Interpolating Beach Profile Data Using Linear and Non-linear Functions

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Interpolating Beach Profile Data Using Linear and Non-linear Functions

by

Lance C. Croft

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Geology
College of Arts and Sciences
University of South Florida

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ABSTRACT

Beach and nearshore surveys are conducted in a variety of ways, the most commonly used being the level-and-transit method; because it is inexpensive, time conducive and highly accurate. Specifically, beach surveys are conducted to better understand cross-shore, long-shore sediment transport processes, as well as to quantify volume changes, which are used to evaluate beach performance. In this study, a section of the beach on Sand Key, FL was surveyed using rod-and-transit. In addition to the commonly used linear data analysis, a non-linear analysis was conducted using NURBS (Non-Uniform Rational B-Splines).

Survey data was collected within a short time window to ensure minimal environmental changes associated with waves and anthropological factors. Beach profiles were surveyed using two spatial resolutions, including 1) a typical variable resolution determined by the rodman based on observed morphology changes, and 2) a uniform, high resolution of 25 centimeters per point. The results indicate that variable resolution survey with careful observation by the rodman provided adequate accuracy as compared to the very high-resolution survey.

The goal of this study is to create a realistic surface between the beach profiles that are spaced relatively far apart. The commonly used contouring method (a linear method) may create mismatch among major morphology units, e.g., bar crest, if they have different elevations alongshore. Here a non-linear method is developed by 1) identifying major morphological units, in this case dune top, berm crest, trough bottom, and bar crest 2) linking the units using a cubic spline, and 3) generating a surface using a NURBS sweep2 function. Bisector profiles are sliced
from the surface generated using linear and non-linear methods, and compared with surveyed profiles at the same location. The profiles generated using the non-linear method matched more closely to the measured profile than that from the linear method. The non-linear NURBS surface resulted in a consistently greater beach volume between the surveyed profiles than the linear method of volume calculation.
CHAPTER 1: INTRODUCTION

Beaches are important to the economic strength and physical protection of our coastal communities (Houston, 2013a, 2013b). The beach can act as a key attraction to an area, causing popular vacation spots to rely heavily on their stability. Pinellas County, FL beaches are widely known for their economic impact to the Tampa Bay area.

Among many others, Pinellas County beaches are maintained artificially by the use of beach nourishment projects. These nourishments provide beachgoers with a recreational area and business and homeowners with security against storm surges. The practice of beach nourishment in this area began in the 1960s and has been nourished since then, with a four to six year frequency.

Due to the high cost of beach nourishments, it is required that beach nourishment be monitored. Beach nourishment monitoring is typically achieved through beach profile surveys. Beach profile surveys are conducted in a variety of ways. Some methods might include more sophisticated instruments, more man-power and even the use of aircraft. The beach adapted rod-and-transit method is common because it is inexpensive, time conducive and highly accurate (Birkemeier, 1981). A Class 1 version of the rod-and-transit survey (Birkemeier, 1981) like the one practiced in this experiment, is used for coastal management and beach nourishment monitoring and requires proper planning, time, man-power, good weather and surf conditions and accurate instruments.
1.1 BEACH SURVEYING HISTORY AND IMPORTANCE

Beach surveying has been in constant need since people began utilizing its land. Beach surveys are conducted to better understand cross-shore, long-shore sediment transport processes as well as volume changes, which are used for nourishments and beach stability (Parson, 1997). Surveying the beach’s main goal has been to monitor and predict morphological changes that happen within a dynamic environment like the ocean. More specific uses include numerical simulations as described in this paper; to verify nourishment sediment volumes and to monitor beach performance (Parson, 1997). Many types of surveying methods exist to get topographic and bathymetric data, albeit, some providing denser data coverage than others.

In order to quantify beach changes, time-series surveys are necessary. Beach surveying frequency relies mostly on the need for data. Frequency of surveying can be determined from the erosional rates of the area, storm activity, tidal changes, construction, or to monitor seasonal and long-term effects (USACE, 1996). In the following section, common beach surveying practices are reviewed.

1.2 BEACH SURVEYING METHODS

The level-and-transit technique is noted as the oldest, simplest, cheapest and fastest method of beach surveying (Birkemeier, 1981). Level-and-transit involves the use of an established monument, a surveying level to determine elevation, and a triangular method of measuring distance. Performance characteristics for the level-and-transit survey technique for beach environment show a vertical accuracy of ±10cm, a horizontal accuracy of 3 meters and a relatively low cost of around $1,000/km with standard 300 meter profile spacing (Parson, 1997). Today’s adaptation of the level-and-transit survey method is much more accurate and typically
uses an electronic total survey station and a surveying rod with a reflective prism enhancing angle measuring accuracy to well under one-hundredth of a degree, measuring ranges upward to several thousand meters and distance measuring accuracies as little as $\pm(2\text{mm} + 2\text{ppm} \times D)$ mean square error (Topcon, 2010), while maintaining a relatively low cost.

Rod-and-transit surveying of a beach is typically executed in a straight line, from the dunes into the water, which allows for the calculation of a cross-sectional volume change. Several cones or wooden stakes act as temporary benchmarks and are driven into the sand to establish a reference line for the rod-man to use. The reference line is created using a pre-created azimuth that is determined as “shore-normal”. The rod-man walks along the path toward the water, taking elevation points at morphological changes while holding the rod straight up. The rod-man continues into the water, taking points until the desired depth. A certain amount of operational uncertainties can be incurred from the above described field operation.

Several problems hinder the rod-and-transit survey: 1) favorable surveying conditions, 2) errors that are additive and can be particularly large on wide beaches, 3) the assumption that data between points is considered to be linearly progressive (Figure 1), 4) obstruction of view by objects, and 5) distance between profiles improperly estimating the progression of morphology in the longshore direction (Birkemeier, 1981). There is a significant importance of the selection of data points along the beach profile, emphasized by the concern for a higher concentration of data points along high angle changes of the beach (Figure 1), as well as the importance of holding the rod straight to prevent inaccurate elevation and distance calculations (Birkemeier, 1981).
Figure 1. Example of the rod-and-transit procedure. The red line is a linear interpolation, connecting the cross-shore profile data points. The black line is the hypothetical beach profile. The survey accuracy can be influenced by point selection, potentially creating a beach cross-section that is not accurately represented. This problem can only be avoided by surveying more data points and adequately capture pivot points in the field operation.

