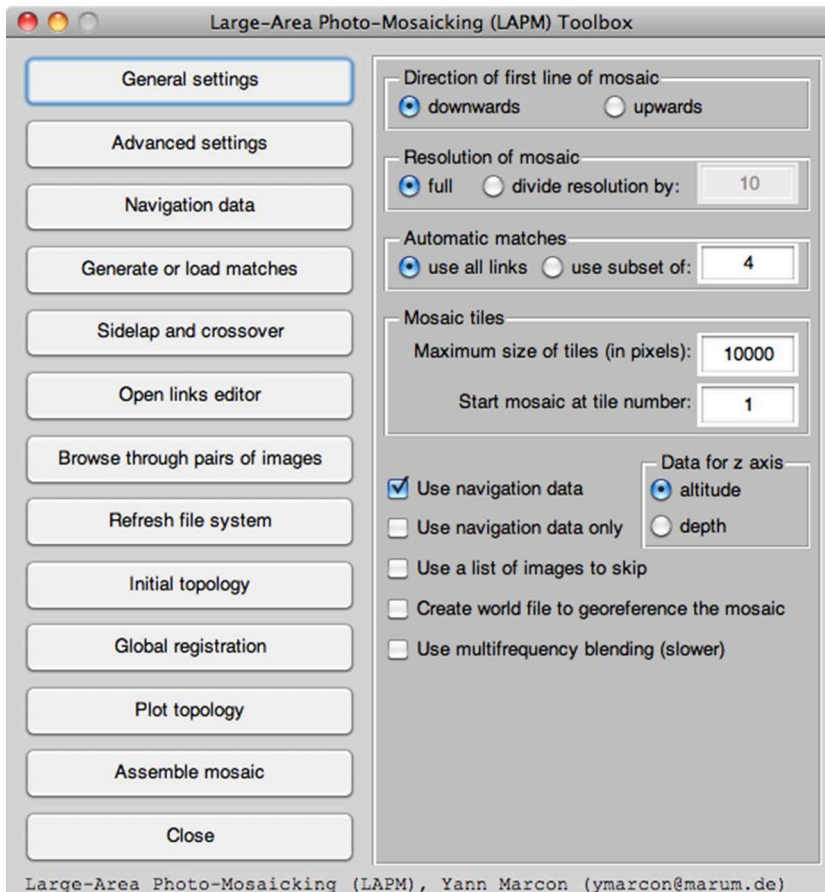


Fig. 2. Graphical user interface (GUI) of the large-area photo-mosaicking (LAPM) tool; the column of buttons is designed to guide the user through the mosaicking process. Several menus allow to fully control the tool.

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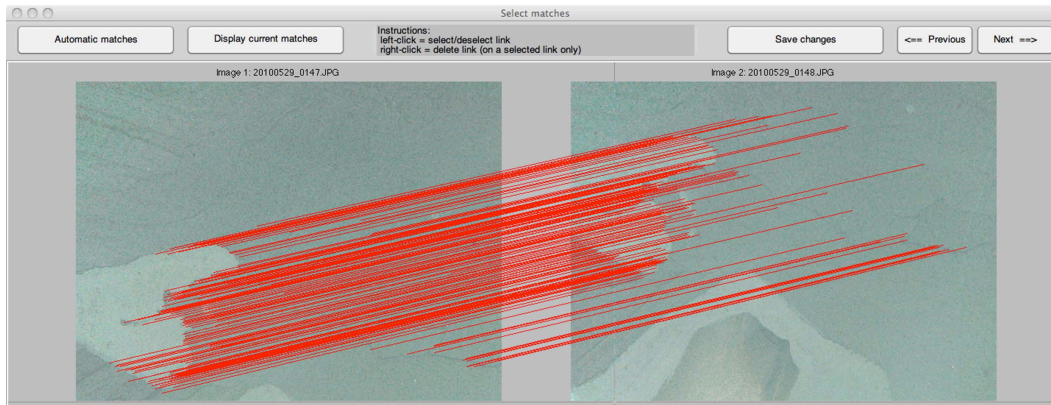


Fig. 3. The interface of the match selector allows browsing through each pair of images and visualizing the computed matches; erroneous matches can be removed and new matches can be manually created.

