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HIGH RESOLUTION DEM DERIVED FROM THERMAL INFRARED IMAGES : EXAMPLE OF ABER BENOIT (France)

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ABSTRACT

Intertidal DEM have a growing interest for ecological, geological and land development purposes. However, due to the characteristics of this environment, DEM are not easy to obtain and frequently not good enough in resolution to be interpreted.

In this study, waterline method has been used to build a high-resolution DEM. This technique is basically based on the accurate localization of the boundary between water and sand. This limit being an iso-height line, multitemporal detection can be used to derive a DEM. Because of the distinct physical characteristics of both sand and water, this limit is clearly visible on thermal infrared images. We tested this method on a beach of Aber Benoit (France) by recording the shoreline movements during a whole tide rise with a thermal infrared camera with simultaneous check of the water height (DGPS on board a boat) to provide an absolute calibration.

The reconstructed DEM, validated by an independent DGPS profile, has a mean resolution of 2 cm and accounts for details smaller than a centimeter.

KEYWORDS

Terrain mapping, thermal infrared imaging, sea coast, topography, Digital Elevation Models

1. INTRODUCTION

Intertidal zone knowledge is a key point for several scientific, atrophic and natural hazard purposed. 3D morphology restitution is challenging. For example, coastal monitoring is considered as a major challenge to anticipate the response of coastal hazards on coastal risks [1]. Topography restitution and evolution is one of the key parameter of this monitoring. [2]

Coastal DEM (Digital Elevation Model) can be derived by different techniques either which can be classified into two groups: bathymetric measurements obtained during high tide and terrestrial measurements realized at low tide. However the mild slope of these regions makes it difficult to

measure the bottom topography and sometimes the soft mud flat is dangerous place to survey

1.1 High tide methods

The spectral method is based on multispectral imagery recorded by sensors on board satellites [3], planes or unmanned platforms [4]. The spectral response of a pixel is function of the thickness of the water level. This approach has been validated on both rivers [4] and sea [3]. However calibrations are required and limitations are severe since the method fully works only in case of homogeneous bottom, low turbidity, smooth surface and the precision decreases with depth.

For small extent area, mono and multibeam echosounder is actually the most common used technique. The uncertainties are 0.5% of the depth, that is to say 2cm minimum for shallow water [5]. Due to the boat platform, this technique cannot be used for very shallow water (less than 50cm).

1.2 Low tide methods

During the low tide, beach topography can be measured with a DGPS [6]. However, to obtain a satisfying precision, the points must be measured during a few seconds, which reduces the number of points which can be acquired during the low tide. Rayburg et al. [7] propose that the precision of the data is about 1cm. Furthermore, as a punctual method, interpolation would be required to reconstruct a DEM.

Another method, LIDAR (Light Detection and Ranging), is increasingly used. The principle of this technique is detailed by Brock et al. [8]. The resolution is limited by laser pulse footprints, which are typically 1 m large [9] and has a vertical precision of a few centimeters.

Finally, studies based on photogrammetry have been realized to derive underwater DEM. The main problem encountered in that cases, is the non-obvious correlation of images and the need of numerous ground control points. Feurer et al. [10] realized a DEM of various sites on the Durance river, with a mean root square error of 1cm.

1.3 Optical waterline method

The waterline method was first used by Chen et al. [11]. The so-called waterline is the shore-sea limit. It is therefore, at a given time, a line of equal elevation. However, the water height varies with time following the tide. Stacking

waterlines can consequently provide a DEM of the intertidal zone.[11]

In this paper, we present a method allowing to extract a DEM from a batch of thermal infrared images recorded during a rising tide. We tested this technique on a beach in order to reconstruct a DEM and estimate its maximum resolution.

2. THE THERMAL WATERLINE METHOD

2.1 Potential of thermal infrared for the waterline detection

The crucial point for the waterline method is to distinguish the water body from the tidal flat. On thermal infrared images, the contrast is clearly visible. Indeed, for a blackbody, the luminance L is dependent of three variables: the temperature T , the emissivity ε and the incident energy $E_{incident}$.

$$L = E + R = \varepsilon(\sigma T^4) + (1 - \varepsilon)E_{incident}$$

In our case, the thermal contrast is mainly due to a difference of thermal inertia between sand and water. Unlike the sand, the water mixes and is thus much more difficult to warm up or to cool down. Since our experiments were done during sunny spring daytimes, the water was cooler than the sand. At usual temperatures, a contrast of 1K implies an emission contrast of more than 5W/m² for a blackbody.

The emissivity contrast can be important for oblique incident rays. Sobrino [12] pointed out that for very oblique angles, water emissivity can decrease down to 0.85 whereas sand emissivity remains constant (around 0.97). The unclouded atmosphere has a Rayleigh diffusion mode. So it emits roughly 100W/m² vertically, whereas a blackbody at ground temperature has an emission typically around 400W/m². This huge radiation contrast counterbalances the weakness of the $(1 - \varepsilon)$ parameter and the observed contrast of reflected energy accounts for an important part of the luminance contrast, in regions where a cloud-free sky reflects.