Real-time Kinematic Global Positioning System (RTK-GPS) utilizes satellite positioning to accurately measure the position and elevation of the beach surface. RTK-GPS can be especially useful and efficient when mounted to vehicles. Data point clouds derived from this method of surveying tend to be dense, making RTK-GPS one of the upcoming methods for surveying today. Limiting factors for RTK-GPS can be cost, weak satellite signal strength creating inaccuracy and salt-water damage. Currently, its accuracy is not as high as carefully executed level-and-transit surveys.

Bathymetric surveying is a method that uses sonar device(s) mounted to a watercraft. These sonar devices ping signals that reflect from the ocean bottom and return as a depth reading relative to the device. Bathymetric surveying is very popular for projects such as port dredging or surveying shoals. Some problems that arise from bathymetric surveying on a beach are water depth, filtering noise in the data from waves, utilizing a vessel, cost of the unit and the time it takes to obtain data from the offshore area of a beach system. Bathymetric surveying is often
paired with a land based survey system in a coastal setting, when there is a need for both land and offshore information.

Airborne lidar, conceptualized in the 1960s for meteorological application (Goyer and Watson, 1963), is an evolving application for the coastal setting. Airborne lidar (LIght Detection And Ranging) uses a laser system typically mounted to a fixed wing aircraft or helicopter, and flown over the study site. Lidar, more specifically for example, the Airborne Topographic Mapper, developed by NASA, utilizes a blue-green laser that reflects toward the beach from an elliptically rotating mirror. As the aircraft flies along, a GPS combined with on-board computers track the aircraft’s position and marry that to the data absorbed from the reflection off the beach and water surface (Krabill et al, 1995). Lidar allows for rapid collection of GPS-based, estimated shoreline position over hundreds of kilometers with an accuracy of ±1.4 m (mean confidence interval of 95%) (Stockdonf et al, 2002), making it ideal to use for pre and post storm analysis (Krabill et al, 2000). Lidar has proven to yield accurate results in a very timely manner. Data output comes as a high-density point cloud or digital-elevation map (DEM), both of which are common to today’s GIS programs. However, airborne lidar has its limitations. Poor water clarity, especially in the dynamic surf zone, can cause attenuation and penetration problems associated with backscattering and give incorrect depth data (Wang and Philpot, 2007). Obtaining a helicopter or fixed wing aircraft to fly and the operating cost of a helicopter or aircraft, along with the lidar unit can be substantial.

The Coastal Research Amphibious Buggy (CRAB) is a three-wheeled vehicle developed and built by the Wilmington District of the US Army Corps of Engineers (USACE) to survey the beach and nearshore system. It practically follows the level-and-transit procedure except the survey rod is mounted on an amphibious vehicle. CRAB can be driven from the dry beach,
through waves up to six feet in height and into water that is a depth of 26 feet, allowing for rapid and accurate surveying. The CRAB is useful, but unpractical for a budgeted coastal research group. Other pertinent issues involve the inaccuracy due to sediment subsidence created from driving an 18,000lb vehicle over soft sediment and it’s lethargic speed of 2 mph.

Another method of surveying, utilizes tower-mounted video. Video cameras atop a tower record nearshore wave conditions over time and the video is analyzed for the breaking wave index, relating the wave height to water depth. This method can be monitored remotely. This form of surveying is especially useful for monitoring sandbar migration over time, but lacks the accuracy for quantifying berm and dry beach changes.

1.3 SOFTWARE THAT PROCESSES BEACH PROFILE DATA

There are many programs that process and illustrate beaches and nearshore morphology. Some software packages require a large data set to produce three-dimensional representations, while others might require very simple survey data and produce a two-dimensional representation, i.e., a beach profile. Typically, rod-and-transit data is analyzed using a program that analyzes it in two-dimensions. Two-dimensional representation of the beach in a computer has been especially useful for accurate analysis of morphological changes in the cross-shore direction. For processing three-dimensional data, many types of software have the ability to produce meshes, albeit using different statistical or geometrical means. Several surfacing programs have adopted kriging, a statistical approach that triangulates data to create a mesh. Kriging is useful but requires more evenly spaced survey data than a method such as the beach adapted rod-and-transit method can provide. The rod-and-transit method for beach profiling
typically produces dataset that has dense coverage in the cross-shore direction but sparse
coverage in the longshore direction. This can induce large uncertainty from the kriging method.

1.4 NON-UNIFORM RATIONAL B-SPLINES (NURBS)

Non-uniform Rational B-splines (NURBS) are a mathematical method to accurately
create a 3-dimensional object from its representative 2-dimensional curves in a freeform, organic
approach (Piegl, 1991). NURBS can represent standard geometry, but has capabilities to also
adapt to complicated free-form objects, such as the human body (Woo Jo and Soo Han, 2005).
Since NURBS are descendants of Bézier curves, the amount of data needed to create a NURBS
curve or surface can be smaller than that of a traditional shape (Piegl, 1991). Also, NURBS
surfaces give respect to the applied curvature of the function.

NURBS were created by the increasing demand for an accurate representation of free-
form surfaces to be used in the automotive industry for car body panels, aerospace industry for
fuselages and wings or for hulls of a ship. In the beginning days of NURBS use, car
manufacturers were the only users, having NURBS integrated into their Computer Aided Design
(CAD) programs.

NURBS curves and surface functions are similar in behavior and both use a combination
of elements to control their shape. The, knots, control points, and an evaluation rule that
parameterizes the curve or surface, are what make NURBS so different from other geometrical
representations. The core of a NURBS curve contains the B-spline basis function in combination
with its rational basis function (Piegl and Tiller, 1995). A NURBS surface is created as a tensor
product of two NURBS curves, linking U and V, as independent parameters that represent the
horizontal and vertical directions, respectively (Piegl and Tiller, 1995). This product is unified with its specific rational basis function to create the NURBS surface.

