Visualization of Pallets:

Recognizing 3D Objects In LADAR images

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Joint project between NIST and Transbotics

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Automate Truck Loading

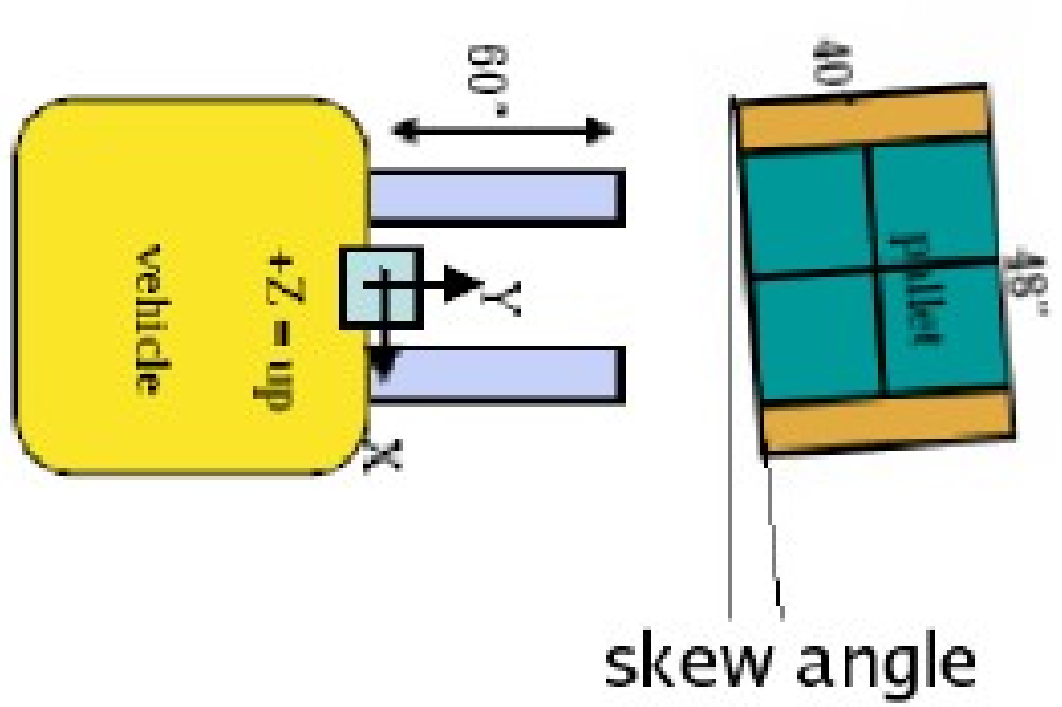


Figure 1: Forktruck AGV and palletized good.

Automate Truck Loading (2)

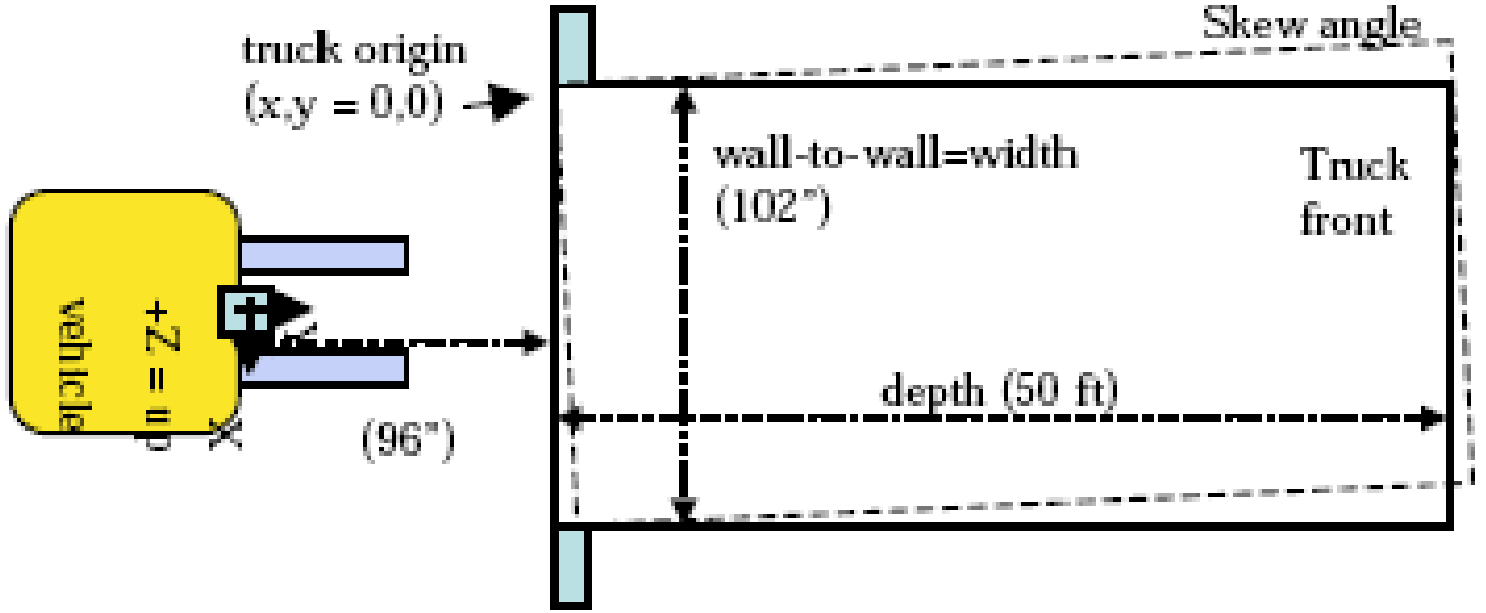


Figure 2: Forktruck AGV outside the truck container.

figure not in scale

Automate Truck Loading (3)

