Thanks to technology breakthroughs in the last two decades, autonomous underwater vehicles (AUVs) have become a standard tool for autonomously surveying the ocean floor using a variety of optical [1] and acoustic [2] sensors. AUV surveys support many applications such as marine geology [3], dam inspection [4], underwater archeology [5] and mine countermeasures [6], to name a few. Furthermore, AUVs require little human supervision compared to their ship- or remotely operated vehicle (ROV)-assisted counterparts, and hence operate at a lower cost.

However, off-the-shelf AUVs present serious limitations in their ability to reliably inspect the ocean floor in close proximity. In a typical survey mission, an AUV follows a path pre-planned by a human operator keeping a safe, constant altitude from the bottom using measurements from a down-looking echosounder. On one hand, this approach does not account for any unforeseen obstacles in the survey path planning phase, arising a collision threat. On the other hand, since only simple altitude measurements are used, the AUV must fly at a conservative distance to avoid collision with the bottom in rugged terrain. Moreover, from the perspective of imaging applications (optical or acoustic), following the elevation profile of the terrain at a conservative altitude does not provide satisfactory results in rugged terrain. As illustrated in Fig. 1, a survey at a safe altitude from the bottom provides an askew angle of incidence with respect to the bottom normal, which results in poor imaging. In contrast, an angle of incidence parallel to the bottom normal is desired in these applications.

These limitations can be addressed in the context of coverage path planning, which is the task of passing a sensor over all points in a target surface while avoiding obstacles. Such task is integral to all the applications mentioned above. However, although coverage path planning has been studied in in 2D [7], 2.5D [8], [9] and 3D [10] environments and in domains such as agricultural robotics [11] and unmanned aerial vehicles (UAVs) [12], [13], little attention has been given to the coverage path planning problem in underwater environments, especially in complex, rugged terrain. Exceptions are our prior work in off-line coverage path planning [14] and the method by Englot et al. for ship hull inspection [15].

In this work, we present a coverage path planning solution that generates a coverage path for an underwater region of interest, which is well suited for imaging applications. Our method detects regions on an (typically rough, low-resolution) a priori map of the area that cannot be properly imaged using a classic constant-altitude survey. In such regions, our method plans a path that follows the horizontal contours of the terrain, from which the target surface can be imaged from fair vantage points. A simple classic survey is used only on the effectively planar regions. Furthermore, beyond off-line planning, our method includes techniques for detecting the target surface using on-board profiling sonar information and refining the planned path during on-site mission execution. We test our method using our GIRONA500 AUV (shown in Fig. 2) on a diving site off the Costa Brava in Girona, Spain. The site presents a protruding rock hosting habitats of biological interest. A low-resolution map of the area (Fig. 3) was obtained by means of an autonomous survey mission conducted by GIRONA500. We apply our coverage path planning method on a triangle-mesh representation of the map and obtain a coverage path for the rugged region that follows its contours at 2, 4 and 6 m. depth (from the top-most point in the region). The triangle-mesh representation with its corresponding coverage path is shown in Fig. 4.

In the final paper, we will describe in detail the proposed coverage path planning method, including rugged region detection, full coverage path generation for both rugged and effectively planar regions and on-line path refinement using profiling sonar data. Likewise, we will report on experimental testing of the proposed method obtained in sea trials using GIRONA500 AUV on l’Amarrador diving site.

Fig. 1: Askew angle of incidence provided by constant, safe altitude survey (a) in contrast to the fair vantage point obtained by imaging the surface in parallel to its normal (b).

REFERENCES
Fig. 2: The GIRONA500 AUV with the profiling sonar used by our method protruding on the top-left.

Fig. 3: Bathymetric map of l’Amarrador diving site. Data were autonomously collected by GIRONA500.

Fig. 4: Coverage path for the rugged region of l’Amarrador diving site planned on a triangle-mesh representation of the a priori map.


