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# FEATURE EXTRACTION FROM RANGE DATA

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## ABSTRACT

Laser mapping has become quite popular in recent days due to its capability of providing information directly in three dimensions. Three dimension data are used in many applications, like navigation, urban planning and management, utilities planning, virtual reality, computer games etc. However, there still lacks a reliable and quick method of acquiring three dimension data of the urban area at higher resolution. Most of the vehicle-borne systems developed so far are based on stereo photographs as the main source of data. In order to overcome the problem of acquiring three dimension data in urban area reliably, quickly and at high resolution, we have developed a vehicle-borne laser mapping system (VLMS). The system is equipped with laser scanners and line cameras for data acquisition. The system will assist in building 3-D GIS database of urban areas.

In this paper we focus our discuss on feature extraction of such a system including it's capabilities and limitations. In an urban area we encounter many different types of features like buildings, roads, utility facilities, trees and many others. Our discussions will be basically limited to the extraction of road surface, building faces, poles, trees, tunnel and some other features on the ground. We believe that this type of mobile mapping system will provide complimentary data to the existing photogrammetry method for the generation of more accurate 3-D data of urban environment.

## INTRODUCTION

The vehicle-borne mobile mapping technology has been developed around late 80's. The development of the mobile mapping system became possible due to the availability of GPS signal to the civilian community. This system is capable of observing the objects at closer range, thus giving greater details. As per our knowledge, so far, the vehicle based mobile mapping system are based on CCD cameras (in combination with video camera in some cases) for data acquisition. Combination of GPS with either INS or Gyro is used for navigation purpose. For reference of some of these systems, refer GPS-VanTM (Bossler et al, 1991), VISAT-Van (Schwarz et al, 1993, Li et al, 1994), TruckMapTM (Pottle, 1995), KiSS (Hock et al, 1995), GPS Vision (He, 1996) and GeoMaster (Tamura et al, 1998).

We have used laser scanners as the main data acquisition devices. The system is supplemented by line cameras for texture information and as usual combination of GPS, INS and odometer is used for position and attitude information. Refer Manandhar and Shibasaki (2000) for details about system description and calibration of our first prototype model, refer Manandhar and Shibasaki (2001) for details about system description and calibration for second version of the system.

Feature extraction from range data is quite a complex task, as the range data contain nothing except the range distance itself. The range distance is later converted into 3-D coordinates. Thus we have only clouds of 3-D points. Some laser scanners also provide intensity data. The extraction is more complex as the observation is from a moving platform (vehicle). The outdoor observation from a moving platform captures all the points reflected from the features like building faces, road surface, trees, poles, cables, guard rails etc. Thus the data consists of a mixture of laser points. The challenging work is to automatically identify and classify the points reflected by each of these features and then finally make a 3-D model represent the features. In this paper, we present some of the algorithms to classify these points into different groups and then generation of 3-D models from these groups. The algorithms are presented for road surface, building face, poles, trees and tunnel.

# 1 SYSTEM CONFIGURATION

The current version of mobile mapping system is shown in figure 1. The system is called Vehicle-borne Laser Mapping System (VLMS). This system consists of six line cameras, three laser scanners and Hybrid Inertial Survey System (HISS) which consists of DGPS, INS and an electronic odometer for position and orientation data. Our previous version of system had four CCD cameras instead of the line cameras. Refer Manandhar and Shibasaki (2001) for details about this system. We have made significant improvement in the present version especially in data acquisition period and operational vehicle speed. In the previous version, the vehicle speed is limited to about 10~20km/hr due to lower scanning frequency (10Hz) of the laser scanner. In the present version, the laser scanning frequency is 20Hz, which enables driving at a speed of 40km/hr or more (we have acquired data at 80km/hr) without any serious problem. Continuous data acquisition period has been increased from 50~60mtr to unlimited amount of survey distance or as long as the INS / GPS errors (especially the drift error) are within the allowable limit by improving the data writing mechanism from each of the sensors to the disk.