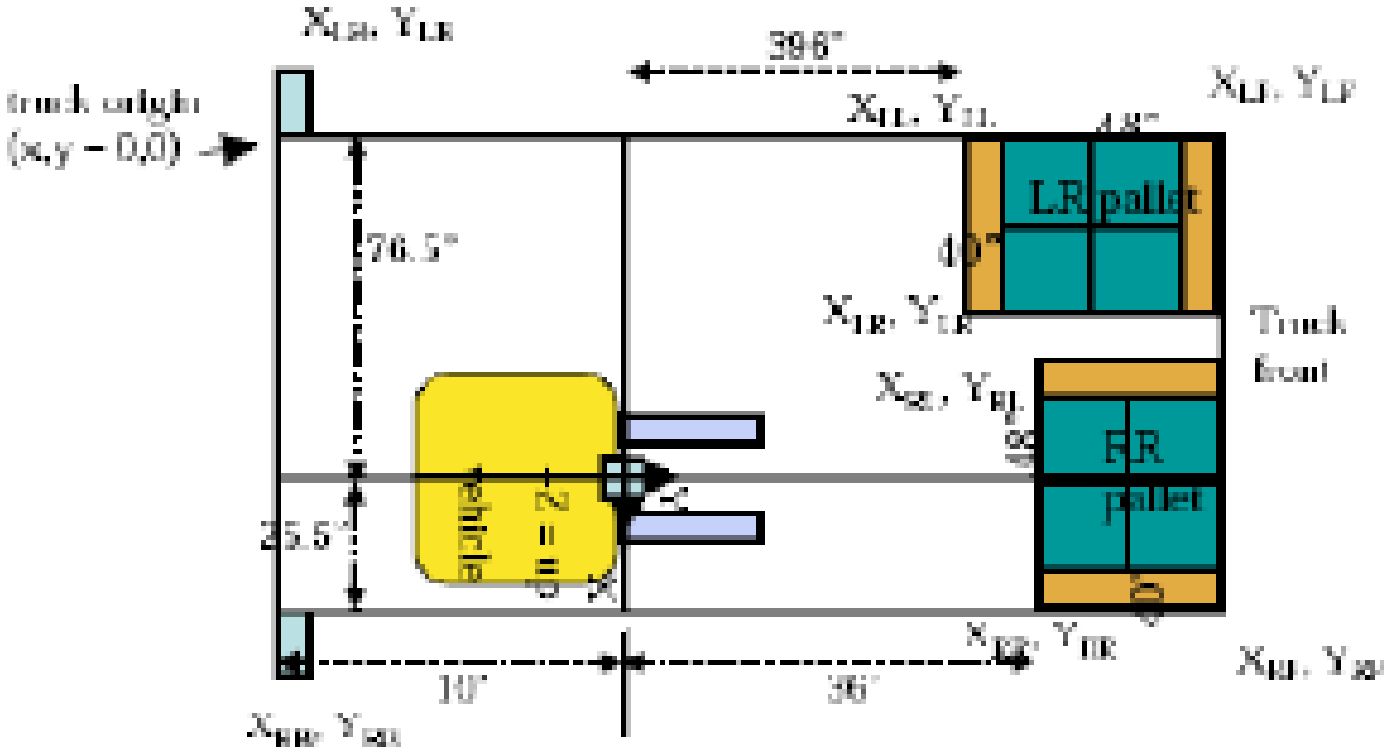
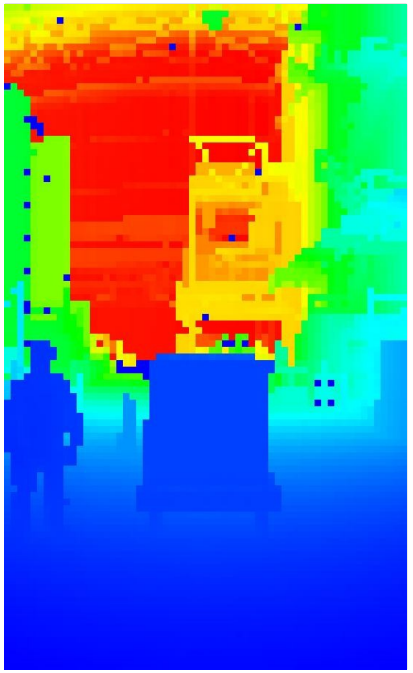
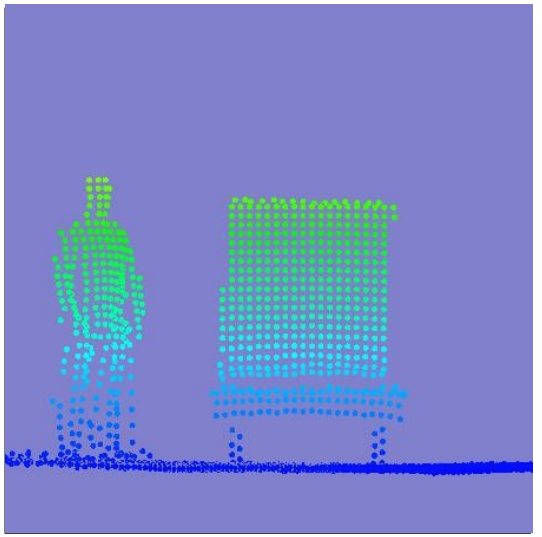


figure not in scale

Background: LADAR sensor (1)



Each pixel in the image encodes the range information. Blue=close Red=far



Corresponding 3D point cloud

Background: LADAR sensor (2)

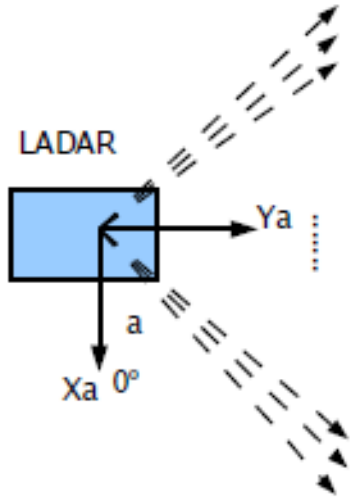


Figure 7:LADAR frame (Xa,Ya). Angle 'a' goes from [45° to 145°] ==>100° fov.

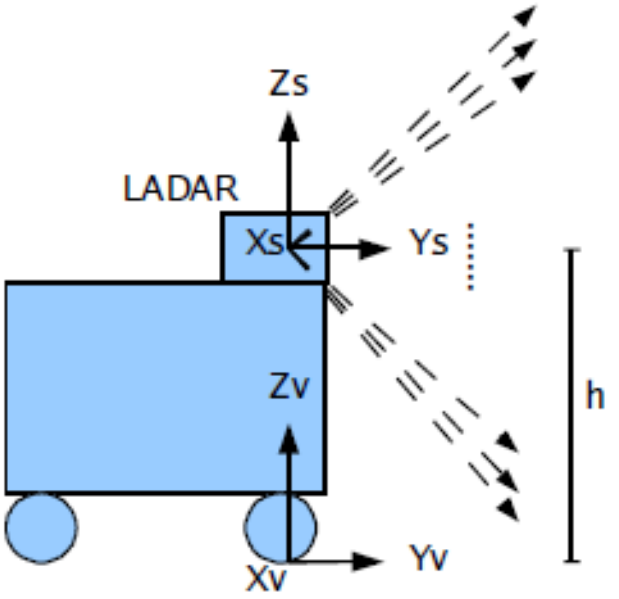


Figure 8: Sensor frame (Xs,Ys,Zs) and Vehicle frame (Vx,Vy,Vz). X-axes point to the right of the vehicle.

