Evaluation of Coastal Vulnerability with Mobile Laser Scanning from a Vessel

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***Abstract*— Coastal communities and infrastructure are at continuous risk from the dangers imposed by our oceans. Hazardous geography, episodic weather events and, of more recent concern, sea level rise pose threats to our communities which put lives and infrastructure at stake. Be it landslides, earthquakes or tsunamis, our coastline is in peril of nearly instantaneous devastation. Similarly, slower geologic processes promise eventual loss of beaches and coastline. As development continues within these exposed coastal areas, infrastructure and housing acquire increased risk of impact. Both nationally and internationally, many nations continue to struggle with the economics of sustainable coastal zone management and maintaining sea defense infrastructure. Therefore effective assessment of coastline and sea cliff retreat becomes very important in understanding the condition and prospective needs of a coastal community to best mitigate risk.**

Due to the nature of many of these locations, access to the site can be challenging and/or the site may have sensitive habitat present. Using remote sensing technologies, such as laser scanning (LiDAR) can be an advantage by reducing disturbance to the sites. Mobile laser scanning can provide a very flexible methodology for monitoring cliff erosion and retreat, especially for relatively small areas with high detail. Performance of periodic surveys can allow quantification of cliff/beach retreat rates and volume assessments which can in turn be used for coastal management planning.

Keywords—laser scanning; lidar; coastal mapping; cliff erosion; beach; coastline; coastal zone management

I. Introduction

Coastal zone management is a critical issue for most areas around the world. The impacts of sea level rise as well as potential storm events are of critical concern – not only to urbanized areas, but also to natural habitat that is encroached upon. Those tasked with monitoring and managing these coastal zones are typically ill equipped to quantitatively assess the retreat of the coastline – particularly for steep cliff terrain that is subject to erosion.

Remote sensing practices can be applied to capturing coastal topographic data for the purpose of assessing erosion/accretion. Multiple data sets can be used to assess the temporal change and used to deduce average rates of change (or even episodic change). The scale of the area of interest and the level of detail and accuracy required are the key factors in determining the appropriate technology to use for these assessments. Larger areas with coarser requirements are better suited with aerial techniques while smaller areas with more stringent accuracy requirements are typically better studied with ground or vessel-based techniques. The analysis of the collected data can be done to monitor the dynamics of the change in the coastline.

This paper will discuss a case study of the use of mobile laser scanning to monitor cliff retreat.

II. Project Overview

In Provence-Alpes-Côte d'Azur, France, an approach to monitor the retreat of coastal cliffs at Carry-le Rouet. The drivers for this study are the safety of people in the community, assessment of threat to infrastructure, socio-economic impact, and impacts on the environment. Twenty kilometers east from Marseille, the cliffs of Carry-le-Rouet are among the four representative sites in coastal cliff area, chosen by Bureau de Recherches Géologiques et Minières (BRGM), the French Geological Survey.

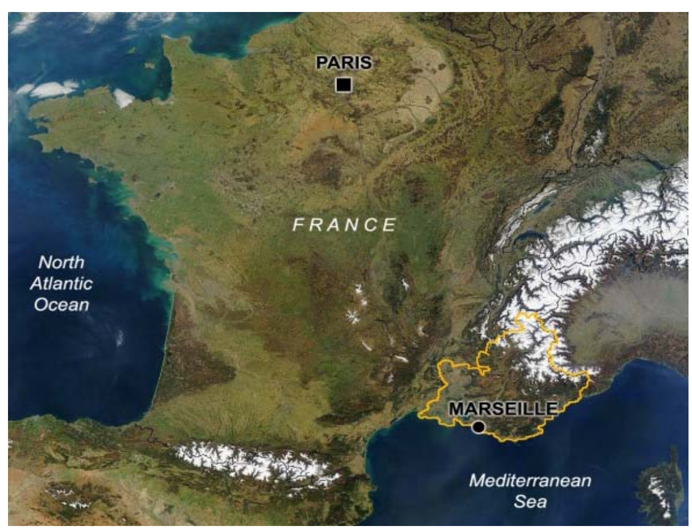

Fig. 1. Location of project in Provence-Alpes-Côte d'Azur

Fig. 2. Location of project at Carry-le Rouet, France

In order to characterize and establish the rate of cliff retreat, BRGM performed field investigations of the site in order to evaluate the erosion and develop land-use planning guidance. The end goal would be to create a methodology for long-term monitoring and risk management of coastal cliff instabilities.

III. TECHNICAL METHODOLOGY

The study of the site quickly identified that conventional methods of survey would be unsuitable for the program. Traditional GNSS/GPS or total station surveys are accurate but not suitable for a good rendering of the particular morphology of the cliffs, and high density is required to detect and measure the volume of rock compartments torn by the sea.

