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ORIGINAL PAPER

POTOS: a portable topographic system for measuring inaccessible muddy creek areas

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Abstract Tidal flats and marshes in intertidal environments and estuaries generally cover large areas. The access to these places is usually complicated. The area suffers cycles of flooding and drying under the influence of the tide, which in conjunction with soft and muddy soils makes every movement very difficult. In particular, in tidal channels mud is softer and, many times, it is impossible to move around these areas. Furthermore, muddy tidal flat creeks are often located far away from conventional vehicle access. Then, to perform a topographic study using traditional methodology is not feasible; therefore, an alternative methodology has been developed to deal with these problems.

POTOS is a light metallic frame developed to measure creek topography indirectly with good precision. The tensed frame, up to 12 m long, simply supported and weighting only 40 kg allows making relative height measurements of the surface between the supporting posts. The field methodology is described and some results obtained with the instrument developed are presented. Errors were calculated by comparing measurements obtained with the instrument and those gathered by traditional methodologies. Field results are a series of measurements obtained in Bahía Blanca Estuary tidal flats and marshes at different periods of the year.

Keywords POTOS · Topographic survey · Tidal creeks · Survey methodology

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Introduction

The topographic determination of tidal channels and their drainage areas over muddy tidal flats imply a logistic problem that must be considered carefully. In Bahía Blanca Estuary (Argentina), the detailed geomorphology and growing rate of a series of tidal creeks are being studied on a marsh of about 4.5 km^2 of predominantly silty clay soil. To step on the study area is unacceptable because the area would become perturbed. Tidal creeks are about 2 km away from the closest accessible spot by car. Also the tide floods the marsh quite often, so a fast, light, easy to carry, and accurate device must be considered to make periodic determination of their geomorphology and evolution.

In the Earth Sciences topographic measurements for the construction of Digital Elevation Models (DEM) and the representation of three-dimensional objects with non invasive methodologies of measurements have always been an object of study. This kind of problems has resulted in different measurement techniques, each one with a certain field of application. One of the techniques is the use of remote sensors (Butler and Walsh 1998). Systems mounted in satellites like the Topographic Laser Mapping Altimeter (TMLA, Harding et al. 1994), Laser Shuttle Altimeter (SLA, Garvin et al. 1998), Vegetation Canopy Lidar (VCL, Bufton and Blair 1996) among others have made important contributions to determine the relief of the Earth surface. Another accepted and widely used technique in the field (Ryu 2002; Mason et al. 1999, 2001; Naicker 2001) as well as in laboratory (Minkoff and Fernandez 2001) it is the method of the ‘‘line of water’’. It consists of extracting from an aerial photo the line that is an intersection of the water level with the relief that contains it, since this line marks a topographic level which can be correlated to an independent reference datum (i.e., tidal gage zero, local mean sea level, etc.). Another methodology is the use of the Relief Electronic Measurer or Rugosimeter (Huang et al. 1988; Mwendera and Reyen 1999; Planchon et al. 2001; Bertuzzi et al. 1990). This device consists of a structure of 4.5 m on the side, 1.2 m high which is buried 0.50 m into the ground. Around the field-levelled structure, a beam with a sensor is free to move around the area covered by the structure. When the sensor is located at a specific point, the sensor is lowered until it touches the soil and the *x*, *y*, *z* position is recorded.

However all these methodologies do not adapt satisfactorily to the exigencies of the work in intertidal environments. Remote sensors have a resolution of the order of the decimeter in height. The method of the line of water is not applicable since it requires sequential vertical photos taken from a plane along the full tidal cycle. Finally the rugosimeter requires of a zone very stable to work which is relatively difficult to find in these environments. A device and its corresponding field and post processing methodology has been developed which contemplates the requirements and logistic complications needed in coastal wetland research. Therefore, the aim of the present article is to describe POTOS: a Portable Topographic System, including its field methodology and to provide examples of results gathered with it.