The Objective (1):

- to locate some pre-specified box-like objects.

prior knowledge :

  - All boxes have the same width and depth but they may have different heights.
  - The depth and width of the box are different.
  - Boxes are placed flatly on their bottom facet on some supporting surface parallel to the floor.

Prior Knowledge (1)

- Boxes are placed anywhere in the room and in any orientation.
- Boxes may be stacked.
- Boxes are opaque (sensor can not see inside or see through them).
- Sensor's mounting parameter with respect to the floor is known. Sensor pose has no roll component.

Prior Knowledge (2)

- The room may contains no boxes at all.
- There is no knowledge about the background.
  - Typically the background is often cluttered with junk and other man-made objects. This kind of background is typical in a warehouse-like environment. The vision system must be robust enough not to confuse target boxes with other objects in the background.

The Approach:

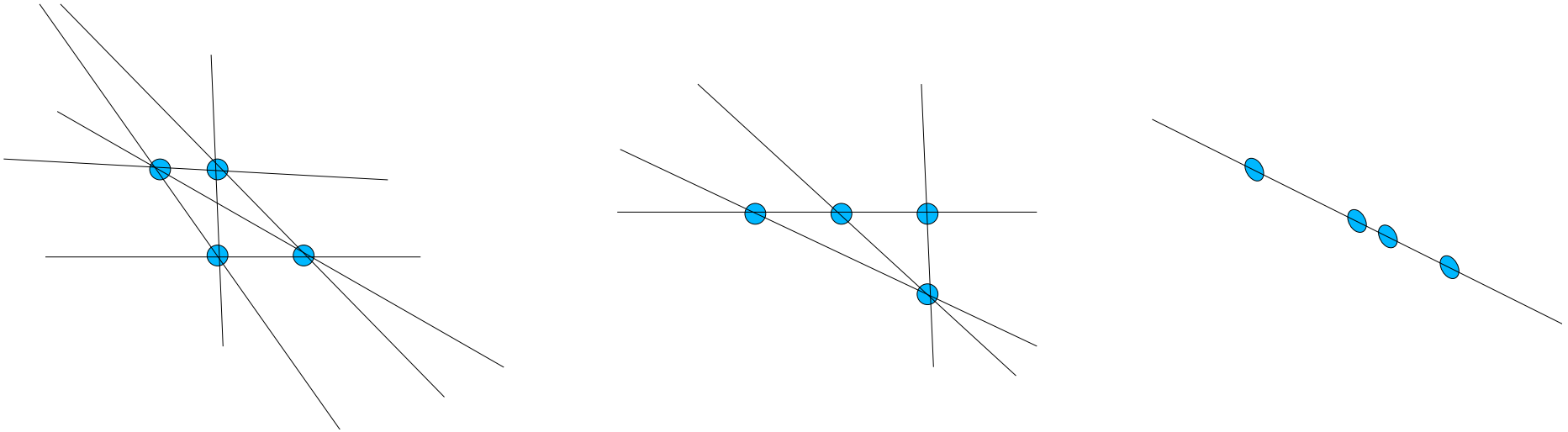
- **Bottom-up:**
  - Convert raw range data into corresponding Cartesian X,Y,Z coordinate.
  - Extract and retain all points that lie on any vertical surface.
  - Group vertical points into corresponding individual vertical plane / surface.

The Approach (1)

- **Model-based (top-down)**:
  - Retain only vertical planes that:
    - satisfy target box's side facet constrain **and**
    - are consistent such that there is no contradiction with any other vertical plane.
  - Report the locations and dimensions of boxes that are detected from step 4.

