Benthic Habitat Mapping Using High-Resolution Image Mosaicking

Solving the Problem of Counting Species Multiple Times By Using a New Image Mosaicking Algorithm

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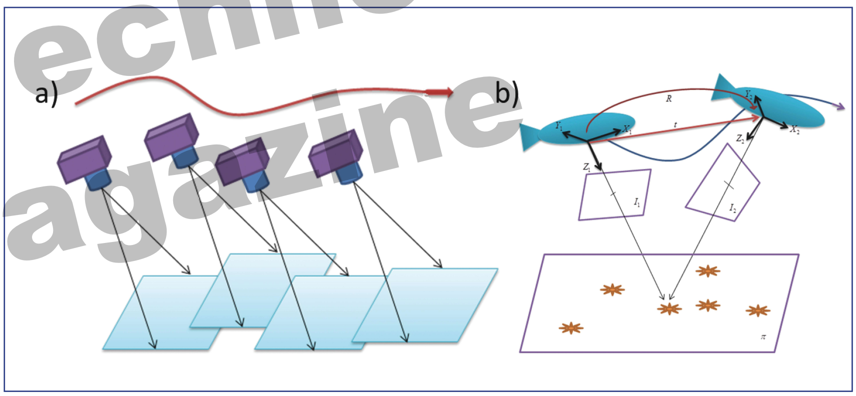
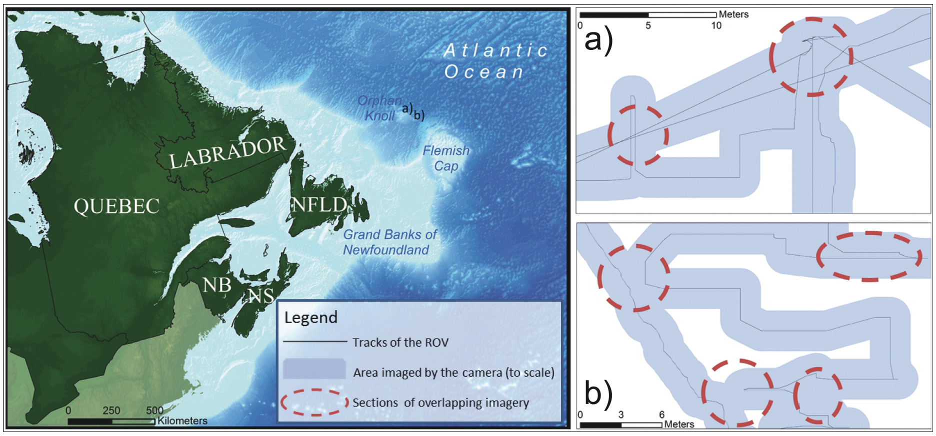
Benthic ecosystems of most continental shelves, slopes and seamounts are altered by the use of bottom-contact fishing gears and other human activities, such as hydrocarbon drilling and seabed mining. Such activities can impact the structure and function of benthic habitats directly and indirectly.

For example, physical disturbances of the seabed can produce changes in local water flow and sedimentation patterns, which are important for suspension feeders like cold-water corals and sponges. Partial or complete destruction of benthic habitats can reduce the number of species, their abundance, richness and diversity.

In recent decades, efforts have been made to study these remote environments. Mapping seafloor habitats based on species' environmental preferences is often the first step when implementing scientific management, monitoring environmental change and assessing the impacts of disturbance on benthic habitats.