This potential was primary pointed out by Ryu et al. [13] They performed a 10m vertical accuracy DEM from 28 images including Landsat near infrared data [14] on a 5km-wide flatland, although they showed the highest potential of thermal infrared [13].

2.2 Overview of the method

So far, waterline methods used satellite images which are highly dependent on satellite orbits. Consequently, many time can pass between to waterlines imaging, and, consequently the beach topography may have significantly changed.

In this paper, we used a fixed sensor to get a large number of thermal infrared images during a single rising tide, in order to improve vertical precision. The absolute water level was measured by a DPGS on board a boat.

Furthermore, the use of a fixed camera decreases the distance from the sensor to the scene and consequently improves the resolution and the accuracy.

Fig 1 : Overview of the method

3. MEASURES DEVICES - STUDY AREA - DATA PROCESSING

3.1 The thermal camera

The sensor is a VarioCAM® hr head set with an uncooled bolometer detector able to record energies from 7.5 to 14 μ m (thermal infrared) with a claimed thermal resolution better than 0.08K (0,5W/m²). The size of the detector is 384x288 pixels.

The lens has a focal length of 25mm. One pixel located 20m from the camera will therefore represent a square of 2cm.

The sensor was left during the main part of the tide rise with an acquisition frequency of 1Hz. It is fixed so that each picture can be exactly stacked with the previous ones.

3.2 The tidal gauge

The tide gauge is constituted of a DGPS set on board a boat. When the tide is coming in, the boat raises with the water level. In order to have a good vertical precision, the acquisition frequency was set at 0.1Hz.

The DGPS data are fitted by a cosine curve to smooth the dataset.

3.3 Description of the study area

Aber Benoit is a ria located in northern Brittany (see Fig. 2). This 12km-long basin is a famous place for oysters culture (for example the Prat-Ar-Coum fish-ponds), and several studies on oysters have been carried out [15, 16]. Due to the weak rate of flow of the river, and the distance from the open sea, sediments are mainly silty ones. Consequently, the shore is mainly constituted of mud which strongly complicates in-situ studies.

Fig 2 : Location of the study area

The camera was set on the Treglonou bridge located on the road RD 28. It is the last bridge over the Aber Benoit 8.5km away from the open sea. The site was mostly free of rocks and algae.

The line of sight is oblique. Indeed, the scene is located 6m below the camera. The distance from the sensor ranges between 15 and 30m. Consequently, a pixel is 1.5cm width at the bottom of the image, and 3cm width at the top.

The experiment took place on April, 23rd 2009. The low tide was at 12h06 and the high tide at 18h02. The tide range was announced to be 5.40m., and there were no noticeable waves so the rising of the water level was continuous.

The sky was completely free of clouds, so the emissivity contrast was clearly visible.

3.4 DEM extraction

In order to separate the shore from the water, we defined a cutoff emission: a pixel is considered as emerged as long as its luminance is above the cutoff emission defined empirically.

For each pixel, we determined the time when it was recovered by water. Then, we converted this time into an absolute height using the tidal gauge. (Fig. 3)

The DEM is quite insensitive to the choice of the cutoff luminance. For this example we choose 418W/m^2 , which is approximately the mean value for sand and water emissions. Nevertheless choosing a higher or a lower cutoff emission would simply translate the DEM of a given height.

Superimposing thermal infrared images on visible ones is quite easy, since, because topographic irregularities (footprints, rocky block...) are easily distinguishable on thermal infrared images. We chose ten easily recognizable points on both optical and thermal images to project the visible picture on the contour level image. (Fig. 3)

Fig 3 : DEM extracted from infrared images (m) and comparison with optical image. Due to the obliquity of the line of sight, the width of the image varies from 2m at the bottom to 4m at the top. The height of the image is 7m. For the optical image, contour lines are spaced out by 2.5cm.

4. RESULTS

The validation of our DEM has been realized using a DGPS profile (see Fig 4). The root mean square of the difference between both profiles is 4mm, which is the typical error that we attribute to the DGPS.

Fig 4 : Comparison of a profile made by GPS and the profile made with thermal images

Fig 5 : Transects of a small channel on the shaded DEM

In order to illustrate the limit resolution of our method, we studied a little channel flowing in the big one. In the series of transects of Fig. 5, we see that the camera can reconstruct details of less than 1cm depth and 5cm wide.

5. DISCUSSION - CONCLUSION

Multitemporal thermal imagery provides high resolution DEM, and allows to detect details smaller than 1cm in height. It can derive topography in very shallow water (0m to low tide height).

Furthermore, as it is a remote sensing technique, it may not require measurements on the study area, which can be difficult of access in muddy zones.

The main limitation of the technique is related to the conversion of time of pixel immersion under water into absolute height. However, ancillary measurements of water heights such as pressure sensor could lead to better precisions.

The DEM obtained by this technique have a resolution better than 10 cm in average on the image which is sufficient to for modeling the water dynamics.

The next step is to obtain thermal images of an onshore zone by a thermal camera on board a UAV or a plane, in order to derive DEM covering larger surfaces with less distortion than those obtain from the soil.

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