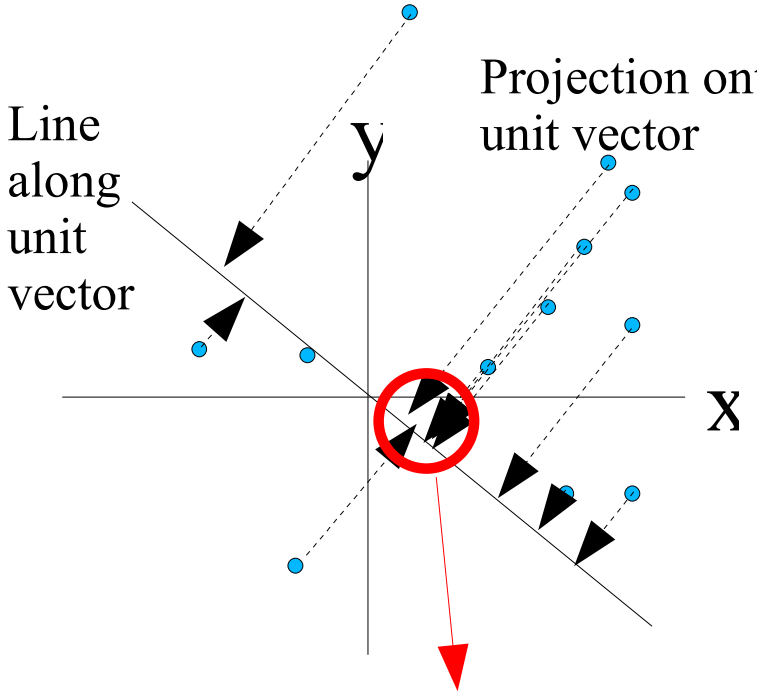
Hough Transform

- find all possible lines in a set of 2D points

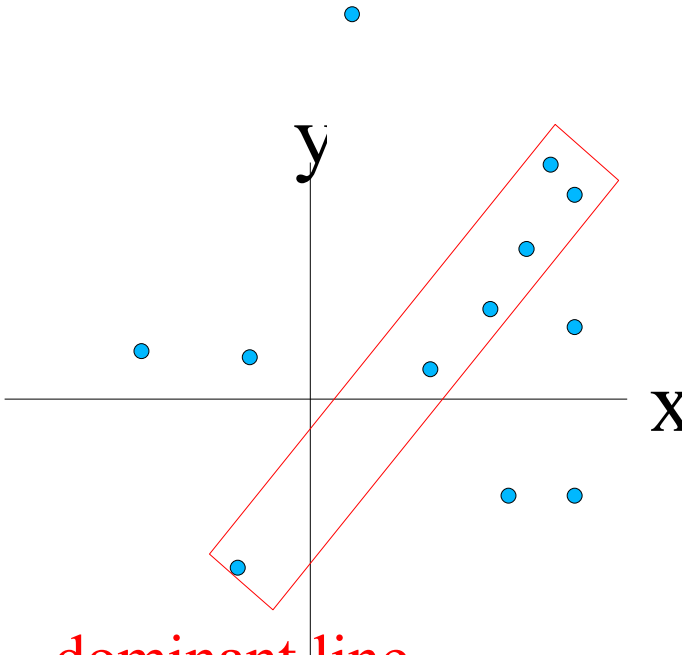


Given 4 points, there are at most (4 choose 2) 6 lines.
However, there are less lines if some points lie co-linearly

Hough Transform: Projection and clustering



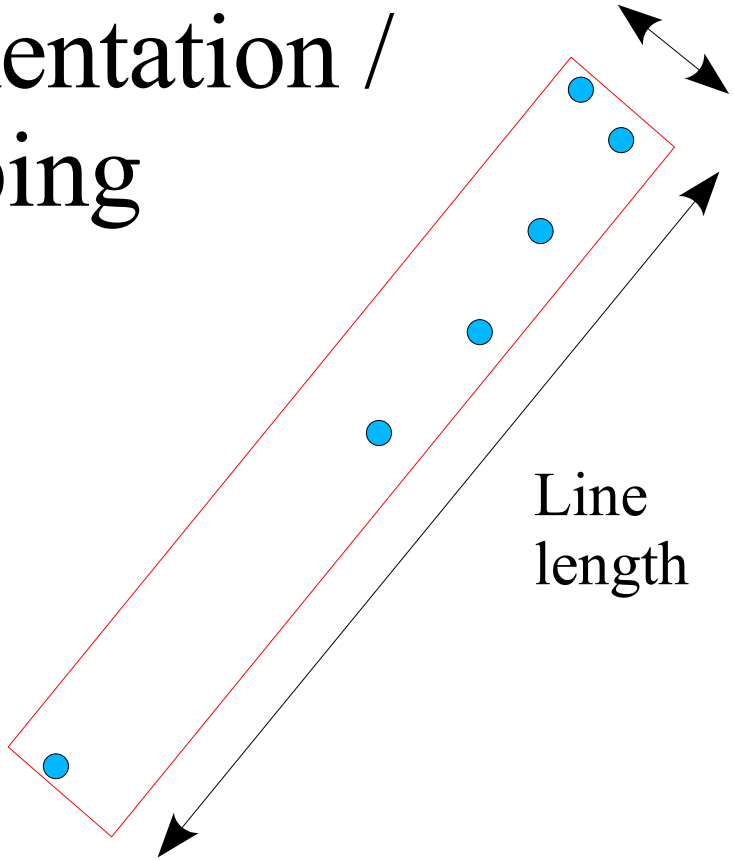
dominant cluster
(within pre-specified tolerance)



dominant line
(line angle is perpendicular to the projection unit vector)

Line Attributes

Segmentation / grouping

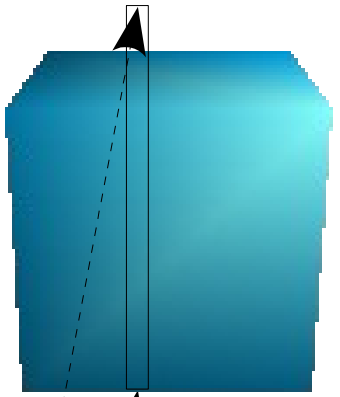


Some attributes include:

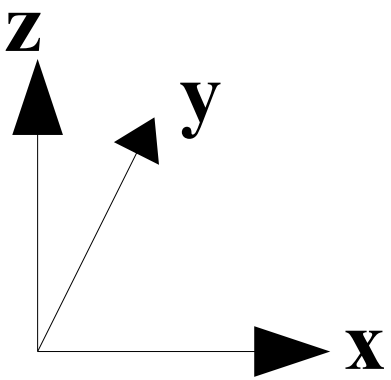
- fitting error
- compactness
- line density
- line dimension
- number of points in line
- starting/ending points
- median point
- line equation f(x)
- etc.

