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Technical note

A simple data transformation technique for pre-processing survey data at embayed beaches

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Abstract

This note explains a technique used for pre-processing three-dimensional survey data obtained at embayed beaches that exhibit distinct alongshore curvature. Using a log-spiral function fitted to the beach planform, the data is transformed from Cartesian into an alternative alongshore–cross-shore coordinate system. When undergoing this transformation, the curvature in the survey data is effectively removed. This greatly simplifies the application of standard interpolation methods, and in this transformed coordinate system the alongshore and cross-shore directions are now explicitly defined. Using a property unique to the log-spiral, the interpolated data is readily transformed back into the original Cartesian coordinate system for further analyses and interpretation. The practical application and advantages of this technique are then demonstrated using survey data from two embayed beaches in south-eastern Australia.

Keywords: Embayed beaches; Beach surveys; Logarithmic-spiral; Interpolation methods; Data gridding

1. Introduction

Many coastal developments around the world are located at embayed beaches (also known as headland-bay, crenulate, spiral, hooked, half-heart, zeta-form and pocket beaches), where large natural or artificial barriers (such as rocky headlands or groyne structures) cast a degree of curvature on the beach planform. Coastal engineers are routinely involved in monitoring and investigating the processes that govern the morphodynamics of embayed beaches, as a means of protecting or maintaining coastal infrastructure and/or natural beach amenity. A common approach to these types of studies is through the implementation of a beach survey program.

With the advent of survey technologies such as RTK-GPS (real-time kinematic global positioning system) and LiDAR (light detection and ranging), beach survey methods are shifting from the traditional two-dimensional, transect-based surveys (e.g., Emery, 1961; Larson and Kraus, 1994; McLean and Shen, 2006) to fully three-dimensional data coverage (e.g., Dail et al., 2000; Haxel and Holman, 2004; Ruggiero et al., 2005). The introduction of far more dense and three-dimensional beach survey datasets provides the opportunity to better monitor and quantify coastal change, but also introduces new data-analysis challenges. Plant et al. (2002) provide a comprehensive description and solution to address inherent sampling limitations, which result in aliasing and measurement errors that may otherwise lead to large errors in the representation of the morphological scales of interest. The curvature of embayed beaches further complicates the processing and analysis of high-density and often irregularly-spaced survey data. Problems arise such as defining the alongshore and cross-shore directions and attempting to interpolate the curved data to a rectangular grid, since it is often the case that the great majority of the imposed rectangular grid-nodes lie outside the surveyed region.

Recently, Ranasinghe et al. (2004) and Holman et al. (2006) analyzed the morphodynamics of an embayed beach using a time-series of rectified video images. To determine alongshore rip spacings and cross-shore bar and shoreline movements, they utilized the logarithmic-spiral (hereafter abbreviated as log-

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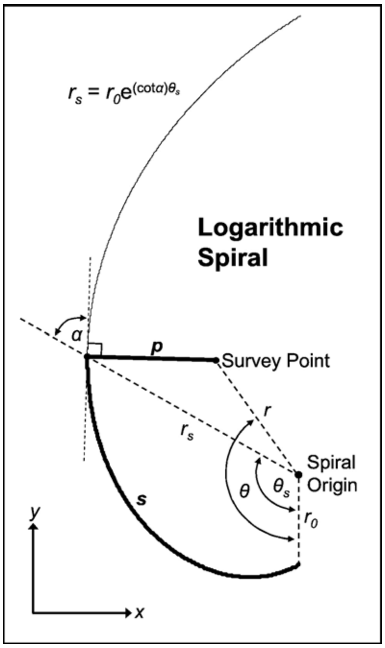

Fig. 1. Geometry of a survey point (r,θ) relative to a log-spiral.

spiral) function, which has been shown by many researchers to be a commensurate approximation for the planform of embayed beaches (e.g., Krumbein, 1944; Yasso, 1965; Bremner and LeBlond, 1974; Moreno and Kraus, 1999). Alongshore and cross-shore distances were then defined as the length along and orthogonal to a log-spiral fitted to the duneline of the beach.