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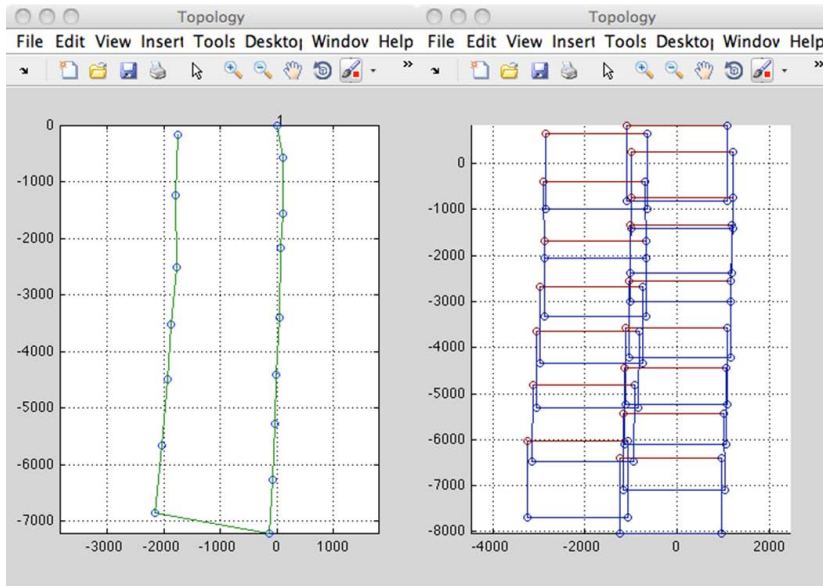
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Final mosaic

Fig. 4. Illustration of the initial topology. Left panel: estimation of the center position of each image. Middle panel: estimation of the projection of the image frames onto the 2-D plane of the mosaic. Right panel: corresponding mosaic.

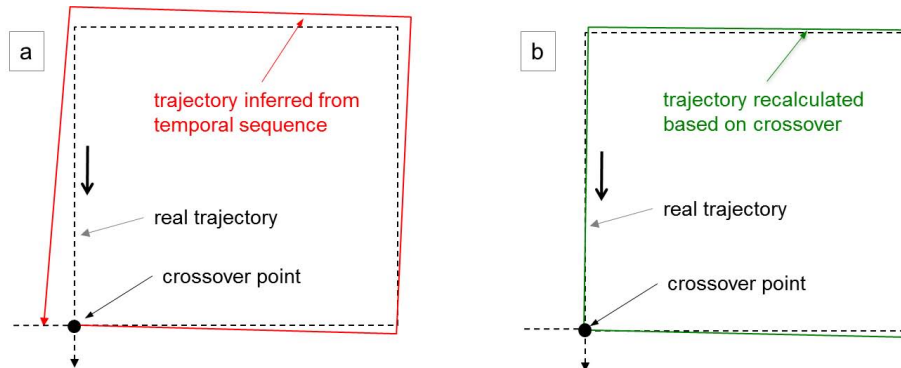


Fig. 5. Illustration of the contribution of crossover points in limiting registration errors. **(a)** Small positioning errors add up along the trajectory and grow unbounded. **(b)** By forcing the trajectory to cross itself at a given point, the position of each point within the loop can be recalculated backward; the registration error of each image is reduced.

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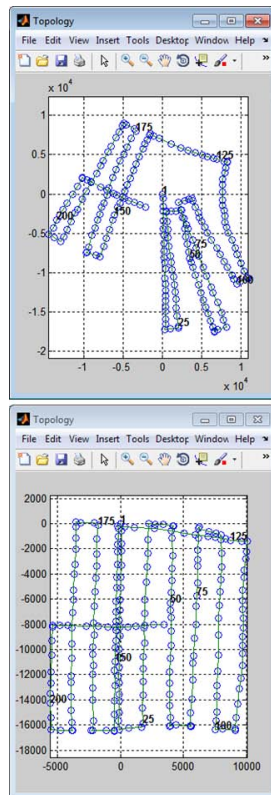


Fig. 6. Illustration of the benefits of using crossover points. Top panels: pairwise registration errors add up and lead to a huge global error. In this example, the right line of the mosaic corresponds to a featureless area, and the pairwise image registration is impacted by large errors. Bottom panels: the use of crossover points allows constraining the error. The final mosaic is consistent.