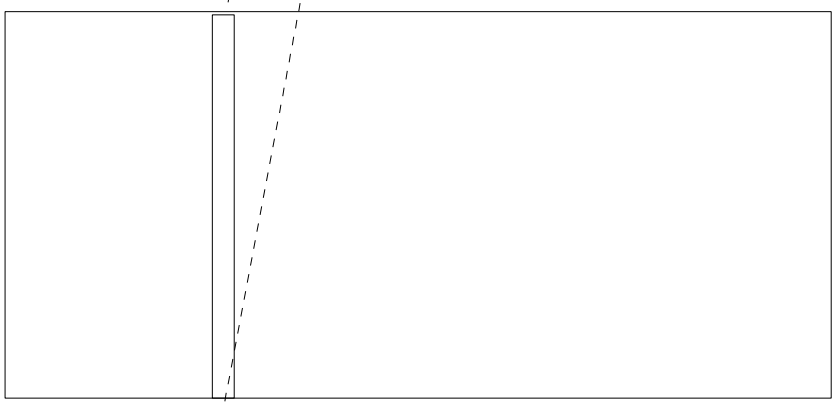
Divide-and-Conquer

A box in 3D



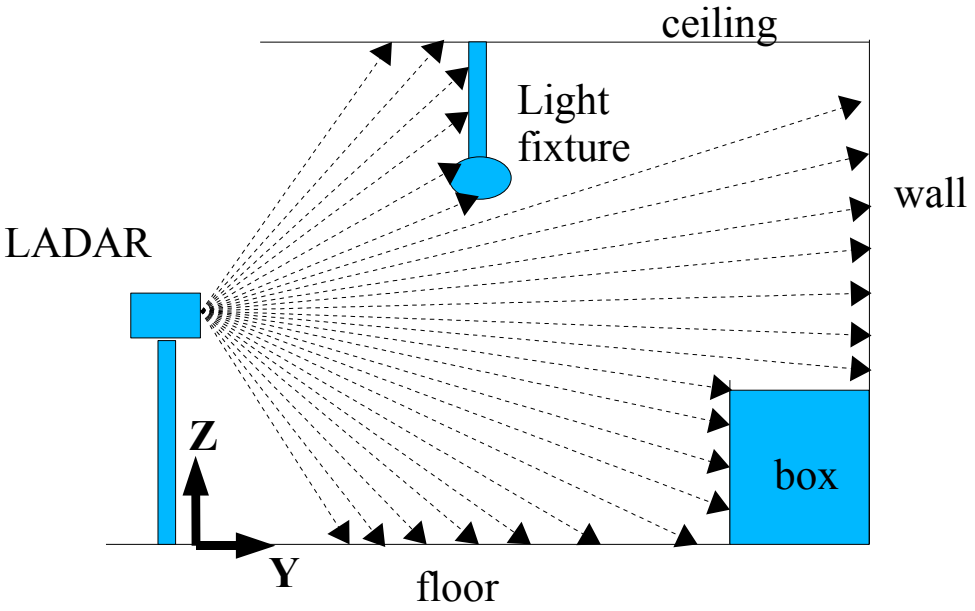
Vertical stripe in 3D projected to a column in the LADAR image

