Space Based Lidar Shot Pattern Targeting Strategies for Small Targets such as Streams

Gary D. Spiers

Jet Propulsion Laboratory, MS 168-214,

California Institute of Technology,

4800 Oak Grove Drive,

Pasadena, CA 91109, USA

Tel. +1 (818) 354-7831

Abstract

An analysis of the effectiveness of four different types of lidar shot distribution is conducted to determine which is best for concentrating shots in a given location. A simple preemptive targeting strategy is found to work as adequately as a more involved dynamic strategy for most target sizes considered.

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Introduction

There are a number of situations where it may be required to place as many lidar shots as possible on a target area that is small relative to the swath width of the lidar. Examples of such applications include maximising the number of lidar shots that penetrate through holes in cloud cover or maximising the number of shots on a river during a stream flow measurement.

Assumptions

We shall consider a lidar with fixed nadir and variable azimuth angles on a platform at some orbit height and latitude with a rectangular target area at some altitude that falls beneath the lidar swath (figure 1). The target has a cross-track length, d1 and an along track length, d2 offset from the center of the satellite track. Figure 1 is drawn from the perspective of the lidar i.e. the lidar shots occur on the circumference of the circle and the target area moves into and then out of the field of view. As we are interested in the differences between the shot sampling strategies we also assume that the target area always falls within the swath width on a given satellite pass. We can see that the corner of the target area to first intersect the circle does so at an azimuth angle, az1 and an along track distance, a1 from the lidar. The second corner similarly intersects the circle at an azimuth angle, az2 and an along track distance, a2 from the lidar. Four different scanning strategies will be compared.

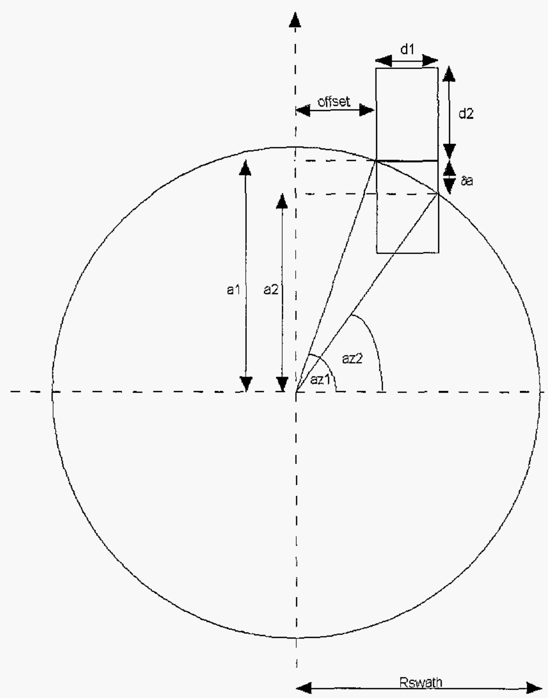

Figure 1) The scan geometry

Targeting modes considered

1) Fixed Pointing

This is the simplest case in which the lidar azimuth angle is fixed with respect to the spacecraft velocity vector. If the fixed azimuth intersects the target area then the shots placed in the target area will simply draw a line of length, d2 parallel to the along track direction. There is a finite probability that the target area will not intersect the lidar beam at all. Statistically the number of shots into a given target area on a single satellite pass will be:

$$n_{fixed} = \frac{prf\ d2\ \left| \arccos\left(\dfrac{offset}{(a+alt)\left(\arcsin\left(\dfrac{\sin(nadir)}{C1}\right) - nadir\right)} \right) - \arccos\left(\dfrac{offset - d1}{(a+alt)\left(\arcsin\left(\dfrac{\sin(nadir)}{C1}\right) - nadir\right)} \right) \right|}{\pi C1 V_s}$$

where

$$C1 = \frac{(orbh + a)}{\sqrt{\dfrac{1}{a^2} + \dfrac{\tan(lat)^2}{b^2}} \cdot \cos(lat)} + alt$$

and prf, orbh, a, b, V_s, lat, nadir, alt are the lidar pulse repetition frequency, the satellite orbit height with respect to WGS-84, the semi-major and semi-minor earth radii, the spacecraft velocity, the satellite latitude, instrument nadir angle and target altitude above WGS-84 respectively.