In addition, the site configuration prohibits land or aerial access: the cliffs are fully visible only from the sea side, and most of the surface to monitor is vertical, and thus difficult or impossible to capture from an aerial survey. This is a relatively common problem in rocky and steep coastal environments. Thus the conditions make conducting a conventional survey unsuitable or impossible to properly monitor the site as required.

The project objectives also included very accurate data (5 cm absolute accuracy) in order to accurately track changes between surveys.

A. Vessel-borne Mobile Laser Scanning

In response to the need for an alternative solution for the project, mobile laser scanning from a small vessel was determined to be the most effective method for meeting the project goals.

Vessel based mobile laser scanning (also referred to as ground based LiDAR) has evolved in recent years as an alternative to both airborne LiDAR as well as static terrestrial laser scanning. Mobile Laser Scanning operates with the same principles as airborne LiDAR technology: using rapid laser pulses fired for range observations with the sensor coupled to a GNSS/GPS as well as to an Inertial Measuring Unit (IMU).

Mobile laser scanning is the same principal, with the key difference being the vehicle platform being used: the vehicle will typically be either a land based vehicle (such as a truck or ATV) or a waterborne vessel. In this project, the vehicle would be a small vessel. Previous application of mobile laser scanning to coastal surveys was the basis for selecting this as a suitable choice for the project [1] and [2].

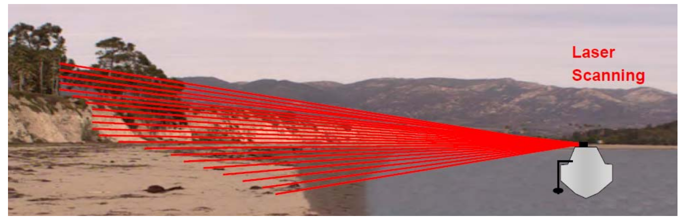

Fig. 3. Schematic of mobile laser scanning from a vessel.

The resulting dataset is a cloud of XYZ coordinates, commonly referred to as a point cloud. Mobile laser scanning is capable of collecting extremely detailed data sets and has the distinct advantage of being able to survey vertical objects very well – especially features like cliffs, building fascia, signs, sides of bridges to name a few. Another advantage is the ability to map underneath some structures, such as piles under a pier when deployed from a boat.

It is worth noting that laser scanning is a line-of-sight technology and therefore one object in the foreground will completely obscure any object behind it. For example, it is only possible to map the side of a building facing the sensor – the backside of the building is hidden and therefore requires driving/sailing behind the building to get the missing side(s). Some aspects, such as the ground above the cliff edge, typically cannot be captured at all from a vessel-based deployment.

Coupled with the laser scanner is a high-resolution digital camera. During the survey, the camera captures side-looking imagery which can be orthorectified to the point cloud.

IV. THE PROJECT

A representative portion of the project area was selected for study. This was a 3.5 km long stretch of coastline known as the Great Cliffs area in the town of Carry-le-Rouet (Bouches du Rhone, France).

3D scanning covered the whole coastline, but processing focused on the cliffs (in red in Fig. 4), not on port/harbor infrastructures (green) or beaches (yellow). Only the area of the site above the waterline was deemed relevant for the project – a bathymetric survey was not considered necessary and its implementation would have been very difficult given the very shallow water depths to operate a multibeam echosounder.

Fig. 4. Mobile laser scanning survey area – red lines represent cliff areas. Yellow lines represent beach areas. Port/harbor facilities (green) were not included in the study.

A. Field Data Collection

The project was conducted with two phases of field data collection. During November 2011, a mobile laser scanning survey was undertaken, recording a first state of the cliff morphology. A second survey was successfully completed in July 2012. The processing of the two sets of data led to a first comparison that provides a complete image of the changes.

For each survey, 2 to 3 hours were first spent to mount the system on a small rigid inflatable boat (Fig. 5), so that the sensor could follow the coastline as closely as possible without occulsions caused by barriers to line-of-sight. Then a quarter of an hour was used to calibrate the system prior to starting each of the surveys.

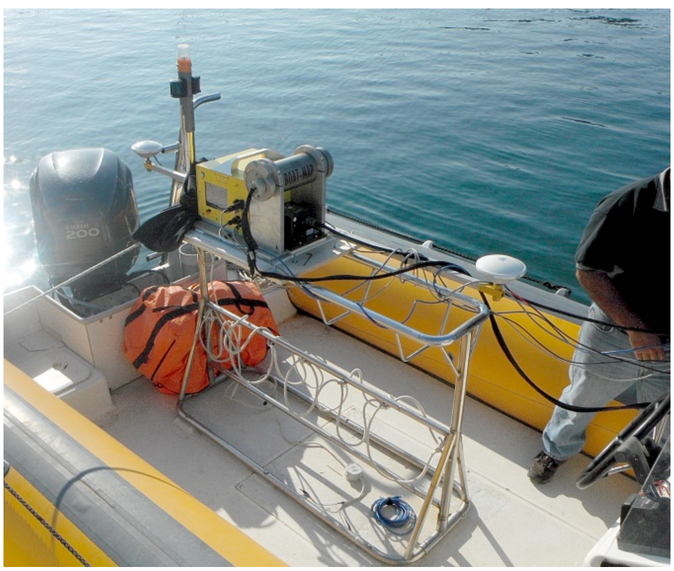

Fig. 5. Mobile laser scanning system (laser scanner, GNSS, IMU, and camera) installed in small vessel for survey.