Description of POTOS

The instrument has 4 ‘‘U’’ shaped iron bars, 3 m long, which can be joined at their ends by bolts and nuts (Fig. 1). It has also three columns; two of them sustain the bridge during the operation and

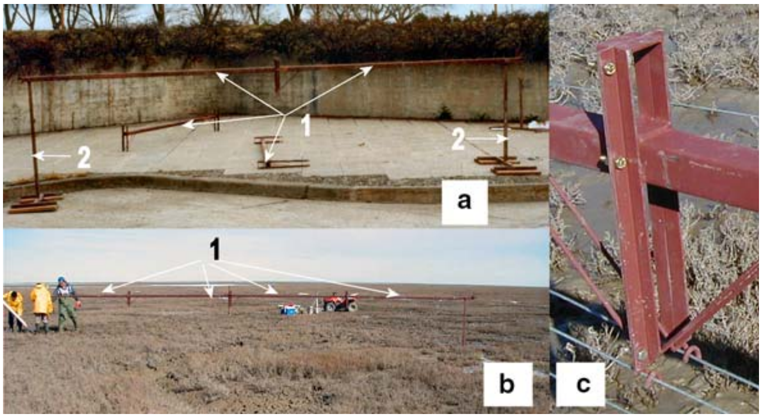

Fig. 1 POTOS set up. (a) Configuration 1: The device utilizes the two 3-m extreme bars screwed and without tensors. (b) Configuration 2: the device utilizes the four 3-m beams screwed and is maintained levelled by tensors. (c) Detail of the union of two bars. Component Parts: (1) Iron bars; (2) Posts with variable height

the third is employed during the assemblage process. Two length configurations can be adopted, one of them uses two 3 m bars, enabling a total measuring distance of 6 m (Fig. 1a), and the other aligns all 4 bars, which allows a 12 m span (Fig. 1b). Due to the low rigidity of the system used with the latter configuration, a set of oceanographic cables are disposed to rectify the instrument both horizontal and vertically (Fig. 2). They are located at each side of the longitudinal bar and hooked at the end to its extremes and passed over the joints.

The bar slot forms a path where a slider moves along pulled by a string. This string is tied to both sides of the slider and closed around two pulleys which enable a backward-forward movement of the slider along the bar slot. The slider carries a measuring tape used to perform the measurements, which holds a weight to tighten it.

Operation

The main objective of the POTOS bridge is to obtain a cross-section profile of a creek. The

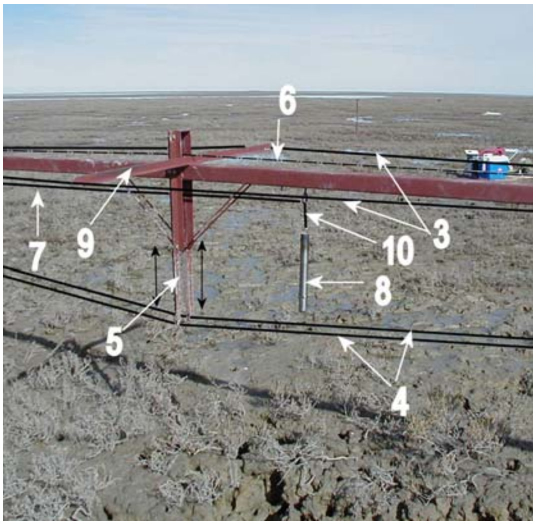

Fig. 2 Detail of POTOS components: (3) Horizontal tensors; (4) Vertical tensors; (5) Extension of variable length for the vertical tensors; (6) Rope without end that passes outside and inside of the structure profile. The latter is attached to both sides of the slider. (7) Measuring tape; (8) Weight to tense the measuring tape; (9) Fixed length extension for the horizontal tensors; (10) Top of the measuring tape to perform the measurement with the weight up

operation consists in moving the slider to the outer extreme of the bridge, and allowing the weight to barely touch the soil. A reading on the tape is recorded, then the tape is pulled up until it reaches a stop on the bridge and a new reading on the tape is recorded. The second reading provides the distance from the reference post, which is located at a known local coordinates (*xmp, ymp, zmp*, where the term *mp* means measuring place). Whereas, the difference between both readings provide the height of the bridge to the land (*hz*). The horizontal bar can be modelled as a straight line in the space. The slider takes the coordinates of this straight line (*x, y, z*) as it moves along it. The weight hangs from the slider and the difference between the distance with the weight down and up (plus the length of the weight itself) provides the ground position referred to the bar.

