Surface Reconstruction for Ground Map Generation in Autonomous Excavation

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Outline

- Introduction
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- Curve Approximation Method
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Introduction

- An autonomous excavator requires perception about its surrounding environment.
  - Navigation path planning.
  - Digging cycle planning.
  - Safety evaluation.
- LiDAR sensor can be used to scan the ground surface.
- Surface reconstruction can be implemented on point cloud data from LiDAR.
- Point cloud data are unordered set of data.
- Constructing a set of unordered data require high computation power and time.

Literature Review

- Galvez et al. Bézier curve and surface fitting of 3D point clouds through genetic algorithms, (2007)
  - Surface reconstruction with scatter data is challenging.
  - Most methods fail to converge to a hole-free and complete surface.
  - Additional information's such as connectivity and/or normal vectors are required for most methods.

Literature Review

- Hoppe et al. Surface reconstruction from unorganized point clouds. (1992)
  - Provide mathematical model for surface.
  - Works on any unordered point cloud.
  - Compute the tangent plane orientation.
  - Vulnerable to noises.

Literature Review

- Gu et al. Neural network approach to the reconstruction of freeform surfaces for reverse engineering. (1995).
- Echevarría et al. Extending neural networks for B-spline surface reconstruction. (2002)
  - Used neural networks approaches to optimize the reconstructed surface.
  - Requires high computation time