The degree of a curve or surface is considered to be a whole number greater than zero. Although the degree can be any number, NURBS curves typically utilize degree 1, 2, 3, or 5. A degree-1 NURBS curve is representative of a straight line or commonly referred to as linear. A degree-2 curve in NURBS is represented as a circle, and degrees-3 and higher are considered free-form, also known as an interpolated curve, or surface (Figure 2).

![Figure 2](image_url)

**Figure 2.** An example of the varying degrees of a point-controlled NURBS curve. Control points are circled, and the control polygon is represented as a red-dashed line.

A series of control points define a NURBS curve or surface. A control point is given a weight and mostly assigned to be consistent throughout the object. Almost all weights of control points are greater than zero. The greater the weight of a control point, the more control that point will have on the curvature within its domain (Piegl, 1991). With NURBS curves specifically, consistent numbers are known as non-rational, and with variability between them, they are considered to be rational curves. The number of control points required to create a curve in any situation is equal to the curve’s degree + 1. Isoparametric curves are lines that run along the
NURBS surface in the U and V-directions and their positioning is managed by the surface’s control points, which can be manipulated by the user (Figure 3).

**Figure 3.** Example of a constructed NURBS sweep2 surface using two rails and three cross-sectional curves. This image is viewed in a perspective view. Notice the U-direction in conjunction with the rail direction of a sweep and the V-direction in conjunction with the cross-section curve direction. Isoparametric curves are the lines that run along the sweep in the U and V-directions and are controlled by the surface’s control points.

Knots are where piecewise polynomial sections connect together. NURBS curves and surfaces possess a high degree of smoothness at knots. For 1\textsuperscript{st} degree NURBS curves, also known as a polyline, there are the same amount of knots as there are control points. In every other situation, the knot number list (knot vector) is equal to the (degree+N)-1, where N is the amount of control points. The knot vector must contain numbers that either remain the same, or increase as the list of existing knots continues, while containing no duplicate values that exceed the degree of the curve. The number of duplicates in a knot vector list is known as the knot’s multiplicity. Knot values are at “full-multiplicity” when the knot value is duplicated equal to the degree of the curve anywhere within the knot list. “Simple knots” are knots that only appear once
on the list. “Uniform” is a term to describe the knot vector that starts with a full multiplicity knot, follows by simple knots and ends with a full multiplicity knot, all while containing equally spaced values. Uniform curves and surfaces exhibit the smoothest structure through their control points. When a curve or surface is considered non-uniform, it means that the object’s knot vector contains duplicates within the list, allowing the curve or surface to have kinks.

Finally, the evaluation rule is a NURBS formula that is based upon the B-spline formula. The evaluation rule uses a given parameter and produces a point. The parameter value is congruent to the data points provided and their distribution. Shown below, in Figure 4, are a group of cubic b-splines that were modeled using the same control points, but different knot parameterizations. This figure shows the effect that knot parameterization has on the overall shape and distance that the cubic b-spline will deviate from it’s control polygon that was formed by the control points (Floater, 2010). B-splines have numerous parameterizations; most notably, chordal, uniform and centripetal parameterizations. All of these B-spline curves behave differently and have their advantages and disadvantages in different applications (Piegl and Tiller, 1995; Haron et al, 2012; Ma and Kruth, 1995).

Today, NURBS are commonly added to CAD programs. Uses of NURBS have increased since their discovery, into a variety of fields of application. Perhaps the largest field of use is in animation or video game graphics.
Figure 4. Cubic b-spline interpolated curves with different knot parameterizations, all using the same control points. Representations are as follows: centripetal parameterization (red), chordal parameterization (green), uniform parameterization (purple) and the control polygon is represented as a black dashed line.

This paper developed a method utilizing a NURBS surface known as a sweep2 that uses two trajectory controlled rails that connect morphology from one cross-shore profile to another, to create a single, three-dimensional model that is computed quickly and retains its accuracy (Figure 3). A simple NURBS sweep is a surface built by taking one cross-section curve and projecting it along the length of another curve. A sweep2 is a more complex version of a sweep, using multiple curves that can act as rails and can project multiple cross-section curves along them. The sweep used in this model uses a planar-trajectory controlled interpolation that exhibits no scaling (Piegl and Tiller, 1995). The trajectory of any sweep’s cross-section curves along its rail(s), can be manipulated by the user.
Same morphological unit, e.g., the sandbar crest, may not have the same elevation alongshore, therefore, creating problems for mapping the specific unit, in this case the bar crest, using elevation contour lines. The method in this paper uses the extrema associated with the selected morphology, linking the self-similar morphologies among the cross-sections using a cubic spline. Cubic curves create a shape that is smooth and potentially more realistic because the natural coastline curves nonlinearly. The section of beach used for this study contained seven beach profiles, four of which were used to create a cubic spline, and the three profiles in between were used to verify the NURBS model. The spline parameterization used to connect the self-similar morphologies in this method was the centripetal parameterization. This parameterization was selected because of its rigidity and closeness to the polygon formed from the control points (Floater, 2010). These cubic splines add the control to the NURBS function, allowing the beach surface to be constructed with respect to the beach’s natural curvature. Morphological units used for the self-similarity test in this method were the top of the seaward most dune, the berm crest, the trough, and the bar crest (Figure 5). These morphologic units were selected because they are the key features defining a beach profile in the study area, and therefore capturing their longshore extension is crucial to realistically representing beach morphology in the longshore direction.

To precisely capture the curvature, as well as the area, of a non-linear object requires adequate amount of survey points and the interval between them (Figure 6). A convexly or concavely curved beach should require more surveyed profiles to capture natural curvature and
subsequently obtain accurate volume (and volume change). The procedure developed in this study exhibits an organic shape that considers the shoreline position, curvature and adjusts the morphology accordingly, therefore, generating a more accurate extrapolation between cross-shore data sets than linear methods.