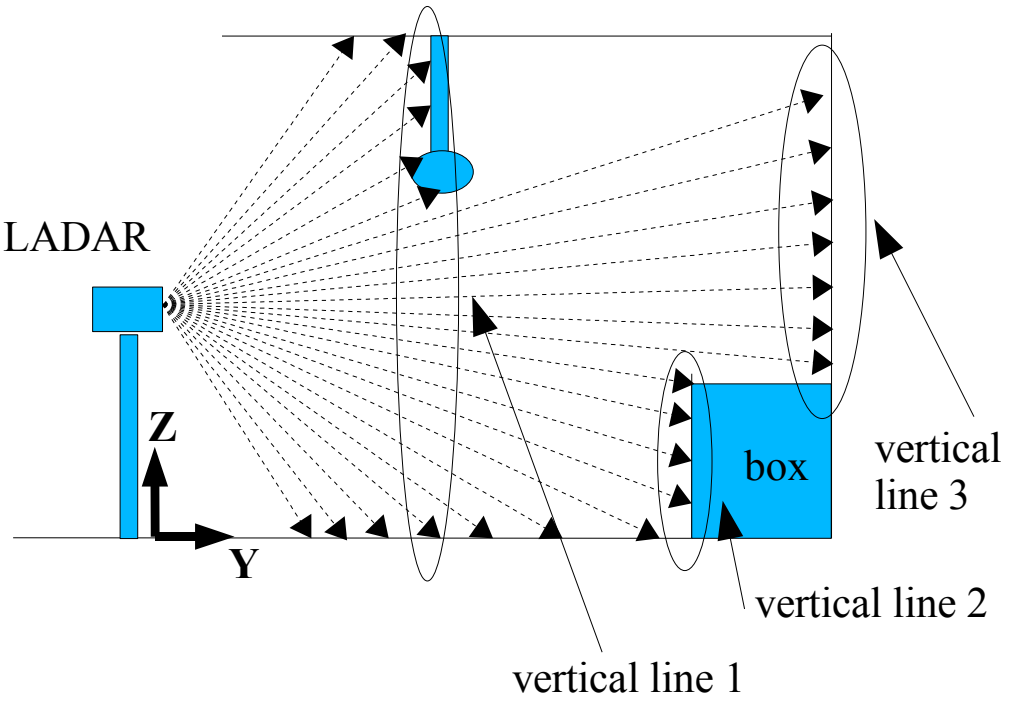




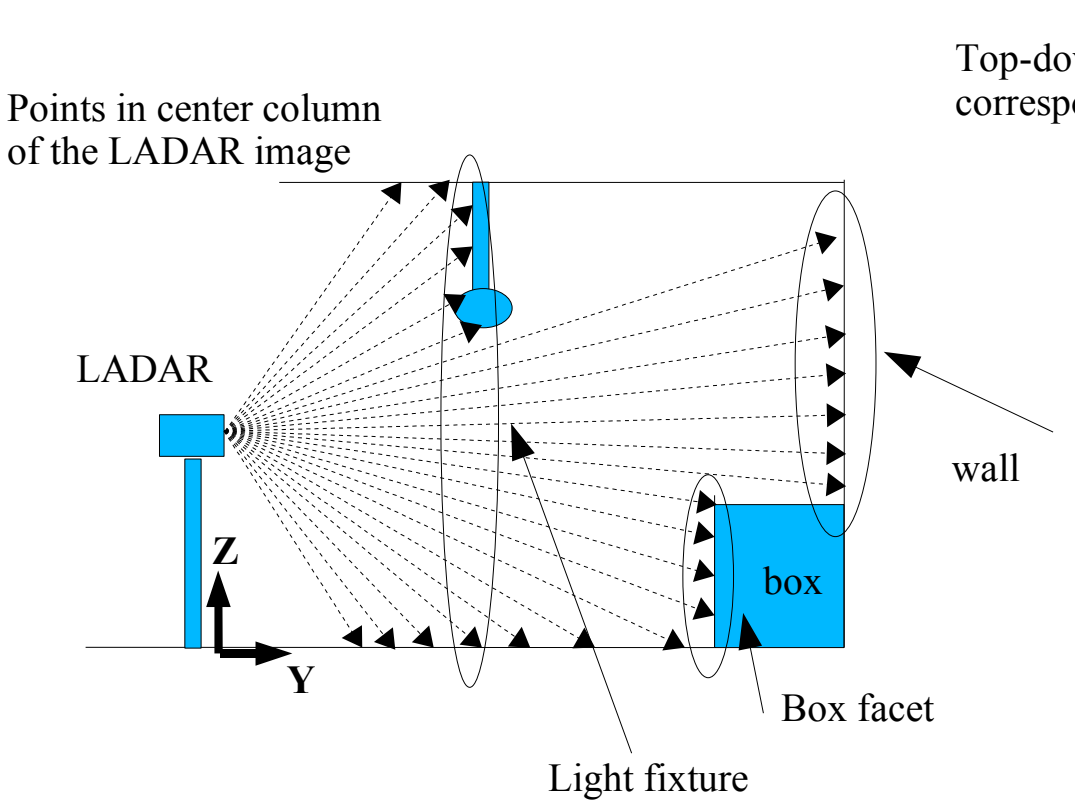
2D LADAR image

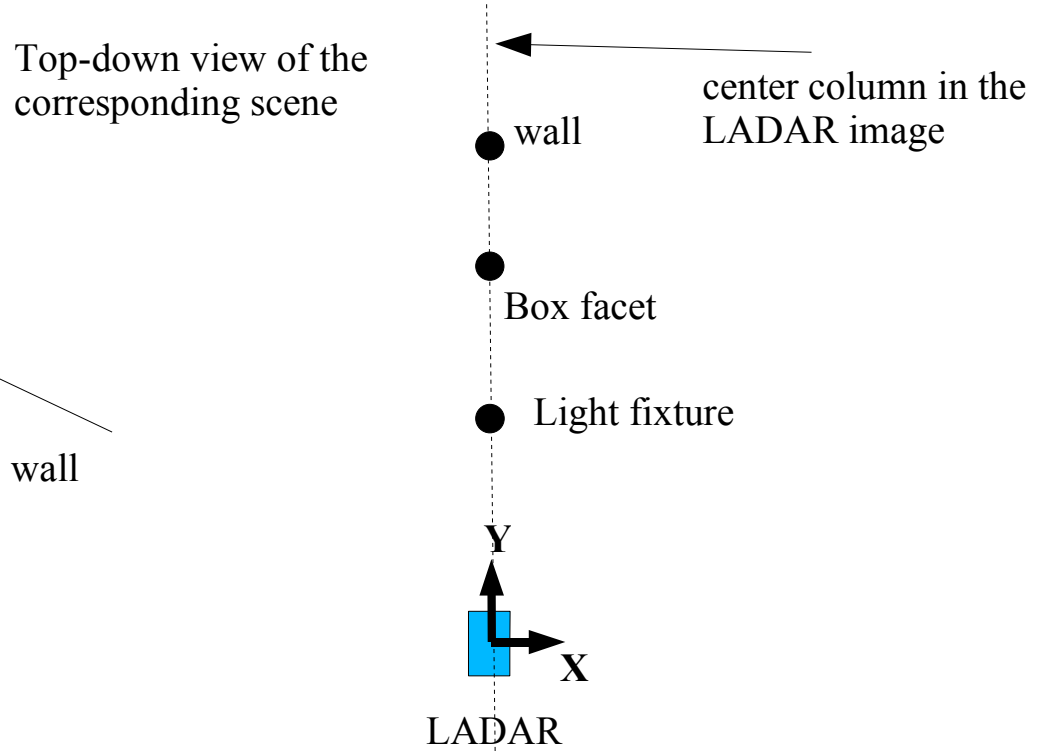
Points lie on Vertical lines



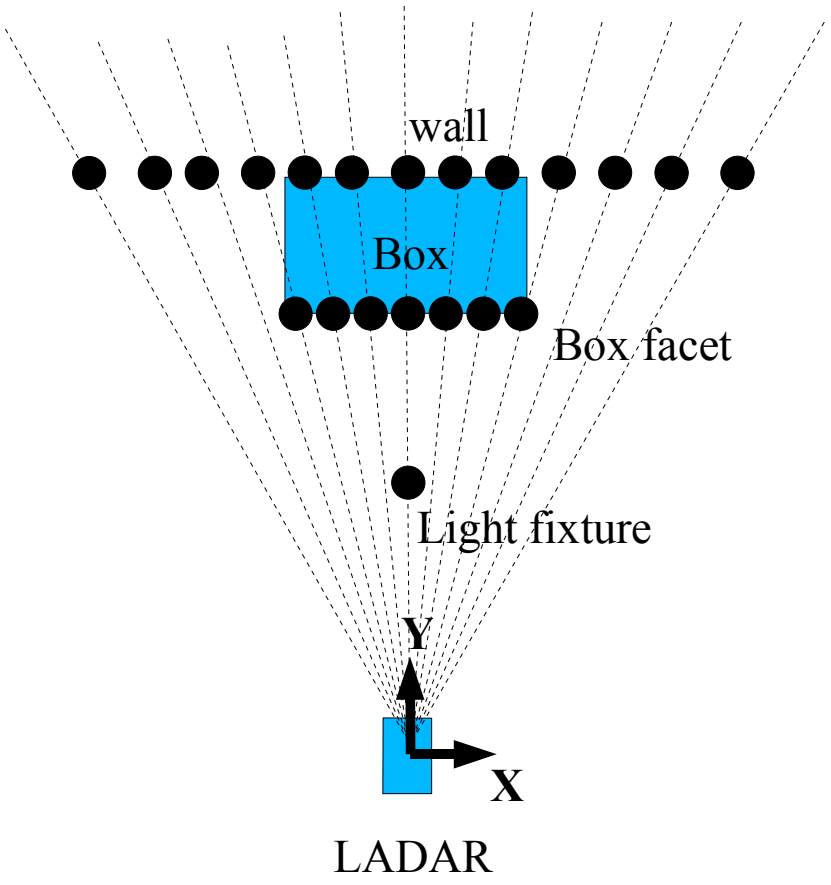


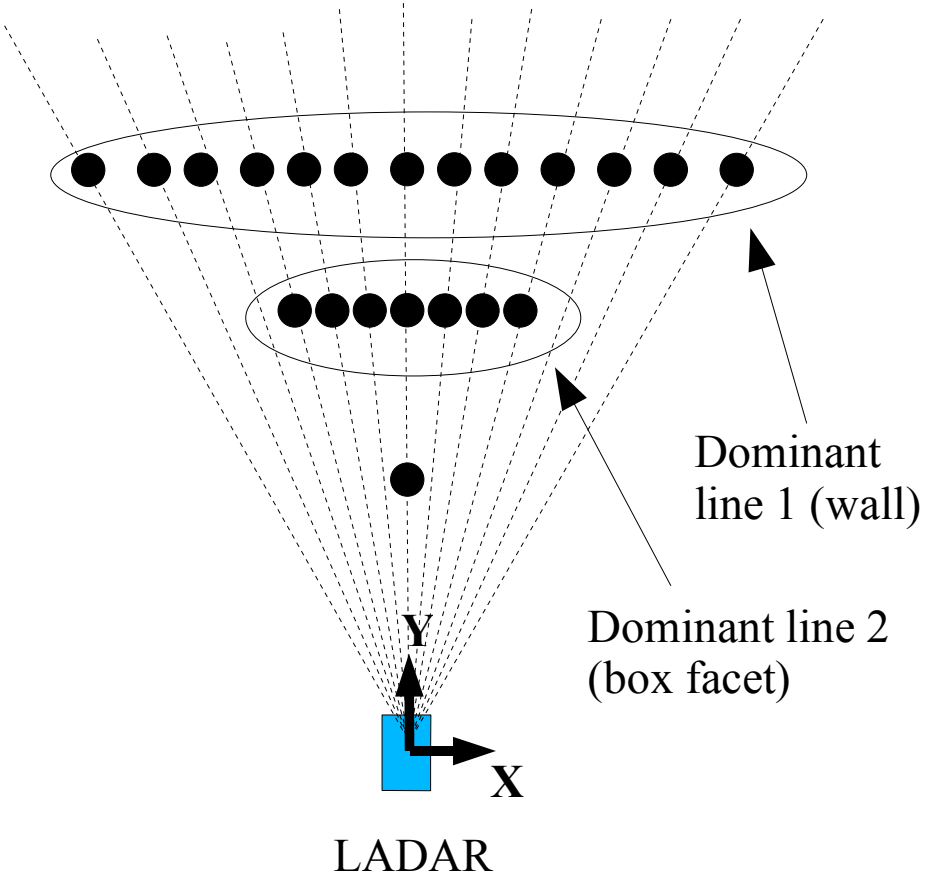
Points lie on Vertical lines (1)





Points line on vertical planes





Constrain Satisfaction Problem

- After grouping point into vertical planes, how do we know which of these planes are box facets? (as oppose to wall or other man-made objects in the background)

Constrain outline

- In order for a vertical plane to be a valid box facet, it must:

- 1.) has width that is either the width or the depth of the box (within some pre-specified tolerance).
- 2.) be consistent with other vertical planes. For example, there should be no vertical plane inside the box!

First Order Logic