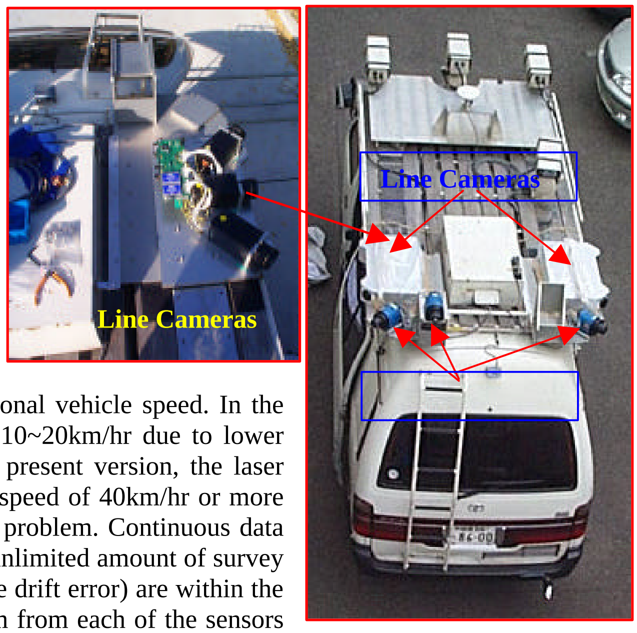


*Figure 1: Mobile Mapping Vehicle*

# 2 FEATURE EXTRACTION

We define feature extraction as the process of classifying the laser points reflected by the urban objects into different groups like building surface, road surface, ground surface (e.g. walking path), trees, poles, tunnel, parked vehicles etc.

The range data includes only clouds of points in three dimensions. Figure 2 shows a sample of range data. It has no other information like reflectance value etc. We would like to extract various features usually seen in the urban environment. Basically, we categorize these features into three classes viz: man-made, natural and dynamic (moving) / static (non-moving) features. The natural features are trees, bush etc. The man-made features are buildings, roads, utility facilities (poles etc), pavement, guardrails etc. The dynamic features include moving cars and pedestrians and the static features include parked vehicles (something which can be dynamic but at static state during the observation period). Our primary focus is on extraction of man-made features like building faces, trees and road surfaces.

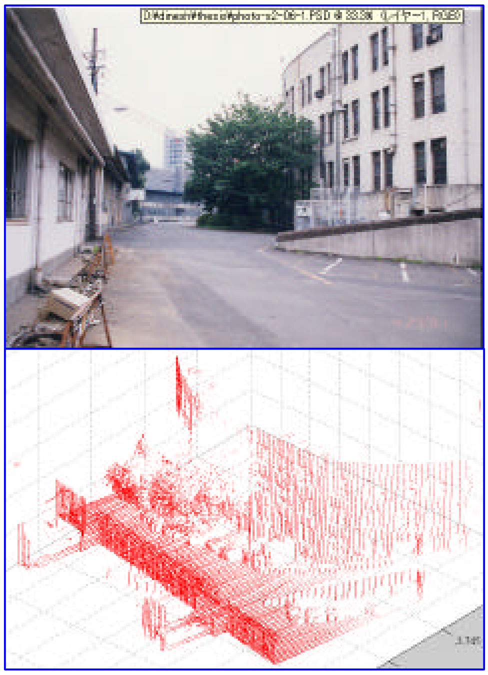

*Figure 2: Top: Photo of study area*
*Bottom: Laser Point Data of the same area*

## 2.1 Basic Concept for Extraction

The laser scanner scans the objects around it's surroundings within $300^0$ of angular coverage. As the vehicle moves forward, the scanner scans the objects sequentially at a frequency of about 20Hz. As the system is designed for outdoor mobile environment, we do not have control on viewing the objects as we like. Thus we get quite heterogeneous mixture of range points reflected by all the urban objects within the viewing angle of the scanner. This makes the identification of the objects very complex. On the other hand, we cannot just ignore some of the scattered points as these points are also reflected by urban objects.

Figure 3 shows some of the laser scan lines which consist of range points reflected by buildings, trees and roads. Generally, we can observe three sets of geometric structure of the range data as shown in figure 3. Building faces reflect points in vertical linear fashion (not necessarily straight line), ground or road surface reflect points in horizontal linear fashion and natural objects like trees reflect points in scattered fashion. Thus a quick look of the data gives us rough indication of buildings, roads and trees. The road surface being the nearest surface to the scanner with respect to other objects, the reflected laser point density is higher compared to other objects. We use these information (geometric structure of points, their scatter ness and point density) for feature extraction.