This model was designed to be directly applicable to beach profile data collected using the rod-and-transit technique. The application of a surfacing function like this one to represent a beach surface has not been explored. No beach mapping software currently uses NURBS surfacing functions. The NURBS sweep function, because of its mathematical complexity requires fewer surveyed points in the U-direction (longshore direction), to create an accurately modeled beach when controlled using self-similar morphological contours.
1.5 OBJECTIVES OF THIS STUDY

In the coastal research community, there is a need for a cost-effective improvement of the 3-D representation of the beach environment in the longshore direction with the limited data set that the rod-and-transit survey provides. This paper addresses this issue specifically by introducing a modified NURBS surface to a rod-and-transit data set. The goal is to retain the beach shape without sacrificing morphological freeform progression in the longshore direction. The objectives of this project are: 1) to create a more realistic and accurate three-dimensional model that can calculate beach volume in the longshore direction, 2) to capture the beach’s curvature using morphology rather than elevation (i.e., contouring), and subsequently allow more accurate extraction of beach profiles in between two survey lines. This method will produce a more organic shape of the area between surveyed cross-shore profiles, by controlling the NURBS surface using matched, comparable (e.g., bar crest, trough, and berm crest) morphological features between survey lines.

Figure 6. Analogy using a circle, which contains an infinite number of straight sections defined as rational by NURBS definitions and polygons of varying edge number and length. This figure illustrates the principle behind curvature of a shoreline and the reduced error associated with increasing the number of cross-shore profiles. Circle diameter is 10m.
CHAPTER 2: STUDY AREA

This study was conducted in west-central Florida along the Pinellas County coast. Pinellas County beaches stretch along 26 miles of barrier island coastline. Ranging monuments (R-monuments) established by the State of Florida were established every ~300 meters along the coastline, mostly on the seawall. Sand Key, FL, where field work for this study was conducted, as well as the rest of Pinellas County beaches are monitored by the Coastal Research Laboratory at the University of South Florida. The surveying of Pinellas County’s beaches utilized the R-monuments and the transect lines extended from them, extending into the water in a shore-normal direction. Typical survey lines along this coast extend to the short-term depth of closure, or roughly -3 meters, NAVD88 (North American Vertical Datum) (Wang and Davis, 1998).

Pinellas County beaches are surveyed by USF Coastal Research Lab using a Class-1 approach, (Birkemeier, 1981) on a monthly to bi-monthly frequency. Bi-monthly surveying is used to monitor beach performance associated with several nourishment projects (Davis et al, 2000), erosional hot spot (Elko and Wang, 2007), and biological effects of nourishment areas on sea turtle habitats (Davis et al, 1999). Specifically, beach erosion and accretion, seasonal bar migration, and sediment volumes are of interest to Pinellas County coastal management.

Sand Key is part of a barrier island system that extends from Clearwater Beach to Madeira Beach in Pinellas County (Figure 7). Sand Key is flanked by two tidal inlets, Clearwater Pass to the north and John’s Pass to the south. Sand Key is a beach on a passive margin, with a barred coastline consisting of low-wave energy and a small tidal fluctuation. A section of beach,
Indian Shores, in the middle of Sand Key was chosen for this study because of its wealth of data from previous and existing studies conducted by the Coastal Research Lab.

The beaches along Sand Key were nourished in 2012, two years before the present study. Based on the on-going monitoring study by the USF Coastal Research Lab described above, Indian Shore’s beach, spanning from R85-R98 monument, has gone through the initial profile equilibration after the nourishment construction. Therefore, the present beach profile shape represents a typical case. This study took place from R-monuments R93 to R96 (Figure 8). This specific area was selected because of the lack of influence from the ebb-tidal deltas as well as anthropogenic structures, and therefore representative of a relatively uniform stretch of beach. Since Indian Shores is located south of the headland, but north of the shoreline curvature at Redington Shores, the area contained a series of R-monuments and associated beach profiles, all with the same azimuth.

The major reason for choosing a section of beach that had the same orientation was to eliminate potential complications of elevation contouring, as well as the NURBS sweep method developed by this study, caused by a background curvature of the shoreline. This allowed for any differences, e.g., calculated beach volume between the profiles and the interpolated profile in between the surveyed profile, to be solely due to the identification of the morphological feature positions, as opposed to the elevation contour approach. In addition, the straight shoreline provides a simplest case study, which should be done before more complicated shoreline conditions are explored.
Figure 7. Study site highlighted within the successive black boxes. Larger image is an aerial image of Florida; smaller image is of the Tampa Bay Area.
Figure 8. Aerial view of the section of Indian Shores used in this study. Labeled using yellow markers, are the R-monuments (R93, R94, R95 and R96).
CHAPTER 3: METHODOLOGY

This study included field data collection and laboratory data analysis. Traditional rod-and-transit method was used in the field to collect beach profiles. Rhinoceros 5.0, a NURBS based CAD (computer-aided design) program was used to connect the morphologic units and model the surveyed beach profiles, create illustrations, and calculate volumes.

3.1 SURVEYING METHOD

Field Surveying was accomplished using the rod-and-transit technique. The electronic total survey station, a Topcon GTS 240NW, and two 2.5m surveying rods with a reflecting prism and Seco, 40-minute bubble level were used to conduct the beach profile survey. The Topcon GTS 240NW electronic total station has a range of up to 1,000 m and distance measuring accuracy of \( \pm(2 \text{mm} + 2 \text{ppm} \times \text{Distance}) \) mean square error (Topcon, 2010). R-monuments R93 through R96 were surveyed along shore-perpendicular azimuths of 290 degrees. Total station locations were measured using a Trimble RTK-GPS. Surveying was conducted using the horizontal coordinate system NAD83 State Plane (Florida West 0902) in meters. The elevation is referenced to NAVD88. Zero NAVD88 in this area is roughly 8 cm above mean sea level based on nearby NOAA tide station at Clearwater Beach.