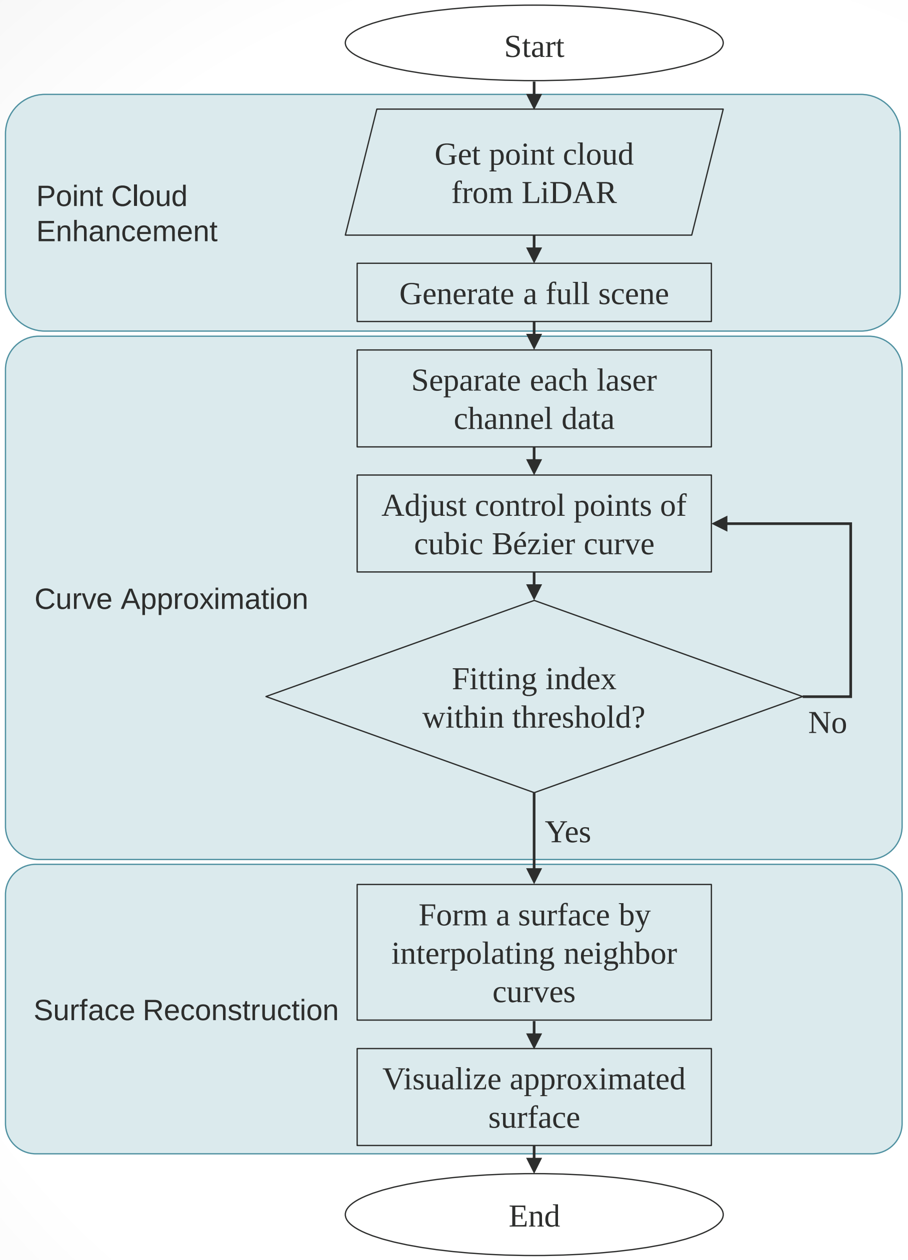
Research Motivation

- Proposed methods suffer from:
  - Prone to errors due to noises and outliers
  - Requiring additional information's
  - Requiring high computation power and time
  - Not guaranteed to produce a complete and hole-free surface

Research Objective

- Propose a method to
  - Reconstruct the surrounding ground surface
  - Hole-free surface
  - Discard noises and outliers
  - Approximate the point cloud with a mathematical model

Proposed Method's Flowchart



Point Cloud Enhancement

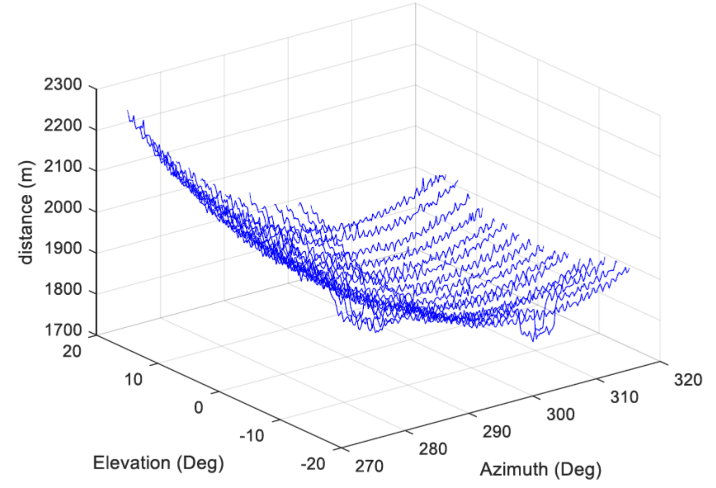
- Velodyne Puck (VLP-16) LiDAR with 16 laser channels was used to obtain point cloud data from the ground.
- Each laser firing may produce multiple reflections.
- The Last and Strongest are reported by the LiDAR.
- This study chose the Last option because the digging ground is always the last visible object in the environment.

Point Cloud Enhancement (continued)

- The LiDAR sensor reports the points in polar coordinates.
- Data points in polar coordinates can be translated into Cartesian coordinates using equations provided by the manufacturer.
- Processing data in polar coordinates has some advantages:
  - Data points can be arranged in an evenly distributed pattern.
  - Ensuring the generation of a valid and hole-free surface.