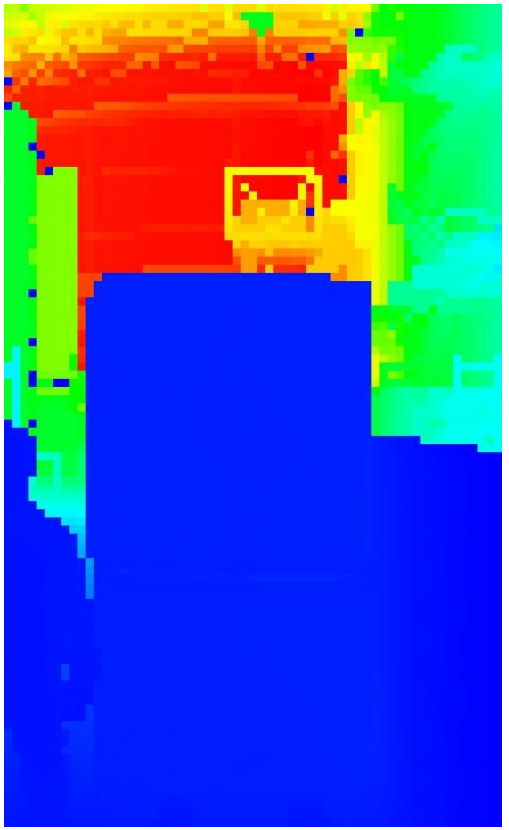
- Axioms:
  - VerticalPlane(v1) “v1 is a vertical plane”
  - ...
  - VerticalPlane(vn) “vn is a vertical plane”
- define predicate symbols, constants, terms and functions:
  - HasBoxWidth(v)
  - HasBoxDepth(v)

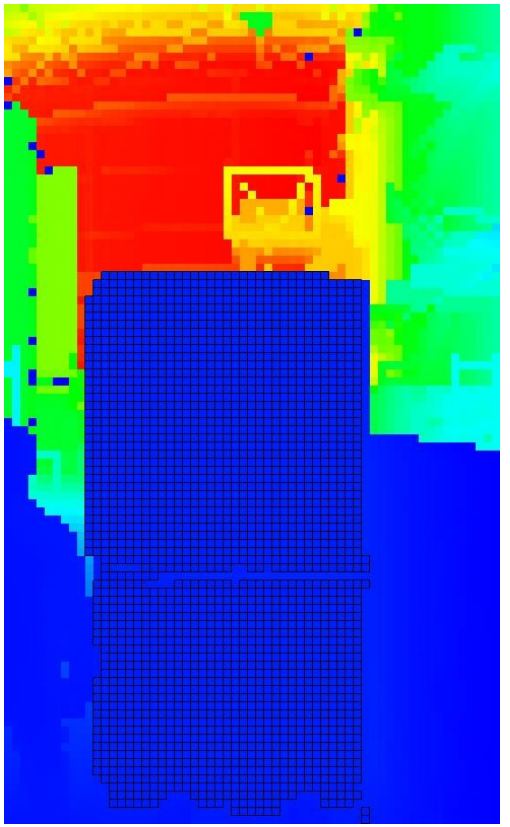
Solution query:

- BoxFacet(v)
  - "true if vertical plane v has box's width or depth"
- InsideBox(u, v)
  - "true if vertical plane u is inside the box formed by box facet v.

- the solution query:
- $(\exists\ v)\ \{(\forall\ u)\ \{BoxFacet(v) \wedge \sim InsideBox(u,v)\}\}$
  - "there exists a box facet v such that no vertical plane u is inside v's box volume"

Result





Truck Measurement Result

Figure 14: Top-down view of a typical panning LADAR truck scan. The truck door is to the left and the front wall of the truck is to the right. Raw scan data provided by Transbotics.