The total station was set up four times at four locations (R93, R94, R95, R96). At R93 setup, only R93 beach profile was surveyed. At R94 setup, three beach profiles were surveyed, including R93A, R94, and R94A. Profiles with an “A” designation present a profile in between
the standard R monuments spaced at 300 meters. At R95 setup, two profiles, R95 and R95A, were surveyed. At R96 setup, only profile R96 was surveyed.

In order to ensure the accuracy of the beach profile survey, two data collection schemes were used throughout the survey of the study site. The first scheme provided an extreme data coverage with a very small point interval of 25 cm. The second scheme adopted a typical method (Birkemeier, 1981). The point coverage was determined by the rodman based on the observed morphology change along the beach profile. The distance between the points varied depending on the trend of elevation change. All seven profiles were surveyed using scheme-one, while four profiles (R93, R94, R95, R96) were surveyed using scheme-two. Therefore, the four profiles were surveyed twice using both schemes. Scheme-two was apparently much more efficient than scheme one. Comparing the profiles collected using both schemes allowed for the estimate of accuracy by the efficient, scheme-two survey, which is used widely.

Beach profile survey began within the dune system for all surveyed profiles. Lines continued seaward toward the shore and ended at shoulder height of the swimmer (-1.83 m NAVD88). This wading survey allowed the rodman to collect data in the water while being able to judge the bottom elevation changes. All surveys were completed in one day to minimize potential beach changes due to anthropogenic effects (e.g., beach raking) and tidal and wave forcing.

In order for the NURBS sweep2’s planar-trajectory controlled interpolation to function effectively, more than three control points are needed in the U-direction (the longshore direction). This is why the survey included four survey lines, R93, R94, R95 and R96. The bisector “A” lines in between the R monuments were used to verify the ability of the models, discussed in the following, abilities to generate data in between the point coverage.
CHAPTER 4: MODEL BUILDING

Building a model that properly represented a dynamic environment, such as a beach, using NURBS functions, required relatively high computing power. Since a NURBS surface combined with extensive control, utilizing cubic splines, created sophisticated control polygons, a hyperthreaded, quad-core, LGA 2011, Intel i7 processor was used along with 16GB of low-latency RAM, a RAID-0 SSD setup and an nVidia GTX 760 graphics processing unit.

Preserving the shape of the beach between cross-shore surveys using NURBS was a task that required a controllable function that stemmed from morphological control. Since the NURBS sweep2 function allowed for two rails to be used to project cross-section curves along, this function was used, rather than another NURBS function.

4.1 NURBS MODELING SOFTWARE

Rhinoceros 5.0 was used to execute the NURBS functions. Rhinoceros 5.0 is a commercial, 3-D, NURBS modeling software developed by Robert McNeel & Associates for the Windows platform (www.rhino3d.com). Rhino is widely used in engineering fields for reverse engineering and prototyping. Rhino is also used in multimedia fields, such as animation and graphic design. Rhino is created as a host of a suite that is offered by McNeel & Associates, running specialized programs as plug-ins. Scripting within Rhino comes from its own native programming language, rooting as a hybrid from the Visual Basic scripting language.
Rhino suited this project well because of its NURBS capabilities, manageable price and because it allowed the user to design and manipulate using four real-time viewports. Rhino is popular to many designers because of its flexibility and wealth of functions as well as its capability of being able to import and export to over 30 file formats. Rhino also communicates well with .xyz file formats, ArcGIS’s use of the .3ds file format and the expandable possibility of integrating higher-degree splines.

4.2 MODEL BUILDING PROCEDURE

Survey data was imported from the Topcon GTS 240NW total station and organized into notepad and each line was separated into its own .xyz file. Rhino 5.0 was opened and the properties were set to meters, grid and axes turned off. Modeled tolerances were set to 0.01m to ensure that any NURBS curves or surfaces created using surveyed data, would be within one-hundredth of a meter both vertically and horizontally of the actual surveyed points. The .xyz files were imported using a scripted batch import command, separating each file into its individual layer and using the root file name as layer name. Rhino was zoomed to view data in all four viewports. Since the surveyed lines were not perfectly walked, points were projected to a plane of original azimuth for each line used to create the sweep. Monuments were deleted and cross-shore profiles were linearly interpolated.

Coarse surveyed lines of R93, R94, R95 and R96 were graphed in comparison to their densely spaced counterpart. This comparison was to examine how well the coarse survey captured the beach morphology as compared to the densely spaced survey, shape-wise and volumetrically. Areas were calculated for each cross-section curve and the distance between
monuments was applied to the volume calculating procedure (Figure 9). Volumes were calculated at depths of 0m (NAVD88), -1.5m (NAVD88) and -1.83m (NAVD88).

![Volume Calculation Diagram]

**Figure 9.** Basic illustration showing the volume calculation used in the currently accepted method using a trapezoidal prism. In a beach system, A1 represents a cross-sectional area of one cross-shore profile and A2 represents the cross-sectional area of the adjacent cross-shore profile. The areas are calculated to a specific depth (NAVD88), averaged together and multiplied by the distance (d). Problems that accompany a calculation like this are due to the distance (d) value being affected by the difference in azimuth angles of the beach profiles represented here by the two trapezoids.

### 4.3 NURBS PROCEDURE

Self-similar extrema marked using control points at the crest of the longshore bar, lowest point within the longshore trough, beach berm crest, and the top of seaward most dune.

Morphologies were linked together using a centripetally parameterized cubic spline (Figure 10).

Sections were swept individually, using a sweep2 NURBS surfacing command, which utilized a maintained height adjustment. The maintained height adjustment kept the concavity of the rails from producing undesirable effects within the sweep. Sweep2 used the two rails to project cross-sectional curves them. No overlap was observed in these NURBS surfaces allowing
them to be joined to create an open surface. The sweep2 surface was closed into a polysurface and the volumes were calculated at three depths, 0m, -1.5m and -1.83m NAVD88.