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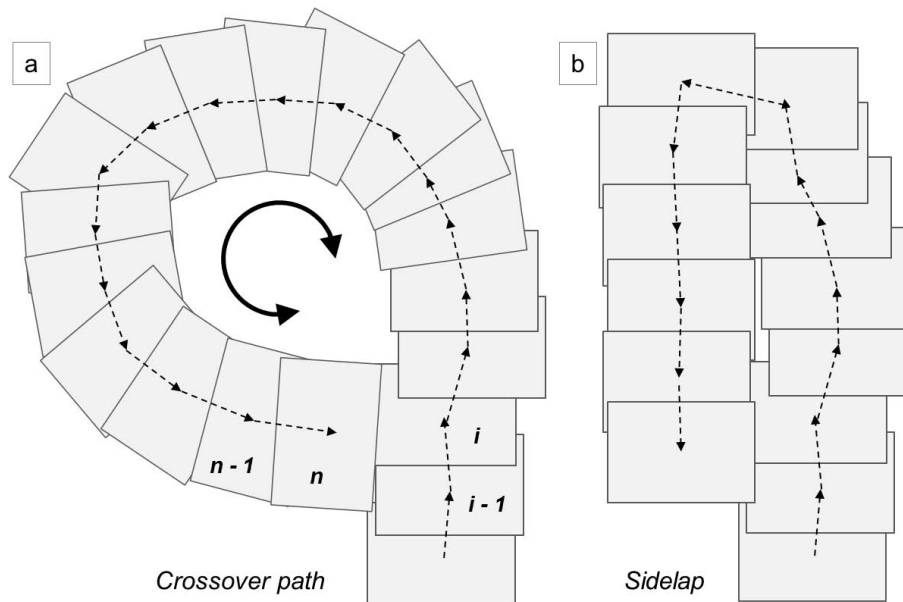


Fig. 7. Examples of crossover trajectories. **(a)** A crossover path is a trajectory, in which the camera crosses its own trajectory and surveys a same point several times; adapted from Fleischer et al. (1996). **(b)** Side-overlap, or sidelap, occurs when parallel lines of mosaic overlap.

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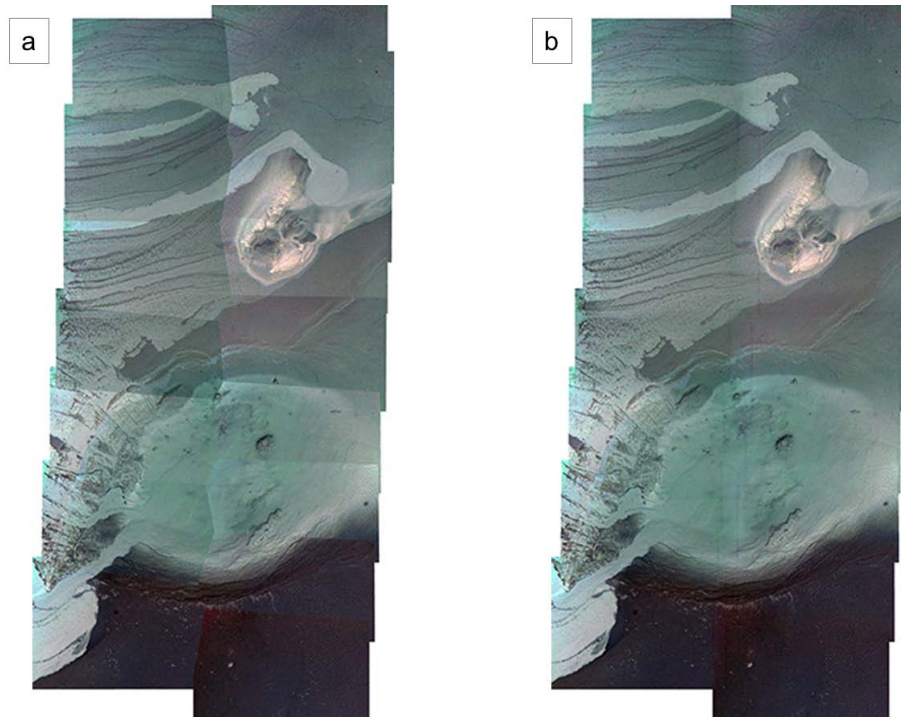


Fig. 8. Illustration of the two rendering options of the LAPM tool. **(a)** Clipping method: clear seams mark the transition between images. **(b)** Blending method: seams are barely visible but computing times are longer.