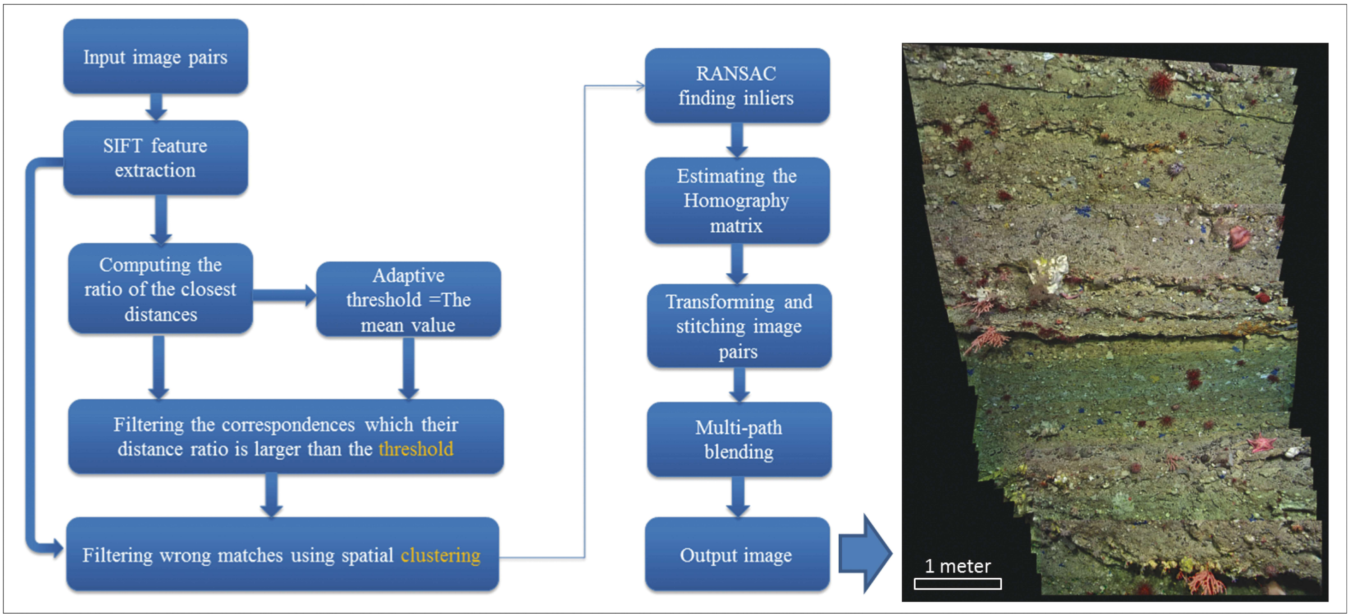
The GeoHab (Marine Geological and Biological Habitat Mapping) international symposium defines benthic habitat mapping as representing physically distinct areas of the seafloor that are associated with a particular assemblage of species. The rapid and recent evolution of technologies





(Top) These diagrams show (a) the overlap between sequential image frames and (b) translation and rotation parameters from a submersible's movement affecting image frames and the overlap area.

(Bottom) ROV tracks and study areas: (a) Sections of video that have overlapping regions (circles) with adjacent tracks and (b) sections that were explored more than once.



A flowchart of the proposed algorithm and its application to 29 images illustrating the local geomorphology and biological assemblage of a rock wall. The data were collected at Flemish Cap in the north Atlantic Ocean in 2010.

has helped provide an almost complete coverage of the seafloor at increasingly higher resolutions.

A new image mosaicking method can facilitate benthic species count recorded from ROV video data. The method creates image mosaics from overlapping images, helping the video data analyst to avoid counting individual organisms twice when an area is surveyed a second time. This improves the accuracy of species distribution maps used to produce benthic habitat maps.

In-Situ Observation of the Seabed

The direct observation of underwater video data allows for an accurate representation of species' distribution and abundance that can improve habitat maps. Knowledge of the geomorphology (e.g., shape of the seafloor) and the surficial geology (e.g., type of substrate) gained from video data collected where specific benthic organisms live helps characterize habitats and test environmental variables that can be good predictors of species distribution.

High-resolution videos also provide relatively accurate views of the seafloor, which can be used to corroborate or complete data collected using other technologies, such as multibeam echosounder systems. Another advantage of the video data is the ability of being analyzed online or offline, and the possibility of extracting image frames if necessary.

A major application of underwater video data in marine sciences is to count and georeference relevant features that are captured in the video, such as biological organisms. Nevertheless, an important issue in using video data for assessing the distribution and abundance of benthic species is the multiple-counting problem, which is counting several times the same feature that appears in several video scenes, a problem that can lead to inflated species counts and inaccurate statistics.

Multiple counting is a problem for machine-reading or automated video analysis, as well as the manual counting process. Assuming that an analyst performed a count properly, there are still conditions that can make the multiple counting possible. For example, a feature can be counted several times if it appears in multiple images or more than once in a video stream.

Overlapping images or videos could happen when the dives are planned for mosaicking or when collecting full coverage of a region of the seafloor. This situation can also occur in dives that had changes to the navigation plan resulting from the topography of the seafloor or scientists requesting exploratory navigation while observing interesting features in real time. These common situations can generate overlaps between sequential images where the submersible is following a route or images taken from adjacent or crossing tracks.

The proposed solution for the problems of multiple counting and overlapping images is to create a photomosaic of the seafloor with imagery data in which each feature only appears once.

Image Mosaicking Algorithms

When creating photomosaics, identifying the portions of an image that overlap with another can be challenging because of specific characteristics of deep-sea environments. For instance, individual organisms can often be surrounded by similar organisms of the same size, generating repeated and nondistinctive features. Seabed sediment structures in the background of images also form similar patterns with nondistinctive features. These reasons can lead to a large number of incorrectly matched features, resulting in an inaccurate matching of the images.

In the context of local invariant features, features represent interesting points of an object ranging from complex, such as the object itself, to simpler structures, such as edges or points. Also, these features can be designed to be invariant to scale orientation and be robust to changes in viewpoint and illumination.

The most popular available algorithm that realizes all the mentioned advantages seems to be the scale-invariant feature transform (SIFT), which describes and detects local features and passes the particular characteristics of invariance and robustness.