The equation of the straight line in the space is obtained using the coordinates of the posts (*xmp, ymp; xop, yop* where the term *op* means opposite to the measuring place) and the distance from the measurement place (λ). These coordinates are referred to a local network which positions were previously determined by DGPS and theodolite. The coordinates *zmp* and *zop* are estimated by the algebraic addition of several terms (Fig. 3)

$$zmp = zlp + (elp - emp) + bt + hmp - hmt$$

where *emp* is the elevation of the base referred to the elevation of a fixed local point (*elp*) with an

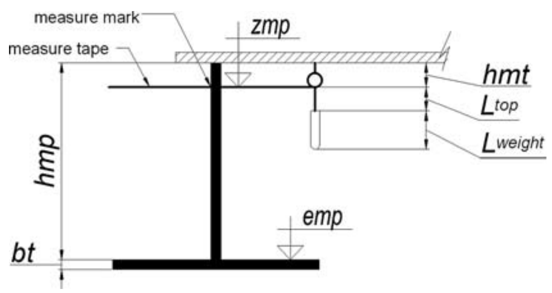

Fig. 3 Detail of POTOS constants. *bt*, base thickness; *hmp*, post height to the horizontal bar; *emp*, elevation of the base in the measuring place; *hmt*, height of the measuring tape to the horizontal bar; *Ltop*, length of the top of the measuring tape; *Lweight*, length of the weight. Data is gathered from the measuring tape with the weight up and the weight down, and both are referred to the post

absolute known altitude value (*zlp*), *bt* is the thickness of the post base, *hmp* is the post height to the horizontal bar, and *hmt* is the height of the measure tape to the horizontal bar.

A similar equation can be written referring to the opposite post

$$zop = zlp + (elp - eop) + bt + hop - hmt$$

where *eop* is the elevation of the base referred to the elevation of a fixed local point (*elp*) with an absolute known altitude value (*zlp*), and *hop* is the opposite post height to the horizontal bar.

The position of the slider on the slot, measured from the post (λ), and the ground surface (*hz*) with the coordinates of the two posts results from the parametric straight line equation written as

$$x = xmp + \frac{(xop - xmp)}{d}\lambda$$

$$y = ymp + \frac{(yop - ymp)}{d}\lambda$$

$$z = zmp + \frac{(zop - zmp)}{d}\lambda - hz$$

being *d* the distance between the post coordinates, which is a constant for each configuration.

Results and discussion

Contrast measurements were done using POTOS in its two configurations and an optical theodolite as reference (Table 1) over levelled surfaces. The standard error for configuration 1 was 1.4 cm and for configuration 2 was 1.2 cm (Emery and Thompson 1997). Even when the standard error for the first configuration was higher than the second one, an ANOVA test ($F_{1,17} = 0.093$, $P > 0.76$, Zar 1999) did not find differences among them. Then, as the two set of measurements carried out with both configurations are comparable, an overall standard error was calculated including all the determinations resulting in 1.2 cm (n = 18).

In the determination of the coordinates, the sources of error are the records obtained from the measuring tape (λ, *hz*), and the different added constants (*bt*, *hop*, *hmp*, length of the weight). The constant errors, once determined, are always added in the same sense, becoming a systematic one. The easiest way to obtain a correction term is to calculate the position of an already known point and determine the total error due to all the constants by difference. The main source of error is the determination of *hz* and λ. The measuring tape describes a curvature under its own weight, which induces error. But the determination of the *hz* is obtained by difference between weight down and up, then the error is compensated. On very windy days (common in our study area) the tape could bend, affecting the determinations. Therefore, working in such conditions is almost impossible.