The 150m bisector lines were added to the diagram, and vertical planes were created for each A-line to project to, for comparison reasons (Figures 11&12). Sections were sliced of the corresponding area of beach surfaces and compared to the surveyed data, focusing on the conservation of curvature between the R-monuments.
Figure 10. Aerial view of the study site, containing morphological contours and the NURBS sweep frame. The longshore sandbar system is marked using a purple curve, the longshore trough is marked as the green curve, the berm crest is represented with a yellow curve and the dune system is identified as a red line. Since R95 and R96 surveys began at the top of the dune, the red morphological contour linking the top of the dune is also considered as part of the NURBS frame.
Figure 11. Linear method represented using the trapezoidal prism type calculation. Sections were cut of this surface at R93A, R94A and R95A ensuring the same location as the surveyed bisectors.
**Figure 12.** Non-linear NURBS sweep2 surface controlled using self-similar morphologies. Sections were cut of this surface at R93A, R94A and R95A ensuring the same location as the surveyed bisectors.
CHAPTER 5: RESULTS & DISCUSSION

The coarse, rod-and-transit surveying method was similar to the method described by Berkemeier (1981) and is commonly used in beach profile surveying. It is not realistic to survey cross-shore profiles at a fine resolution of, e.g., 25 cm, because of time consumption. Figures 13, 14, 15, and 16 compare the profiles obtained with both coarse and fine survey resolution. The deviation of coarse surveyed lines in comparison to fine surveyed lines was small, confirming that coarse survey coverage accurately captured the detailed beach profile. No specific trend can be identified for the point of maximum deviation. This suggests that the error was indeed caused by the operator (i.e. rodman) occasionally, for whatever reason, missing locations of morphology change. Since the coarse data captured the beach profile very well and also since it is the commonly used method, the data used to represent the three-dimensional modeling here are from coarse coverage surveys (Figure 17).

Beach volumes calculated from the coarse and fine surveys provided a method to evaluate the overall accuracy of the modeling. The beach volumes above three contour levels: 0m, -1.5m and -1.83m (NAVD88) were calculated and compared. The 0 m contour represented the dry beach volume, the -1.5m depth represented landward of the nearshore bar, and -1.83m volume represented the entire beach profile. These contour levels were also used by Roberts and Wang (2012) in quantifying beach nourishment performance.
Figure 13. R93 coarse vs. fine deviation. Points of self-similarity marked with circles. Maximum curvature deviation: 0.13m, marked. Survey points are linearly interpolated and magnified using 10x vertical exaggeration.
Figure 14. R94 coarse vs. fine deviation. Points of self-similarity marked with circles. Maximum curvature deviation: 0.08m, marked. Survey points are linearly interpolated and magnified using 10x vertical exaggeration.
Figure 15. R95 coarse vs. fine deviation. Points of self-similarity marked with circles. Maximum curvature deviation: 0.10m, marked. Survey points are linearly interpolated and magnified using 10x vertical exaggeration.
Figure 16. R96 coarse vs. fine deviation. Points of self-similarity marked with circles. Maximum curvature deviation: 0.08m, marked. Survey points are linearly interpolated and magnified using 10x vertical exaggeration.
The beach-profile volumes are summarized in Tables 1 and 2. The nearly identical values further confirm the accuracy of the coarse survey (Table 1) in comparison to the fine survey (Table 2). This comparison verifies that at any calculated depth, volumetric differences between a coarse and a fine survey will be well under 2%. The NURBS sweep, discussed in the following, used profiles surveyed with coarse coverage. The above results suggest that this should not cause any significant uncertainty.

Table 1. Volume calculated at different depths using the coarse survey points. Since the NURBS sweep used the same linear interpolation method in the cross-shore direction, these volumes were similar to the numbers of the currently accepted method. The volumes shown are calculated as an area (m$^2$) and multiplied again by 1 m to display as a volume for use with the procedure shown in Figure 9, for the currently accepted method.

<table>
<thead>
<tr>
<th></th>
<th>Coarse Survey</th>
<th></th>
<th>Total Volume (-1.83m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 m</td>
<td>-1.5 m</td>
<td></td>
</tr>
<tr>
<td>R93</td>
<td>50.9887963</td>
<td>163.888661</td>
<td>198.495739</td>
</tr>
<tr>
<td>R94</td>
<td>62.5486765</td>
<td>186.38277</td>
<td>223.752522</td>
</tr>
<tr>
<td>R95</td>
<td>38.3395728</td>
<td>140.949277</td>
<td>182.669833</td>
</tr>
<tr>
<td>R96</td>
<td>44.0997847</td>
<td>143.227199</td>
<td>174.360837</td>
</tr>
</tbody>
</table>

Table 2. Volume calculated at different depths using the fine survey method. The volumes shown are calculated as an area (m$^2$) and multiplied again by 1 m to display as a volume for use with the procedure shown in Figure 9.

<table>
<thead>
<tr>
<th></th>
<th>Fine Survey</th>
<th></th>
<th>Total Volume (-1.83m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 m</td>
<td>-1.5 m</td>
<td></td>
</tr>
<tr>
<td>R93</td>
<td>50.859806</td>
<td>164.392556</td>
<td>198.919932</td>
</tr>
<tr>
<td>R94</td>
<td>62.934756</td>
<td>185.332114</td>
<td>222.465632</td>
</tr>
<tr>
<td>R95</td>
<td>39.0061796</td>
<td>142.13176</td>
<td>184.044322</td>
</tr>
<tr>
<td>R96</td>
<td>43.9255082</td>
<td>142.378382</td>
<td>173.50682</td>
</tr>
</tbody>
</table>
Figure 17. Linearly interpolated coarse surveys of R-monuments R93, R94, R95 and R96. Interpolations are magnified using 10x vertical exaggeration.
Because the main morphological feature, e.g., berm crest, trough bottom, and bar crest, can have different elevations along different beach profiles (Figure 17), a simple connection using elevation, i.e., contouring, can create a mismatch, as shown in Figure 18. Controlling the mapping of a beach using self-similar morphological units, identified manually, should allow for the conservation of morphology between surveyed lines (Figure 19). Therefore, the application of the control using self-similar morphology would allowed for the elevation and position of the key morphologic units to fluctuate without artificially connecting to a different morphology feature. In the following, the accuracies of the linear and non-linear models are examined through comparing the modeled and measured bisector profile.

