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# Survey design of smooth detour paths around obstructions

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## Summary

A towed-streamer survey design method for plotting smooth detour paths around obstructions that achieves prescribed specifications is proposed. The method comprises a collection of algorithms that can be used to generate detour paths around obstructions such that a specified path smoothness and spacing are achieved. The detour paths are characterized by smooth transitions to and from a straight navigation path that bypasses an obstruction area. The method can be used to shift points of an existing discretized navigation path, such as a survey preplot, away from the obstruction area. The method is applicable to any discretized navigation path, but it is especially well-suited for diverting towed-streamer sail paths. Numerical examples demonstrate that the method can accommodate a variety of scenarios such as rerouting sail paths around multiple obstruction areas, and around an obstruction area encapsulating more than one obstacle.

## Introduction

It can be a difficult task for seismic survey designers to realize a planned nominal geometry in the real world. Obstacles often prevent designers from achieving intended acquisitions, especially in well-established areas. Spatial continuity of the acquisition lines grid can be very important, and so an attempt should be made to acquire smooth lines with a minimal number of discontinuities (Vermeer, 2012). As Vermeer notes, the use of smooth lines is better suited for modern processing steps, such as regularization and prestack migration, than is using lines exhibiting spatial discontinuities.

A method is proposed for designing smooth detour paths around an obstruction area that achieves a prescribed path smoothness and spacing (away from the obstruction area). Path smoothness is controlled by a parameter $r$ called the taper ratio, and path spacing is controlled by a parameter $c$ called the clearance distance as depicted in Figure 1.

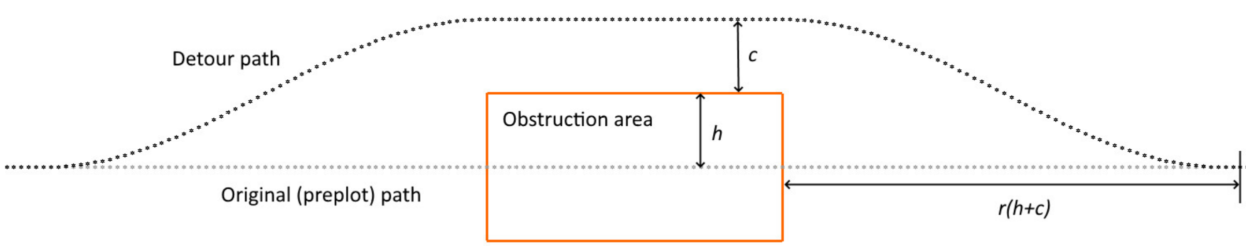


*Figure 1. A depiction of the proposed method with the taper ratio $r$ and clearance distance $c$ parameters.*

A summary of the algorithms that comprise this method is as follows: First, an approach to form an obstruction area by using an oriented bounding box (OBB) is offered. The OBB can be constructed to encompass one or more obstacles. Secondly, a point test for obstruction is presented that can be used to determine whether the point of a navigation path lies within the obstruction area. Thirdly, a method is offered for computing the shifted straight-line bypass section that travels parallel to the existing navigation path. Fourthly, an approach to calculate smooth transitions to and from the bypass section is presented.

### Obstruction area formation

The obstruction area is represented by an OBB that serves to encompass one or more obstacles, providing the direction of the straight bypass section, and to determine which side of the obstruction area the detour path should travel. Rather than working in world space with an OBB, it is both convenient and efficient to work with an equivalent axis-aligned bounding box (AABB) centered on the origin. The region encapsulated by an AABB is given by

$$\text{region } R \;=\; \{\, (x, y) \mid P_{min}.\,x <= x <= P_{max}.\,x, P_{min}.\,y <= y <= P_{max}.\,y \,\},$$

where $P_{min}$ and $P_{max}$ are two opposing corner points (Ericson, 2004). A C++ data representation of an AABB is given by

```
struct AABB { Point p_min; Point p_max; };
```