The survey vessel was piloted to follow the coastline at a very slow speed – under 6 km/h – in order to navigate the complex coastline as well as to capture extremely dense point cloud data of the cliff and beach areas. The vessel was frequently maneuvered to optimize coverage of coves and inlets and/or behind obstructing features. During both survey sessions, the entire area was completed in less than 3 hours.

It should be noted that during the first survey in November 2011, heavy swell made the survey particularly difficult. This created additional challenges for the IMU system, particularly on a small boat. To ensure that the data collected met the required tolerances, the survey was repeated the following day to verify the accuracy of the survey met the 5 cm requirement.

B. Data Processing

1) Pre-processing

For each survey, the data was processed from the coupled GNSS/IMU sensors to produce a final trajectory of the vessel (and thus sensor). The point cloud was generated by associating the range and angle information from each laser observation to the orientation data in the trajectory. Similarly, the photographs were associated with the trajectory data (via time-tag) to geo-reference them. The resulting pre-processed data included:

- 42 million XYZ coordinates in the laser scanner point cloud
- High-resolution georeferenced photos of the cliffs and beach areas of the project

Fig. 6. 3-dimensional point cloud of the Carry-le Rouet cliffs (point cloud rendered in grey-scale using reflectance intensity)

2) Unrolling the coastline

Although the majority of the coastline is south-facing, it is highly variable due to the action of coastal processes and erosion over time. Thus in order to be able to view the entire coastline from a single side-looking viewpoint, the coastline had to be "unrolled". A line was drawn to follow the coastline which was composed of both linear and curved segments and the data was unrolled along the line to allow for the survey area to be analyzed from a single view point. This process was repeated for each survey separately.

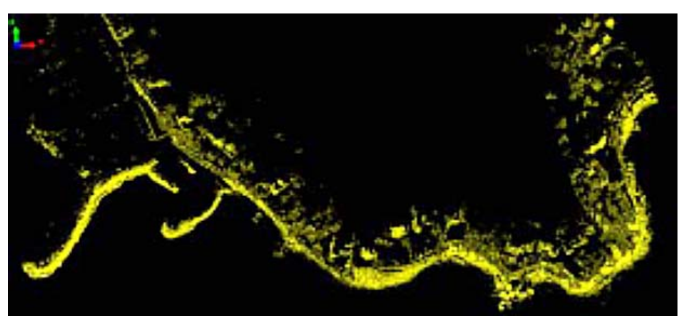

Fig. 7. Aerial view of cliff survey area before "unrolling"

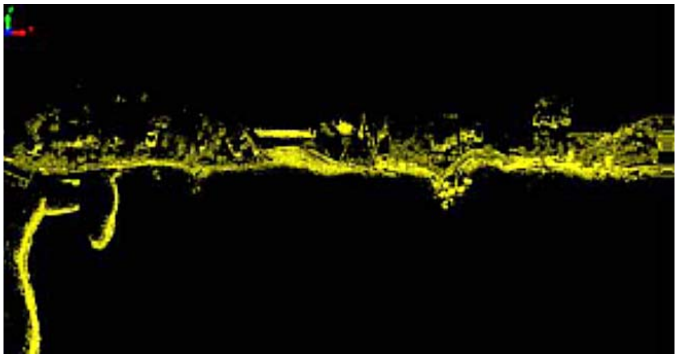

Fig. 8. Aerial view of cliff survey area after "unrolling"

3) Point Cloud Classification and Filtering

Every feature and object within the laser scanner's field of view is recorded – including features that are not relevant to the study. This includes the water surface, boats, buildings, people, but most significantly, this includes the vegetation that partly covers the cliff faces. In order to adapt to this challenge, point cloud classification software typically used for processing aerial LiDAR data was employed to classify the mobile laser scanning point cloud to edit out non-relevant features without deleting the features entirely. Thus the points representing the cliff and beach surfaces can be analyzed while ignoring the non-relevant data points. This data classification was repeated for each survey independently.