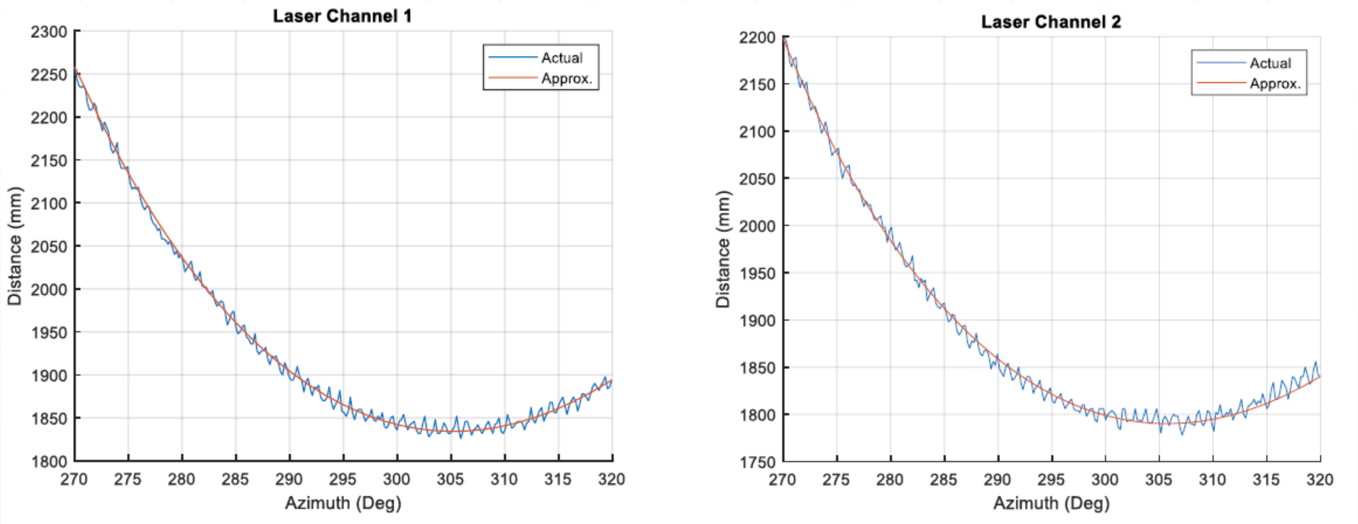
Curve Approximation Method

- The LiDAR sensor reports a series of paired azimuth and distance data for each elevation angle.
- The distance data may contain noises and outliers.
- Apply a curve approximation
  - Retain the shape of the distance.
  - Discarding the noises and outliers.
  - Having an analytical equation rather than sparse points in space



Curve Approximation Method (continued)

- Cubic Bézier curve approximated on each laser channel.
- The place of control points are optimized.
- Cost function is the least square error between raw data and approximated curve.

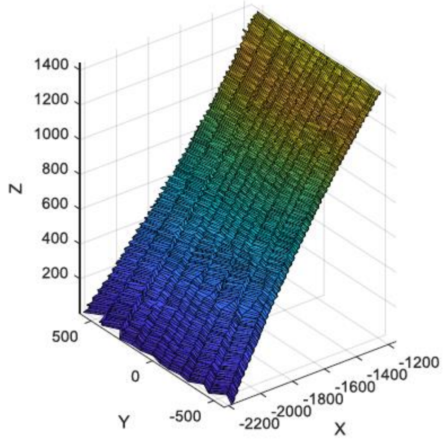


Surface Reconstruction

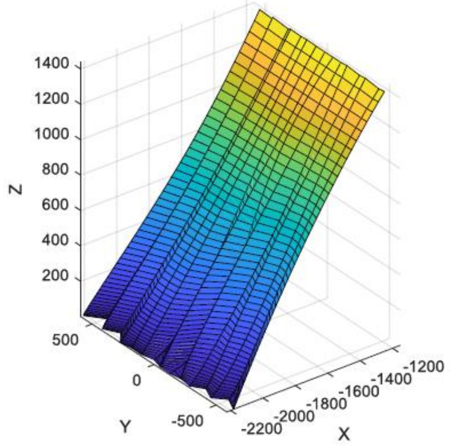
- Stitch the individual approximated curves together to make a single surface.
- A linear interpolation between neighbor curves is used.
- A series of points in polar coordinates were evaluated from the approximated surface.
- Converted into Cartesian coordinates to generate the actual ground shape.

Results

Raw (original) point cloud



Reconstructed surface



- A smooth and noiselessly surface reconstructed from raw point cloud.
- An analytical equation rather than sparse points

Conclusion

- Proposes a curve approximation-based method to reconstruct the surface of digging ground using data sets from a LiDAR sensor.
  - Represent surface in Cartesian coordinates.
  - Reducing computation time.
  - Robust to noises and outliers.
- Helps in:
  - Allow for better identification of the ground shape
  - Provide a solid foundation for the generation of optimal trajectory
  - Accurate tracking control
  - Safety evaluation

Future Works

- Limitation:
  - Linear approximation between neighbor laser channels
  - Poor performance on detecting sharp edges

- Future Works:
  - Use more smoother methods to interpolate between neighbor laser channels
  - Improve sharp edges detection
  - Add boundary constrains (Slope and curvature continuity)

Thank you for your attention.