In the proposed method, the SIFT features of images are extracted and appropriate correspondences are matched by computing the standardized Euclidean distance between descriptor vectors, i.e., features. In the conventional SIFT feature matching, a predefined threshold value is used for finding matching features. This threshold value is fixed for different types of images in a data set (e.g., low-contrast or high-quality images). For an imagery data set of nondistinctive features such as the features in underwater images, this threshold value should be fine-tuned.

The proposed method uses instead an adaptive threshold to eliminate the need for defining a constant threshold value. Distance in this context refers to the standardized Euclidean distance between the feature descriptors. Close features are those with the smallest distance. The expected value of ratio of the closest to the next closest distance for each feature of the stitching image to the mosaic (query image), and all features of the mosaic are defined as the adaptive threshold value.

Feature points that satisfy this condition are chosen as correspondent pairs. In the next stage, *k*-means clustering is used for eliminating a large number of incorrect correspondences.

The proposed hypothesis is based on the fact that if a region of a query image has overlap with a particular region of the mosaic, the corresponding pairs inside these regions could be merged to one cluster.

The RANdom SAmple Consensus (RANSAC) algorithm is an iterative method for estimating a geometric model from randomly selected corresponding points. In this algorithm, inliers are samples following the geometric model, while outliers are the ones that do not follow the model parameters. In computer vision, a homography is a matrix that maps a 2D image plane to another. The homography matrix between each new image stitching to the mosaic is estimated by using the inliers found by RANSAC algorithm. Finally, by using the estimated homography matrix, the final mosaic is generated.

In order to generate a proper mosaic, conditions should be applied during the data collection stage. For example, the equipment mounted on the ROV, such as the manipulator arms, have to be absent from the videos. In addition, illuminating the scene with a uniform light source is required to provide similar contrasts.

Experimental Application

The Marine Habitat Mapping Research Group of the Memorial University of Newfoundland is studying cold-water coral and sponge habitats in Canadian waters. This involves understanding species' environmental preferences in order to describe their typical habitat. The Canadian ROV ROPOS (Remotely Operated Platform for Ocean Sciences) has been deployed to collect in-situ and georeferenced data for mapping the local cold-water coral and sponge habitats.

In July 2010, ROPOS was operated between 1,000 and 3,000 meters depth in the Flemish Cap and the Orphan Knoll regions, off the coast of Newfoundland and Labrador in eastern Canada. In November 2011, another exploration took place in depths ranging from 100 to 500 meters in the Strait of Georgia, British Columbia, western Canada. In order to characterize the studied habitats as accurately as possible, a combination of high-resolution video, oceanographic and multibeam sonar data were collected as well as biological and geological samples. The ROV was equipped with a forward- and a downward-looking camera.

Understanding cold-water coral and sponge habitats requires mapping species distribution, abundance and characterizing their environment. One of the main elements that need to be studied from the video data in this research is the surficial geology, as sediment types (e.g., rocks, gravel, mud) often influence the type of organisms that will be found. Coral-structured environments provide feeding, spawning and shelter for other marine species, making the identification, georeferencing and counting of the associated fauna and of the studied species themselves important.

Finally, other physical or biological attributes of cold-water coral and sponge habitats that can be potential surrogates of their presence, such as the local geomorphology of the seafloor, need to be mapped. Video data are the best way to locate, identify and accurately count these features, but present the issue of multiple counting.

To solve this problem, the mosaicking algorithm has been successfully applied to images that have been extracted from the downward-looking video data collected with ROPOS in 2010. Mosaics were generated for some regions of the seafloor using the downward-looking camera data, but also applied to the videos recorded by the forward-looking camera to reconstruct near-vertical cliffs and rock walls.

Once generated, the mosaics were georeferenced using the location information from the original videos and the navigation data from ROPOS, and imported into a GIS. The study of the georeferenced mosaic with the GIS allowed building a geodatabase that includes the identification and location of cold-water corals and sponges, in addition to their associated fauna, the geomorphological features present in these environments and the surficial geology. This geodatabase was then used to count the species in the study area and will be the main tool used by marine scientists to calculate statistics, such as the density of corals and sponges in some areas or the patchiness of these habitats.

In order to increase the accuracy of the location of the observed elements, further work could consider the orthorectification of the georeferenced mosaic (i.e., its geometrical correction based on the topography of the seafloor) using the collected high-resolution multibeam bathymetric data.

Conclusion

Multiple counting of features is a typical challenge when analyzing underwater imagery data. The experimental application showed the utility of such a seafloor mosaic to help marine scientists define the location of features or organisms relevant to them, using simple photointerpretation and without the overestimation caused by multiple counting. In addition, the proposed algorithm could improve machine-learning or automated video analysis.

Further investigations could consider processing mosaics using supervised image classification as done in optical satellite remote sensing to accelerate and semiautomatize the count and georeferencing of the relevant elements of the seafloor.

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References

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