The methodology explained herein extends this concept and presents a simple and generic technique suitable for the transformation of beach survey data from standard Cartesian coordinates into an alternative alongshore–cross-shore coordinate system. In this new coordinate system, the curvature in the irregularly-spaced survey data is effectively removed, thereby facilitating the application of standard data interpolation methods. Since the data in this modified coordinate system becomes distorted, it is important that the transformation be reversible: i.e., the interpolated data can be readily transformed back into the original Cartesian coordinate system for subsequent analysis and interpretation. Although several authors (see below) have proposed alternative functions to approximate the planform of embayed beaches, the transformation proposed here is unique for its reversibility. In the following sections the log-spiral data transformation technique is expounded, with the practical application and advantages of this methodology demonstrated using survey data from two embayed beaches in south-eastern Australia.

2. Embayed beach planform functions

The general planform of embayed beaches can typically be separated into three sections: a deeply curved shadow zone adjacent to the updrift (or more exposed) headland; a more gently curved central section; and a relatively linear section extending in the downdrift direction (Short and Masselink, 1999). The idea of describing this shape by a mathematical function was first suggested by Krumbein (1944), who observed that the planform of Halfmoon Bay in California resembled a log-spiral. In mathematical terms, the log-spiral is a curve that maintains a constant angle α between the radial vector and the tangent vector. The general form in polar coordinates is:

$$r_s = r_0 e^{(\cot\alpha)\theta_s} \tag{1}$$

where r_s is the radial vector from the origin of the log-spiral to a point on the curve, r_0 is the initial radius, and θ_s is the angle between r_s and r_0 (Fig. 1). Yasso (1965) developed a simple methodology for fitting a log-spiral to the measured beach planform and found good agreement for the four beaches studied. Because of its simplicity and success, the log-spiral approach has been used extensively in studies on embayed beaches. However, the lack of any physical explanation for the spiral origin and its failure to account for the linear downdrift section of the beach has led to the development of other functions (Short and Masselink, 1999). For example, Hsu et al. (1987) analyzed embayed beaches in static equilibrium and proposed a parabolic equation with an origin corresponding to the point of wave diffraction (also see Silvester and Hsu, 1997). For this equation, radial vectors r are constructed from the origin to the beach planform at an angle θ to the wave crest line. A control line is defined as the radial vector R_0 that is the transversal between the parallel wave crest line and the linear downdrift section of the beach planform. The form of the polynomial in polar coordinates is:

$$\frac{r}{R_0} = C_0 + C_1\left(\frac{\beta}{\theta}\right) + C_2\left(\frac{\beta}{\theta}\right)^2 \tag{2}$$

where R_0 is the length of the control line and β is the angle between the wave crest line and coefficients C_0, C_1 and C_2 are a function of the angle β.

Because of the difficulty in fitting the polynomial in Eq. (2) to a measured planform, Moreno and Kraus (1999) introduced a hyperbolic tangent of the form (in Cartesian coordinates):

$$y = a\tanh^m(bx) \tag{3}$$

where y and x are the cross-shore and alongshore distances respectively (with the x axis parallel to the linear downdrift section) and a, b and m are coefficients determined empirically.

Moreno and Kraus (1999) argue that the log-spiral, parabolic and hyperbolic tangent methods each have their advantages, with the choice of function dependent on the type of embayment and its application. However, only the log-spiral has the unique relationship between the tangent vector and the radial vector, which will be useful in developing a transformation method. Because of its ease in fitting and this special property, the log-spiral was chosen to approximate the beach planform of distinctly curved beaches.

3. Transformation technique

The technique outlined below aims to transform between survey points in Cartesian coordinates (x,y) and alongshore (hereafter assigned the variable s)–cross-shore (hereafter