We can transform an OBB into an AABB by translating an estimate of its center point $P_c$ to the origin, and then rotating through the negative of its axis angle $\theta$. Likewise, any point in world space $P = (x, y)$, such as a navigation polyline point, can be transformed with a translation of $P_c$ units

$$P_t = P - P_c, \tag{1}$$

followed by a rotation through $-\theta$ thereby yielding the point

$$P_{AABB} = [P_t.\,x * \cos(-\theta) - P_t.\,y * \sin(-\theta), P_t.\,x * \sin(-\theta) - P_t.\,y * \cos(-\theta)], \tag{2}$$

in the equivalent (origin-based) AABB domain.

The OBB center point should lie directly on the navigation polyline and be positioned centrally to the obstacles. The height of the resulting AABB plays an influential role in deciding which side of the obstruction area the detour path should take. Here $P_c$ is selected to be the point on the navigation polyline that is closest to a central estimate $P_m$ of the set of obstacle points $\mathbf{P_o}$. The central estimate is taken to be the average of the minimum and maximum coordinates of $\mathbf{P_o}$, namely,

$$P_m = \left[\left(\min_x \mathbf{P_o} + \max_x \mathbf{P_o}\right)/2, \left(\min_y \mathbf{P_o} + \max_y \mathbf{P_o}\right)/2\right]. \tag{3}$$

In world coordinates, Algorithm 1 computes $P_c$ by iterating over each line segment of the navigation polyline to find the point on the polyline that corresponds to the minimum distance. The OBB axis angle $\theta$ determines the direction of the bypass section of the detour path and is also computed. Here, it is taken to be the angle of the tangential direction of the polyline at $P_c$, namely, the angle of the polyline segment containing $P_c$.

***Algorithm 1.* Estimating the OBB center point and axis angle**

*Input:* Obstacle points $\mathbf{P_o}$, navigation polyline points $\mathbf{P_n}$.

*Output:* OBB center point $P_c$, OBB axis angle $\theta$.

Set $d = 1.0e50$, and compute $P_m$ using equation 3.

For $i = 1,2, \ldots, n$, do: {

Set $A = \mathbf{P_n}(i-1)$ and $B = \mathbf{P_n}(i)$.

Compute the closest point $P$ on line segment $AB$ to $P_m$ using (Ericson, 2004).

Calculate $d_i = \|P - P_m\|$.

If $(d_i < d)$ then, {

Set $P_c = P$. Compute $N = B - A$. Compute $\theta = \arctan2(N.\,y, N.\,x)$.

If $(\theta < 0)$ then, $\theta = \theta + 2\pi$. } }.

Output $P_c$ and $\theta$, and stop.

With $P_c$ and $\theta$ specified, the AABB is formed by adding obstacle points that have been transformed according to equation 2 with $P_t = P_c$. A point $P$ can be added to an AABB with the representation described above by using four operations (Ericson, 2004)

$$P_{min}.\,x = \min(P.\,x, P_{min}.\,x)\,, \quad P_{min}.\,y = \min(P.\,y, P_{min}.\,y)$$
$$P_{max}.\,x = \max(P.\,x, P_{max}.\,x), \quad P_{max}.\,y = \max(P.\,y, P_{max}.\,y).$$

A survey designer must frequently account for added clearance around obstacles. For example, streamer spread widths can be substantial and additional clearance must be included. This can be accomplished by adding a scalar clearance distance $c$ to the bottom and top of the AABB, namely,

$$P_{min}.y = P_{min}.y - c, \quad P_{max}.y = P_{max}.y + c.$$

For a streamer example, $c$ can be set to half the streamer spread width plus some additional clearance.

## Point test for obstruction

A point test for obstruction is given in Algorithm 2, which transforms the test point into the AABB domain, and then tests whether it falls within the AABB.

***Algorithm 2.* Point test for obstruction**

*Input:* Axis-aligned bounding box *AABB*, center point $P_c$, angle $\theta$, test point $P$.

*Output:* Boolean $b$.