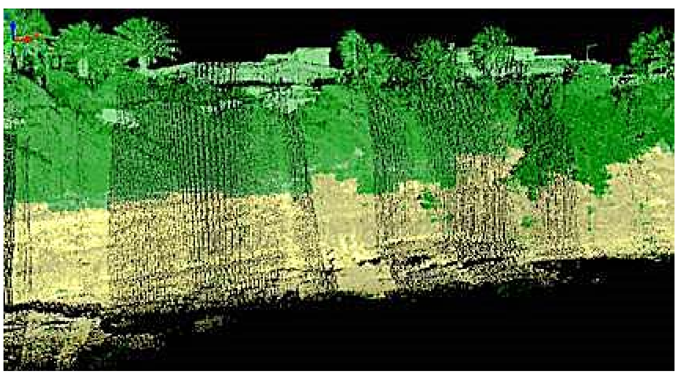

Fig. 9. Point cloud classification – points in dark green and light green are vegetation and buildings respectively. Points in yellow are the key points representing the cliff face.

4) 3-Dimensional Mesh

The filtered point cloud comprising of only the cliff face was used to produce a dense 3-dimensional data mesh. The mesh is an accurate digital reconstruction of the surface of the cliff face. The mesh derived from each survey was used in the comparison to establish the baseline condition and to identify change between the surveys.

Successive digital mesh models of the cliffs surface were subtracted to reveal the location, shape and volume of erosion and material loss (scarring) by coloring the differences using an appropriate color scale. For each scar, thickness, area and volume are then registered in a database and tracked over time.

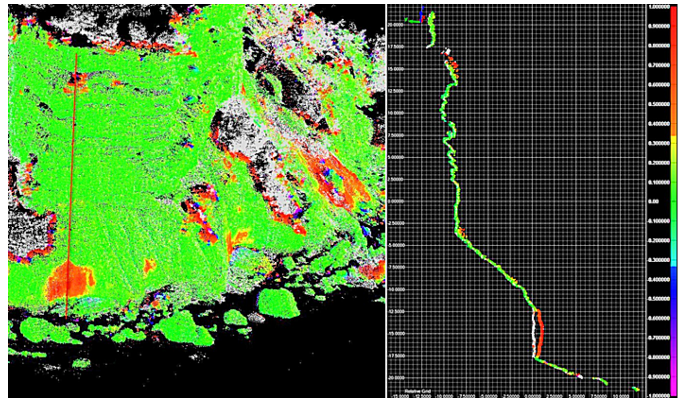

Fig. 10. Cliff meshes are subtracted to detect and quantify change (top view left; cross-section view, right). The mesh is colored to represent the magnitude of material loss.

5) Orthomosaic Imagery

Often, point cloud and/or digital surface data are difficult to interpret, as they lack the same contextual information perceived by the human eye. To improve interpretation, it can be valuable to have a photographic reference.

By projecting the digital photographs onto the mesh surface, it is possible to produce a high-resolution orthophoto. The result is a high-resolution textured surface that incorporates both geometrical and visual information.

Fig. 11. Example cliff where high resolution imagery has been projected onto the mesh.

Further, a mosaic comprised of each image projected onto the unrolled coastline provides a single view of the entire coastline. This view can be particularly valuable for validation of the point cloud filtering as well as for visual interpretation of the coastal morphology changes. The output data can be managed as layers in a GIS environment.

Fig. 12. Orthomosaic imagery of the entire unrolled coastline visible in one panoramic view.

V. Observations

The results of the survey comparison located 23 significant changes in the cliff over the span of the 3.5 km survey in a span of 8 months. Most changes were due to rock falls typically in the order of 0.5 m deep and 1 to 3 m along the longest lateral axis. There were two more drastic locations of cliff failure, the first 1 m deep, 6 m in diameter and the second 2 m deep, 10 m across and 12 m high.

VI. Conclusion

Coastal sites are commonly subject to rapid changes due to environmental conditions and episodic events. Coastal planners are frequently concerned with monitoring change and understanding the risks to people and infrastructure, particularly if the site is developed.

In Carry-le Rouet, France, coastal changes have become a significant concern and mobile laser scanning was tested as a mechanism for monitoring that change.

Periodic repetition of these mobile laser scanning surveys was determined to be a satisfactory method for meeting the project objectives of tracking change, identifying rates of change, and locations subject to different degrees of change in cliff retreat. In the case of Carry-le Rouet, an annual campaign to re-survey the project site would be an appropriate methodology to track changes at the site over time and to help coastal planning activities by providing empirical evidence (rather than anecdotal). With successive surveys it becomes possible to calculate and validate probability distribution functions associated with coastal morphology change, as has been demonstrated in northern France using static terrestrial laser scanning techniques between 2005 and 2008 [1].

References

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[2] T. J. Mitchell and S. Varnell, "Evaluation of Coastal Slopes Using Mobile Laser Scanning and Bathymetric Surveying Techniques", Coastal Zone 11 Conference Proceedings, Chicago, Illiniois, USA, 2011.