Bisector beach profiles, in this case the “A” lines, were obtained using both linear and non-linear surface models. To analyze how well the models captured the bisector profile, the modeled profiles were compared with the measured “A” profiles. Furthermore, to ensure that all morphology was captured accurately between cross-shore profiles, the bisector lines were surveyed at a fine interval of 25cm. The results are illustrated in Figures 20, 21, and 22. The key morphology units, including crest of the longshore bar, bottom of the longshore trough, beach berm crest, and the top of the seaward most dune were marked in the profiles.

The deviations between the modeled and measured key morphologic units were smaller for the non-linear NURBS sweep2 surfacing functions than the linear functions, as apparent in Figures 20, 21, and 22. This suggests that the non-linear method, emphasizing the similarity of key morphologic units produced a more realistic bisector beach profile between data coverage, as compared to linear method.
Figure 18. Assumed linear surface with standard volumetric estimate. Mismatched morphology is deducted using Figure 15, showing that the study area is a dual-barred beach system.
Figure 19. Swept NURBS surface rebuilt using self-similarity. Isomorphological contours control curvature of this NURBS surface (yellow). A-line bisectors are represented in red.
In Figure 21, there was a significant difference between the height of the modeled dune using NURBS and the height of the actual dune that was surveyed. This error was caused by the fact that the dune was not present between the R-monuments. This points to a potential weakness of the NURBS method in that it becomes invalid if the particular morphologic unit is absent in between the data coverage.

Beach volumes of the predicted bisector profile and the measured profiles provided another method to evaluate the overall accuracy of the modeling. The beach volumes above three contour levels: 0m, -1.5m and -1.83m (NAVD88) of the linear method and the NURBS sweep2 polysurface method were calculated and compared with the measured beach volume. The 0 m contour represented the dry beach volume, the -1.5m depth represented landward of the nearshore bar, and -1.83m volume represented the entire beach profile. These contour levels were also used by Roberts and Wang (2012) in quantifying beach nourishment performance.

The sediment volume calculation of the NURBS sweep2 controlled by self-similar splines was conducted using Rhinoceros 5.0. Planes were inserted at 0m, -1.5m and -1.83m depth and the NURBS sweep2 surface was closed into a polysurface to calculate the volume of the solid figure (Figure 23).

The overall beach volume between adjacent R-monument profiles at three contour levels, 0 m, -1.5 m, and -1.83 m NAVD88, calculated based on linear method for both fine and coarse survey coverage, and based on non-linear NURBS surfaces are shown below in Tables 3, 4 and
Figure 20. Comparison of NURBS sweep and standard surface to the actual dataset surveyed of R93A. Actual data is represented as a fine linear interpolation and acts as ground truth. Addition of self-similarity control significantly authenticates morphological features. Circles on the blue line, represent the intersection of the self-similar morphological contours on the NURBS sweep2, three-dimensional surface.
Figure 21. Comparison of NURBS sweep and currently accepted surface to the actual dataset surveyed of R94A. Actual data is represented as a fine linear interpolation and acts as ground truth. Addition of self-similarity control significantly authenticates morphological features. Circles on the blue line, represent the intersection of the self-similar morphological contours on the NURBS sweep2, three-dimensional surface.
Figure 22. Comparison of NURBS sweep and standard surface to the actual dataset surveyed of R95A. Actual data is represented as a fine linear interpolation and acts as ground truth. Addition of self-similarity control significantly authenticates morphological features. Circles on the blue line, represent the intersection of the self-similar morphological contours on the NURBS sweep2, three-dimensional surface.
Figure 23. NURBS sweep2 polysurface controlled using self-similar morphological contours. This polysurface, or connected series of surfaces, was used for the volumetric calculation.

5. The fine and coarse volumetric data was calculated as the averaged area multiplied by the distance between the lines. As expected and discussed earlier, the fine and coarse survey yielded very similar overall beach volume. The non-linear method resulted in consistently greater beach volume.

Above 0m NAVD88 contour, as shown in Table 3, the total volumetric difference between the linear and non-linear was about 2,000 cubic meters. This means that within the dry beach, defined as the volume above 0m NAVD88, the beach surface used in the non-linear method conserved the concave seaward curvature of the berm crest and dune system throughout the study area. Table 4 shows a volumetric difference of close to 4,000 cubic meters for the study area. An increase in the difference, as compared to the dry beach volume, was expected due to the increase in volume-calculation area. Shown in Table 5, a nearly 5,000 cubic meter difference was obtained for the profile above -1.83 m, which was caused by an even larger volume-calculation area.
Table 3. Longshore volumes calculated at 0m NAVD88. Volume is calculated as cubic meters.

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Currently Accepted Method</th>
<th>This method</th>
</tr>
</thead>
<tbody>
<tr>
<td>R93-R94</td>
<td>16,587.83</td>
<td>16,550.35</td>
<td>17,740.75</td>
</tr>
<tr>
<td>R94-R95</td>
<td>17,569.01</td>
<td>17,387.58</td>
<td>18,043.38</td>
</tr>
<tr>
<td>R95-R96</td>
<td>13,298.51</td>
<td>13,219.56</td>
<td>13,555.77</td>
</tr>
<tr>
<td>Total Volume</td>
<td>47,455.35</td>
<td>47,159.49</td>
<td>49,339.90</td>
</tr>
</tbody>
</table>

Table 4. Longshore volumes calculated at -1.50m NAVD88. Volume is calculated as cubic meters.