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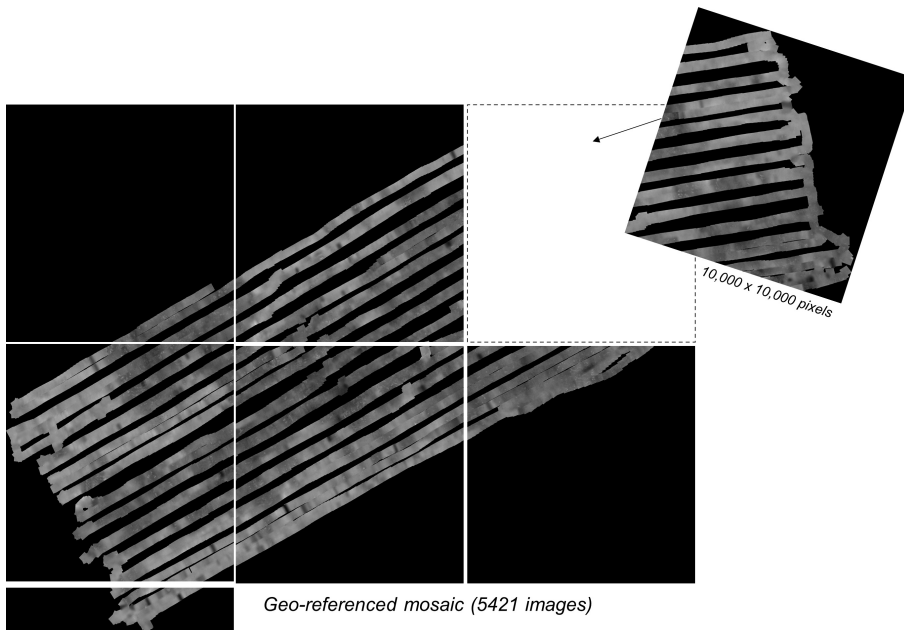


Fig. 9. Illustration of the mosaic tiles as produced by the LAPM tool; in this example, each square tile covers about 100 000 m². Individual tiles are constructed separately in order not to exceed the computing resources; tiles are geo-referenced, hence, loading them into a GIS allows displaying the photo-mosaic entirely.

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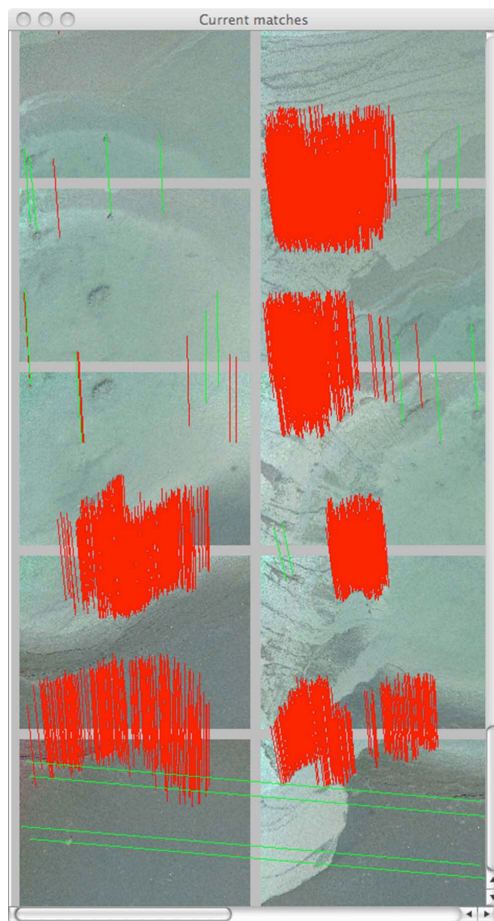


Fig. 10. View of the link editor of the LAMP tool; it gives the possibility to visualize all matches and to identify potential unmatched overlapping images.