2) Conical Scanning

In this targeting mode the scanner continuously rotates at some constant angular rate. The upper bound on the number of shots that intersect the target area is then:

$$n_{conical} = \frac{1}{1800} prf \left(d2 + \left| \sqrt{(a+alt)^2 \left(\arcsin\left(\frac{\sin(nadir)}{C1}\right) - nadir \right)^2 - offset^2} - \sqrt{(a+alt)^2 \left(\arcsin\left(\frac{\sin(nadir)}{C1}\right) - nadir \right)^2 - (offset + d1)^2} \right| \right)^2 rpm \Big/ \left(V_s^2 \cdot C1^2\right)$$

where rpm is the scanner rotation rate in revolutions per minute.

3) Simple Targeting

In this targeting mode the scanner slews to a fixed azimuth that will intersect the target prior to arriving at the target. This is the same as the first case considered but with a probability of 100 % that the lidar beam will intersect the target and the number of shots placed in the target area is therefore:

$$n_{targeteda} = \frac{2\, prf\ d2}{V_s\, C1}$$

4) Dynamic Targeting

The scanner is pre-positioned in advance to an intersect azimuth as in (3) but this angle is chosen to be as close to az1 as possible within the limitations of the pointing knowledge and control system. When the trailing edge of the target area (Figure 1) intersects the scan area dynamic scanning takes place in which the azimuth angle is slewed up to the value az2. This increases the along track distance by an amount, da. After completing this scan the azimuth is fast slewed in preparation to view the target area as it transects the rear portion of the scan field of view and the same scan approach is then used as previously. This scan represents the maximum number of shots that can be placed into a given target area using a conical scan mechanism. The upper bound on the number of shots into the target area is then given by:

$$n_{targetedb} = 2\,prf\left(d2 + \left| \sqrt{(a+alt)^2\left(\arcsin\left(\frac{\sin(nadir)}{C1}\right) - nadir\right)^2 - offset^2} - \sqrt{(a+alt)^2\left(\arcsin\left(\frac{\sin(nadir)}{C1}\right) - nadir\right)^2 - (offset+d1)^2} \right| \right) \Big/ (V_s\,C1)$$

Results

We can now compare the number of shots into a given target area as a function of target area for each targeting mode. For this example a lidar orbit height of 350 km at a latitude of 0 deg, with a lidar nadir angle of 30 deg and lidar prf of 50 Hz were used. A rectangular target area at an altitude of 0 m centered on the cross-track was used. The scanner rotation rate for the conical scan pattern was 12 rpm.

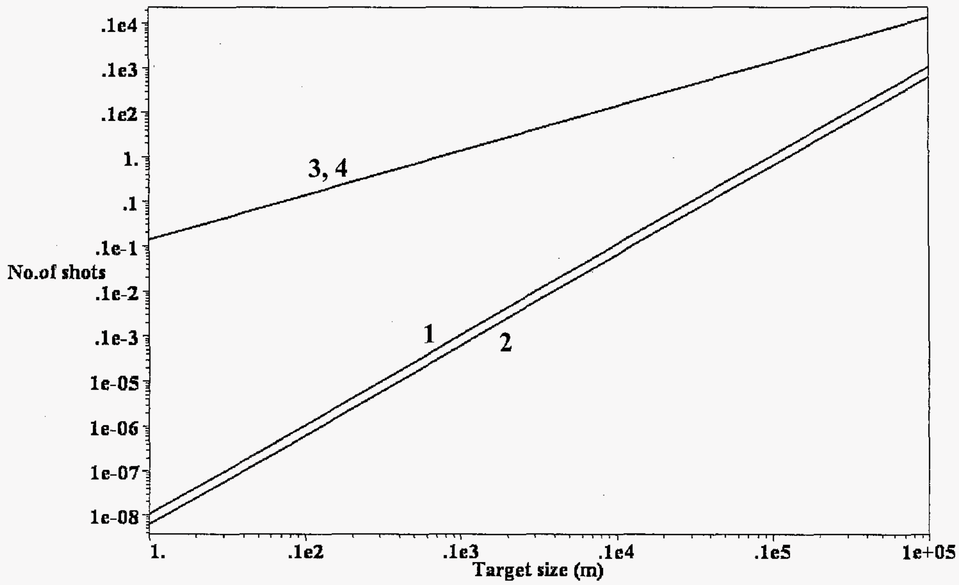

Figure 2) Number of shots into an on-track rectangular target area for a 30 deg. nadir angle lidar operating at 50 Hz from a 350 km orbit. The numbers associated with each line represent each of the numbered scan patterns in the text.