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Currently Accepted Method</th>
<th>This method</th>
</tr>
</thead>
<tbody>
<tr>
<td>R93-R94</td>
<td>50,979.37</td>
<td>51,059.07</td>
<td>52,806.61</td>
</tr>
<tr>
<td>R94-R95</td>
<td>56,436.76</td>
<td>56,414.04</td>
<td>57,412.93</td>
</tr>
<tr>
<td>R95-R96</td>
<td>45,622.62</td>
<td>45,569.12</td>
<td>46,996.73</td>
</tr>
<tr>
<td>Total Volume</td>
<td>153,038.75</td>
<td>153,042.23</td>
<td>157,216.27</td>
</tr>
</tbody>
</table>

Table 5. Total longshore volumes calculated to -1.83m NAVD88. Volume is calculated as cubic meters.

<table>
<thead>
<tr>
<th></th>
<th>Fine</th>
<th>Currently Accepted Method</th>
<th>This method</th>
</tr>
</thead>
<tbody>
<tr>
<td>R93-R94</td>
<td>61,425.37</td>
<td>61,551.13</td>
<td>63,040.02</td>
</tr>
<tr>
<td>R94-R95</td>
<td>70,059.96</td>
<td>70,044.76</td>
<td>71,100.71</td>
</tr>
<tr>
<td>R95-R96</td>
<td>57,335.11</td>
<td>57,251.56</td>
<td>59,562.47</td>
</tr>
<tr>
<td>Total Volume</td>
<td>188,820.44</td>
<td>188,847.45</td>
<td>193,703.20</td>
</tr>
</tbody>
</table>

Table 6 illustrates the profile volume of the bisector transects. Overall, the non-linear method reproduced the measured profile volume considerably closer than the linear method, with
the differences mostly less than 5%. This further verifies that the conserved morphologic units by the NURBS method yielded more accurate prediction between data coverage.

Table 6. Total volume at surveyed bisectors. Calculated depth was -1.83m, NAVD88. Volume is calculated as cubic meters.

<table>
<thead>
<tr>
<th>Survey Line</th>
<th>Depth</th>
<th>Actual Measurement</th>
<th>This method</th>
<th>Currently Accepted Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>R93A</td>
<td>-1.83m NAVD88</td>
<td>213.49</td>
<td>206.96</td>
<td>197.94</td>
</tr>
<tr>
<td>R94A</td>
<td>-1.83m NAVD88</td>
<td>171.01</td>
<td>176.7</td>
<td>169.56</td>
</tr>
<tr>
<td>R95A</td>
<td>-1.83m NAVD88</td>
<td>132.52</td>
<td>139.59</td>
<td>140.68</td>
</tr>
</tbody>
</table>

Perhaps the most benefit from this type of study is the knowledge of locating morphology in the longshore direction. Being able to visualize sandbar location in areas that are not measured was a feat that had been complicated to measure. Accuracy between survey lines can aid with coastal management, nourishment monitoring programs, sediment volume estimates required for nourishment of specific areas. This could reduce the cost of dredging by properly estimating volumes required by specific beaches. This could allow for berms to be designed for specific beaches as well. Coastal over-washing from storm surges can be better predicted and assessed.

Since this method is flexible enough to work in a dynamic beach setting, regardless of shoreline shape and rapid cross-shore changes, there is no reason it could not be consistently used for Class 1 rod-and-transit surveying. Having reliable accuracy between survey lines can aid with coastal management, nourishment monitoring programs and sediment volume estimates required for nourishment of specific areas. The rising cost of nourishment grade sediment poses a concern to local and federal budgets, as well as taxpayers. This adaptation could reduce the
cost of dredging by properly estimating sediment volumes required by specific erosional hotspots. This could allow for better assessment of a sediment budget, designed with specifications for separate beach areas.

Control point manipulation is one of the most sought after features of NURBS. NURBS surfaces can allow for control point manipulation, allowing the surfaces to be “pulled” and flexed from their original shape, while still maintaining calculable shapes and volumes. This ability of freeform shape building could be applied to offshore berm site planning and shape designing. Offshore berm effectiveness could be enhanced if engineers utilized the ability of NURBS to design a berm to a specific beach’s dominant environment characteristics.

Beach shape is more organic than a simple model can show. Berms are not the same height everywhere, neither are sandbars or dunes. Dynamic environments like the beach do not create uniformity within their morphological features, but all of those features are still there. However, as indicated in this study, if morphologies connect along the beach and the profiles are made to be shore-perpendicular, then a function to build a three-dimensional surface can be used as long as the function blends cross-sections along those morphologies.
CHAPTER 6: CONCLUSIONS

Beach and nearshore surveys are conducted in a variety of ways, the most commonly used being the level-and-transit method, because it is inexpensive, time conducive and highly accurate. Specifically, beach surveys are conducted to better understand cross-shore, long-shore sediment transport processes, as well as to quantify volume changes, which are used to evaluate beach performance. In this study a section of the beach on Sand Key, FL was surveyed and analyzed using both a linear and a non-linear method.

Beach profiles were surveyed with two spatial resolutions, including 1) a typical variable resolution determined by the rodman based on observed morphology changes, and 2) a uniform high resolution of 25 centimeters per point. Two methods were used for data analysis. The commonly used contouring method (a linear method) may create mismatch among major morphology units, e.g., bar crest, if they have different elevation alongshore. Here a non-linear method was developed by 1) identifying major morphologic units, in this case dune top, berm crest, trough bottom, and bar crest 2) linking the units using a cubic spline, and 3) generating a surface using a NURBS sweep2 function. Bisector profiles are sliced from the surface generated using linear and non-linear methods, and compared with surveyed profiles at the same location. The conclusions of this study are:

- Variable spatial resolution survey with data points determined based on careful observation by the rodman captured the beach profile accurately as compared to the very high resolution survey with point spacing of 25 centimeters.
• The profiles generated using the non-linear NURBS sweep method matched more closely to the measured profile than that from the linear method, suggesting that the non-linear method is an improvement over the simpler linear method.

• Morphologic units comprised of the top of the seaward most dune, berm crest, bottom of the trough, and bar crest provide adequate representation for the application of NURBS surfacing.

• The non-linear NURBS surface resulted in a consistently greater beach volume between the surveyed profiles than the linear method of volume calculation.
REFERENCES


Topcon. “*GTS 240NW Series Total Station*.” pg. 2, Topcon Corporation, (2010)