The system has been used from August 2002 till November 2004 on a muddy marsh where we are investigating the advance of tidal creek heads. During the first field measurements on the marsh,

Table 1 Comparison of measurements made with POTOS and a theodolite for configurations 1 and 2

Reading	Configuration 1			Configuration 2		
	Elevations (m)		Error (cm)	Elevations (m)		Error (cm)
	POTOS	Theodolite		POTOS	Theodolite	
1	10.065	10.067	–0.2	10.146	10.141	0.5
2	10.031	10.057	–2.6	10.111	10.125	–1.4
3	10.033	10.046	–1.3	10.095	10.107	–1.2
4	10.024	10.032	–0.8	10.077	10.085	–0.8
5	9.886	9.883	0.3	10.054	10.061	–0.7
6	9.916	9.903	1.3	10.043	10.044	–0.1
7	9.926	9.926	0.0	10.033	10.026	0.7
8				9.886	9.878	0.8
9				9.928	9.902	2.6
10				9.919	9.914	0.5
11				9.942	9.932	1.0

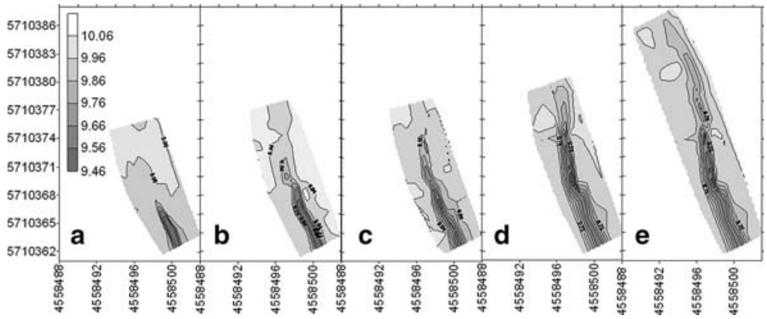

Fig. 4 Evolution of the topography estimated with POTOS at one of the tidal creeks on the study area. (a) November 2002; (b) May 2003; (c) November 2003; (d) April 2004; (e) October 2004. Coordinates are in Gauss-Kruger and vertical scale in meters

a number of marks were placed and detailed positioned around the creeks to define the locations where the posts were going to be positioned during the surveys. These marks were referred to a local net and also their coordinates defined using a DGPS.

An important issue regarding the use of a system like POTOS in the field is the time required to set up and dismantle the structure, and the sampling time as well. A trained team of four technicians can set POTOS in 15 min for the 6 m format and 30–35 min for the 12 m setting. Dismantling takes on average 15–25 min in both cases. Once any of the configurations are in place, a series of 15 data points along a transect can take between 5 and 10 min depending on the wind conditions. During a period of 2 h a total of seven transects with 15 points each can be made. Most of this time is taken in moving from one transect to another and insuring that the bridge maintain is level. On the other hand, data analysis (including graphics) in the office for a single creek could be done in about 1 h once the data was input on a spreadsheet.

During the study period, seven creeks were surveyed five times. From the data obtained on each survey a DEM was built with Surfer ™ software using an irregular triangular net (Fig. 4). Residuals were obtained as the difference between the interpolated altitude from the DEM and the measured one. The standard error for the five field works performed was between 1.25 and 2.6 cm.

Conclusions

POTOS is a measuring system for inaccessible areas, simple and easy to carry. The determinations of the ground surface on muddy marshes, especially at tidal creeks, have several inconvenients. Traditional methods inevitably disturb the study area since the observer must step at or near the points of interest. As marshes provide only relatively few hours to work, a system that can be easily transported, readily used, and can provide minimum repetition error is required. The solution for all these problems were satisfactorily solved by the bridge system described.

Precision given by the POTOS is of the order of that provided by traditional methods. Also the data processing gives a standard error of the same order of the measurements, thus, the final product obtained is acceptable. The advantage of this system is that the unperturbed area can be followed in time and records of the evolution can be kept without even touching the sampling area. During windy days the precision obtained is not acceptable due to the deformation of the measuring tape. Therefore, field work with POTOS on very windy days is not recommended.

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