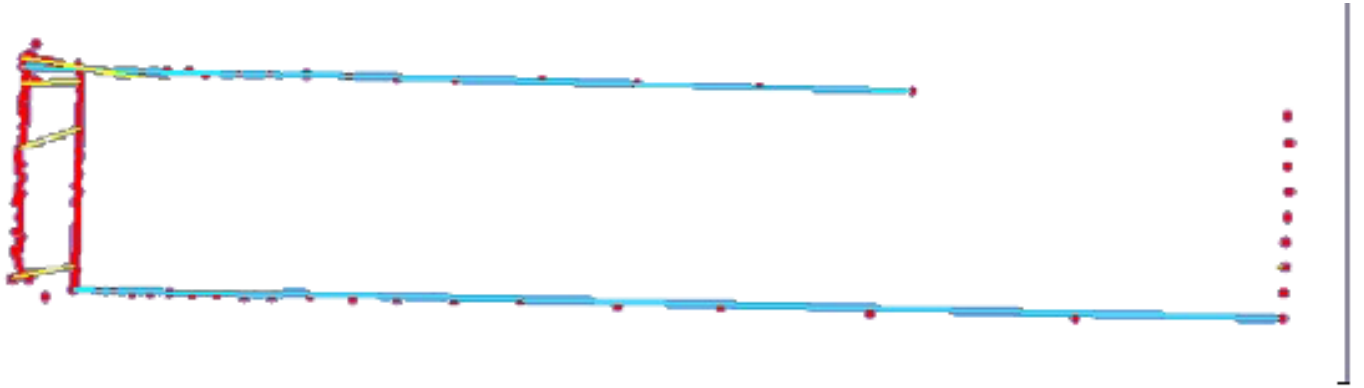
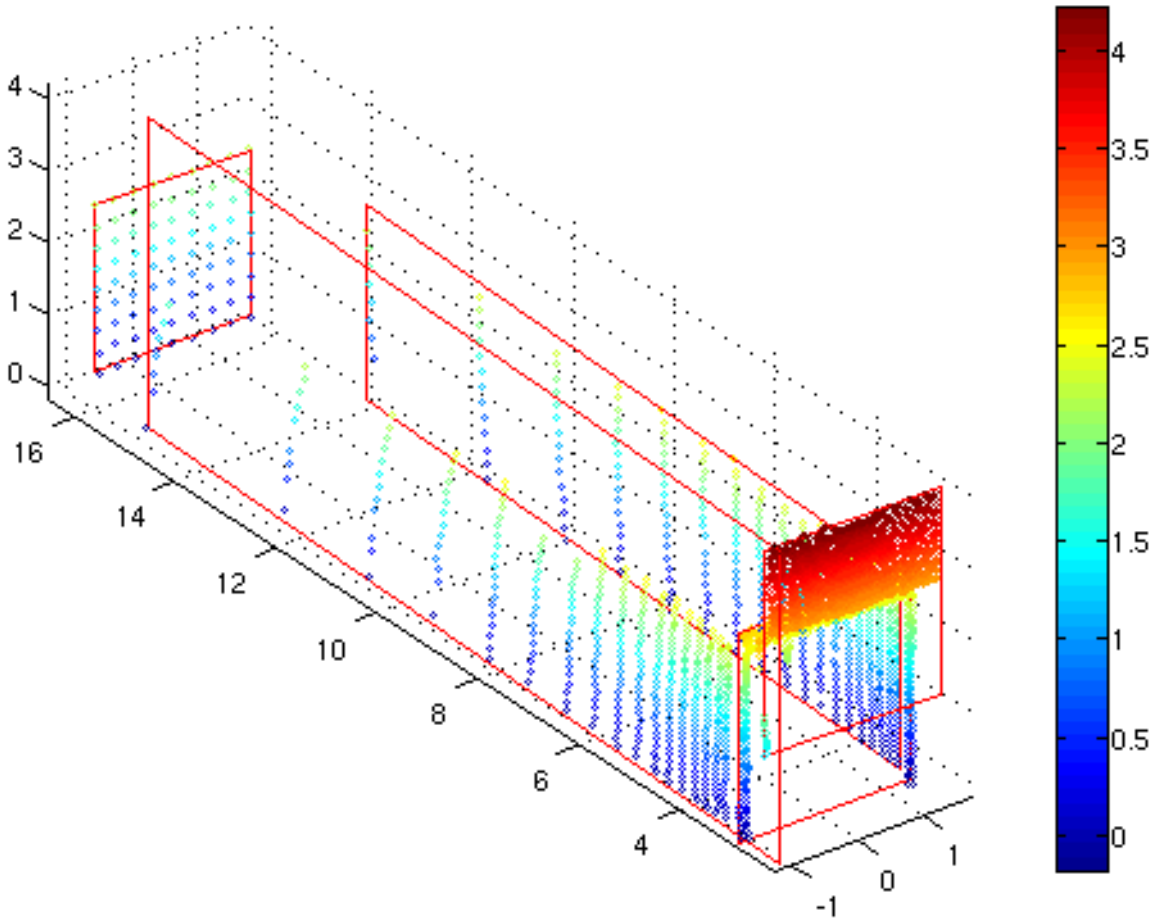


Figure 15: Detected truck side walls are marked in cyan color, they corresponds to two most dominant lines. Measured skew angle =-1.5°(with respect to the forktruck AGV not shown). Measured width = 2.5m.

Figure 16: The detected front wall of the truck is shown in cyan color on the right. Depth of the truck measured 16.45 m from the forktruck AGV. Note the truck door was partially detected as an overhanging object.



All vertical surfaces inside truck.

Last Slide

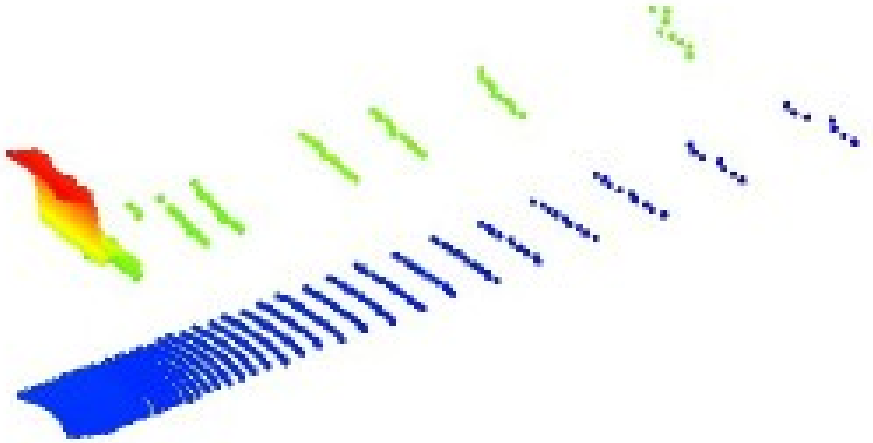


Figure 17: Truck height. Measured as the lowest point = 2.10m.