As the casual observer might anticipate, the two targeted shot patterns are much more efficient than the non-targeted scan patterns. From this figure it is not apparent that there is any significant difference between the two targeted patterns however figure (3) shows the number of shots into the target for targeting mode (3) as a percentage of the shots into the target for targeting mode (4). Figure (3) suggests that the complexity of implementing the dynamic targeting mode (4) must be carefully weighed against the small gain in number of shots on to the target relative to the simple targeting mode (3). Caution must be taken when interpreting these results for the smaller target sizes under consideration as platform pointing knowledge and control as well as atmospheric effects will have an impact on any practical system.

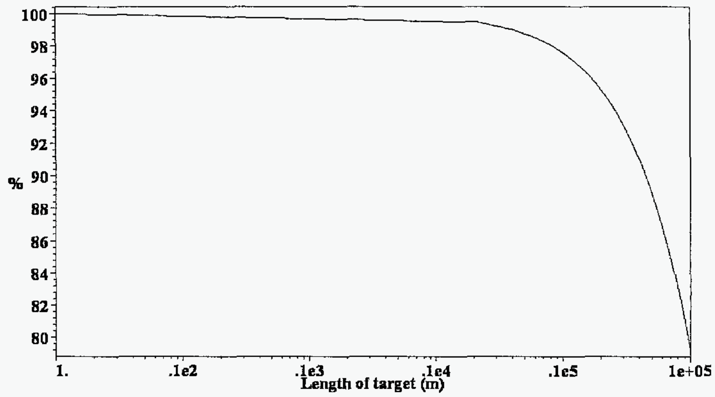

Figure 3) Number of shots into a rectangular target area for targeting mode (3) as a percentage of the number of shots for targeting mode (4).

Stream Flow Mission

Figure (4) shows modeled shot distributions in the vicinity of St Louis, MO where the Mississippi, Missouri and Illinois rivers converge and it is intended to illustrate the sampling issues in attempting to measure river stream flow. In both figures the arrows indicate the line of sight of the instrument for that shot and both represent the data from a 10 day shuttle mission with a 30 deg nadir angle and 50 Hz PRF. The first panel assumed a conical scanned lidar and the second assumed a fixed azimuth scanner. The shot arrows in the right panel are smaller in order to accommodate the higher density of shots. The rectangular box in the left panel represents the location of the right panel.

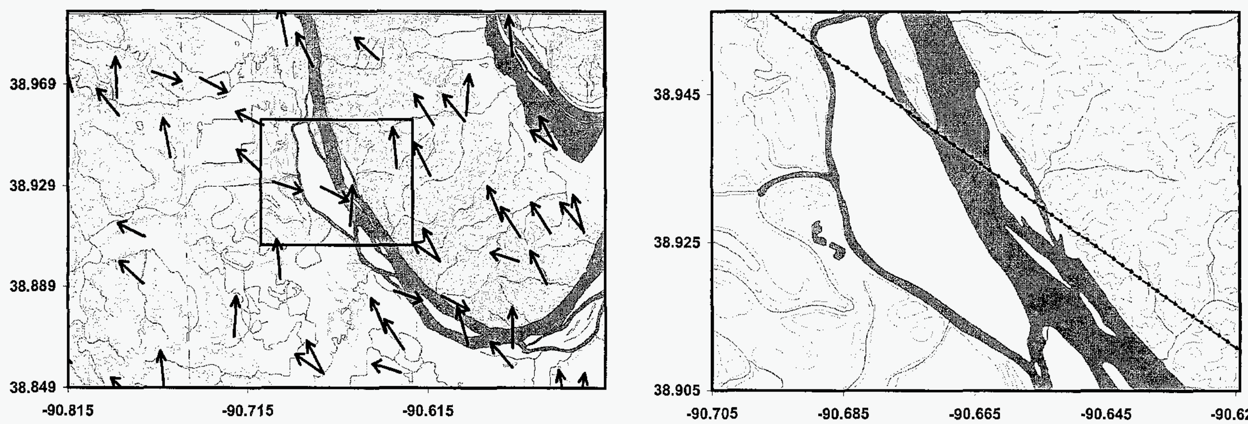

Figure 4) Representative shot patterns for a conical scan and a fixed azimuth scan over a region of the Mississippi (see text).

In this pair of figures the fixed azimuth scan has resulted in more samples of the stream however the number of samples is still small (<10) considering the 10 day data collection period. Figure (2) implies that for the 0.5 – 1 km feature size that the Mississippi represents using one of the targeting strategies outlined here should improve the number of samples by several orders of magnitude.

Summary

A simple approach to targeting a space-based lidar was shown to provide essentially all of the benefits of a more complex scheme.

Acknowledgements

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology and at the University of Alabama in Huntsville under contract with the National Aeronautics and Space Administration (NASA).