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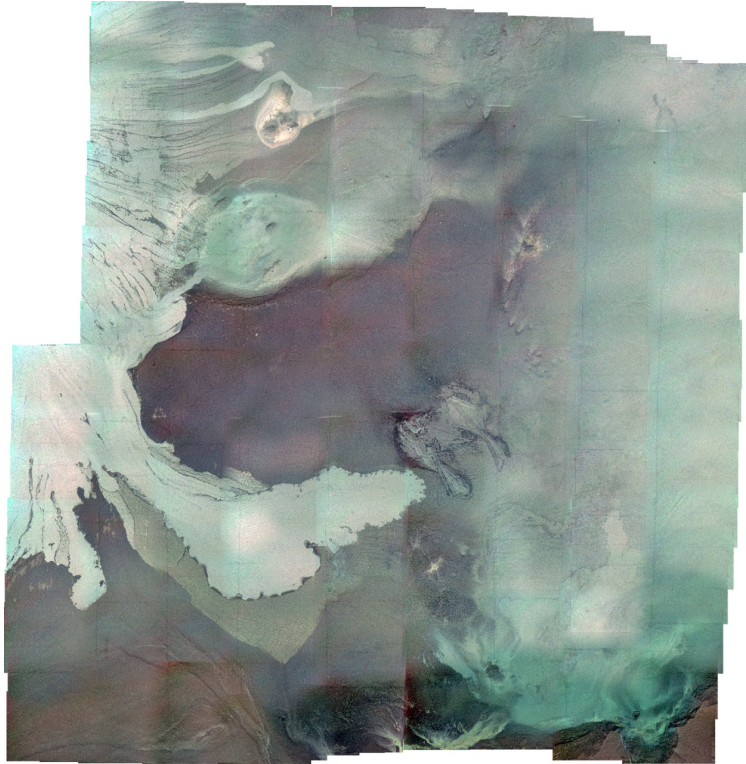


Fig. 11. Photo-mosaic showing mud pool and mud flows at the Helgoland mud volcano; the mosaic was built with 218 images and covers an area of about 400 m².

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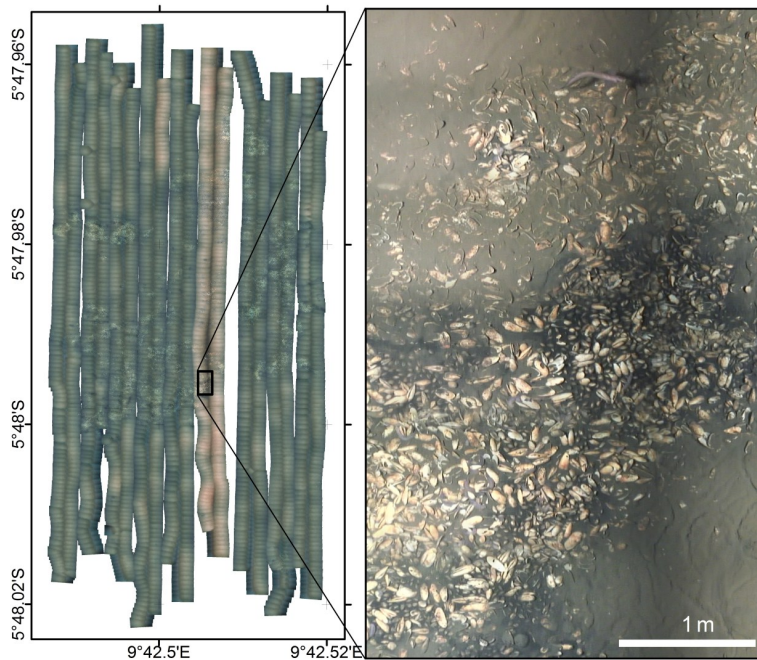


Fig. 12. Geo-referenced photo-mosaic constructed from high-definition video material; the mosaic covers an area of 5800 m² with a resolution, which allows distinguishing individual living and dead clams.

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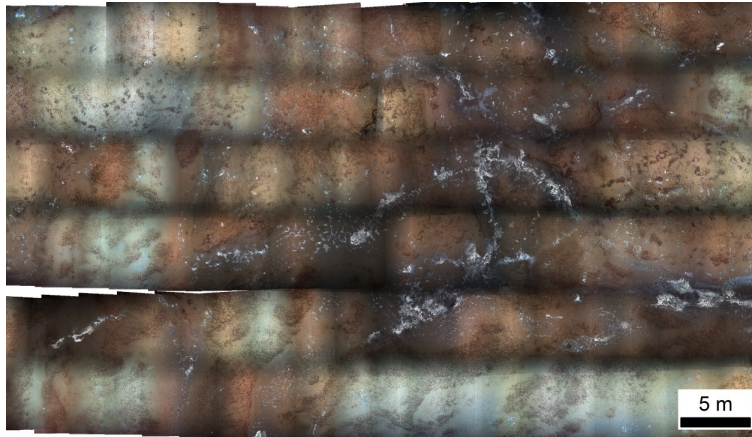


Fig. 13. Excerpt of the photo-mosaic of Håkon-Mosby Mud Volcano; the continuity of the *Beggiatoa* mats (white patches) and pogonophoran (brown patches) distribution across the mosaic indicates that images were accurately registered.

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