Compute $P_t$ using equation 1, and then compute $P_{AABB}$ using equation 2.

If $(P_{AABB}.x < AABB.P_{min}.x \,||\, P_{AABB}.x > AABB.P_{max}.x)$ then, Output $b = \text{false}$, and stop.

If $(P_{AABB}.y < AABB.P_{min}.y \,||\, P_{AABB}.y > AABB.P_{max}.y)$ then, Output $b = \text{false}$, and stop.

Output $b = \text{true}$, and stop.

## Bypass formation

The bypass section comprises a contiguous set of obstructed points $\mathbf{P_{obs}}$ that have been moved in world space. Sets $\mathbf{P_{obs}}$ are found by identifying candidate points that are obstructed using Algorithm 2, and then for each obstructed candidate point, searching along the navigation polyline in the forward and backwards directions for more obstructed points until a non-obstructed point is found. It has been found that users require the capability to customize individual detour paths. This is accomplished by starting the search with only user-selected candidate points.

In the absence of other information, here we propose that bypass sections take the shortest route around an obstruction area, and therefore the bypass should traverse the edge of the AABB that is closest to the navigation path ($x$ axis) and parallel to it. The shortest distance to the $x$ axis is given by

$$h_{up} = P_{max}.y, \qquad h_{down} = -P_{min}.y, \qquad h = \min\left(h_{up}, h_{down}\right). \tag{4}$$

For straight navigation lines, the bypass section can be formed by shifting all obstructed points according to $\mathbf{P_{bypass}} = \mathbf{P_{obs}} + \boldsymbol{m}$, where $\boldsymbol{m}$ is the move vector as calculated by Algorithm 3. For non-straight navigation lines, obstructed points can be moved along the perpendicular direction from the $x$ axis until it intersects with the AABB edge.

***Algorithm 3.* Calculation of the move vector in world space**

*Input:* Axis-aligned bounding box *AABB*.

*Output:* Move vector $\boldsymbol{m}$.

Set $\boldsymbol{b} = (0,1)$, and compute $h_{up}$, $h_{down}$, and $h_{min}$ using equation 4.

If $(h_{up} < h_{down})$ then set $\alpha = \pi/2$, else set $\alpha = -\pi/2$.

Rotate $\boldsymbol{b}$ through the angle $\theta + \alpha$.

Output $\boldsymbol{m} = h\boldsymbol{b}$, and stop.

## Smooth detour transitions

Smooth transitions to and from the bypass section can be accomplished by tapering nearby unobstructed points $\mathbf{P_{unobs}}$ with a weighted version of the move vector

$$\mathbf{P_{taper}}(i) = \mathbf{P_{unobs}}(i) + w_i\boldsymbol{m}$$

where the taper weight $w_i$ varies between 0 and 1. We employ a cosine taper computed in terms of its distance $l_i$ to the nearest obstructed point $P_{\text{obs}}$ given by

$$l_i = \text{dist}(\mathbf{P_{unobs}}(i), P_{\text{obs}}), \qquad w_i = [1 + \cos(\pi l_i/r)]/2$$

where $r$ is a parameter called the taper ratio, which serves to vary the distance $r(h + c)$ over which unobstructed points are tapered from each edge of the bypass section. For example, if we set $r = 5$, then the distance over which unobstructed points are tapered is $5(h + c)$.

## Numerical examples

#### Example 1: Three separate obstruction areas

In this example, we have three separate obstruction areas each containing one 500-m radius circular polygon, which represents the exclusion zone of an offshore rig. Preplot sail paths have inline and crossline spacing of 25 m and 525 m, respectively. Shot events comprise 4480 channels with a configuration of 14 streamers, 320 hydrophones per streamer, 12.5-m hydrophone spacing, 75-m streamer spacing, and 18.75-m crossline offset for flip-flopped shots.

Figure 1a shows detoured sail paths produced by the proposed method with the following parameters: taper ratio $r$ = 6, clearance distance $c$ = 500 m. The clearance distance was chosen to be a rounded-up version of half the streamer width, that is, $c$ = half the streamer width = (14-1) $*$ 75 m / 2 = 487.5 m ~= 500 m.

First, we observe that streamers of the shot event have indeed cleared the 500-m yellow circles. Because we rounded $c$ up to 500 m, there is an additional 12.5-m clearance outside of the circle. Second, the choice of $r$ = 6 yields relatively smooth sail paths and streamers. Third, we observe that some sail paths cross over others and that they can bunch up around the edge of an obstruction area. This is a consequence of using constant-valued $r$ and $c$ for all obstruction areas and sail lines, respectively.

#### Example 2: One obstruction area containing multiple obstacles

In this example, we have one obstruction area containing a cluster of three 500-m radius circular polygons. Sail and vessel configurations are the same as in Example 1.

Figure 1b shows detoured sail paths produced by the proposed method when using the following parameter combinations for different lines: Innermost two lines ($r$ = 5, $c$ = 500 m), the next two lines outwards ($r$ = 6, $c$ = 700 m), the outermost two lines ($r$ = 8, $c$ = 900 m). Evidently, values of $r$ and $c$ must be adjusted in an inversely proportional way to the path shift (required to clear the obstruction area) to achieve evenly spaced non-overlapping detour paths.

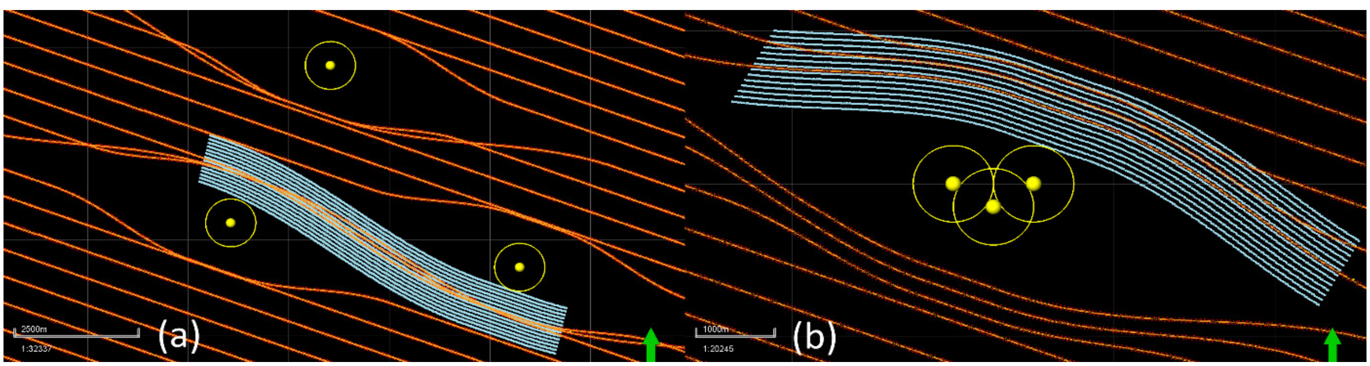


*Figure 2. Detoured sail paths produced by the proposed method. (a) Example 1: Three separate obstruction areas. (b) Example 2: One obstruction area containing multiple obstacles.*

## Conclusions

A method for the design of smooth detour paths around an obstruction area that achieves prescribed path smoothness and spacing was proposed. Path smoothness and spacing are proportional to the taper ratio and clearance distance parameters, respectively. Numerical examples demonstrate that the proposed two-parameter method is flexible enough to accommodate a variety of scenarios. It is recommended that the designer consider increasing the clearance distance when faced with adverse conditions, such as strong ocean currents or significant streamer feathering.

**References**

Ericson, C., 2005, Real-Time Collision Detection, Morgan Kaufmann Publishers, San Francisco CA, USA.

Vermeer, G.J.O., 2012, 3-D seismic survey design, 2nd ed.: SEG, doi: 10.1190/1.9781560801757.