## 2.2 Road Surface Extraction

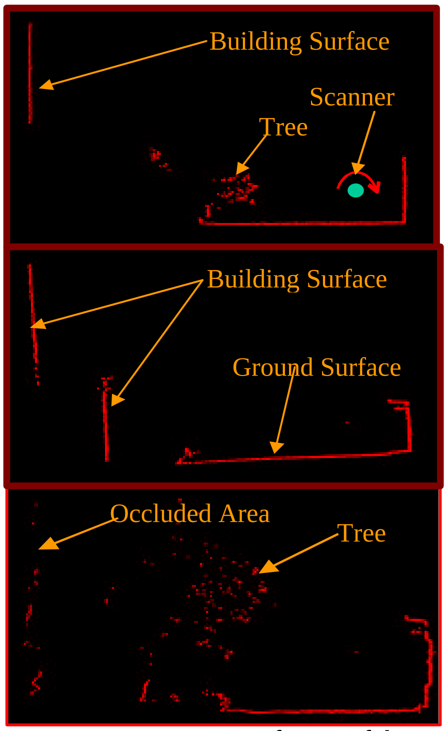


*Figure 3: Range Data of some of the scans. Each figure is one scan range*

A lot of range points are reflected from the road surface, as there are no obstructions between the scanner and the object. A general road structure is shown in figure 4 for illustration purpose. Road surface being the nearest object compared to other objects like buildings and trees, the point density is also bigger due to higher across track scanning resolution. Since, the road surface height varies smoothly with a very small deviation (about 1% slope) along the width of the road, we get reflected range points that have a variation in height value within 10~20cm. A 1% slope gives a change in height of 1cm for every one meter. While setting the threshold value both the road slope and width of the road is considered. A thumb rule is given by equation 1

$$R_{th} = \pm\left( slope \times \frac{RoadWidthth}{2} + std \right) \qquad (1)$$

where,

| | |
|---|---|
| $R_{th}$ | is the Road Threshold value for selecting range points from road surface in centimeters |
| *slope* | is the road slope from the center of the road to the edge of the road in percentage, generally it is 1~2%. |
| *RoadWidth* | is the width of the road in meters |
| *std* | is the accuracy of the scanner (standard deviation at 1 sigma) in centimeters. The value is about 3cm. |

The range data is processed scan line by scan line. This scan line by scan line processing is opted because the HISS data (GPS/INS) has unavoidable positioning error due to cycle slip or loss in satellites. This effect is very prone to height component, due to which the height data sometimes jumps as high as 20~30mtr. Thus if a single scan line is taken, the sudden jump or error in neighboring lines will not have any effect on a particular line. All the range points within a single scan line are assigned the same positioning data.

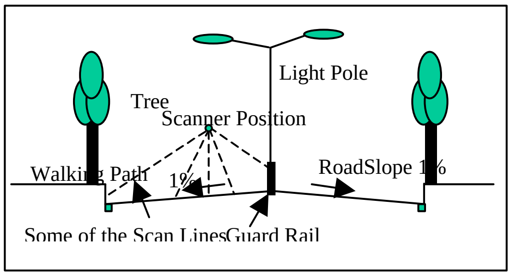


*Figure 4: General representation of a road surface*

Frequency analysis is computed for every scan line with a bin width equal to 10cm. The bin with highest frequency value is taken as the height threshold value for selecting range points reflected by road surface. Let's say this is bin N. Next; we check whether bin N+1 has at least 60% of data points of bin N. If it has then, we take bin N+1 as the height threshold value. Still, we check bin N+2. If it has at least 80% of data points of bin N+1, then we take bin N+2 as the height threshold value. The percentage values of data points in bin N+1 and bin N+2 are determined completely by hit and trial with some data sets, before finalizing the values. The road type also affects this value. It is necessary to consider bins N+1 and N+2 as well, since we simply limited the bin width as 10cm. Otherwise, we should have some mechanism to fix the bin width value. The threshold value is then given by the sum of the road threshold value and height threshold value. The histogram of the analysis of the laser data is shown in figure 5. The filtering of data using the threshold value results in the selection of points from the road surface as shown in figure 6(a). However, there might be some points reflected by neighboring objects on the edge of the road. In order to remove these points, a straight line is fitted to the points of each scan line using robust least square method and finally the end points of

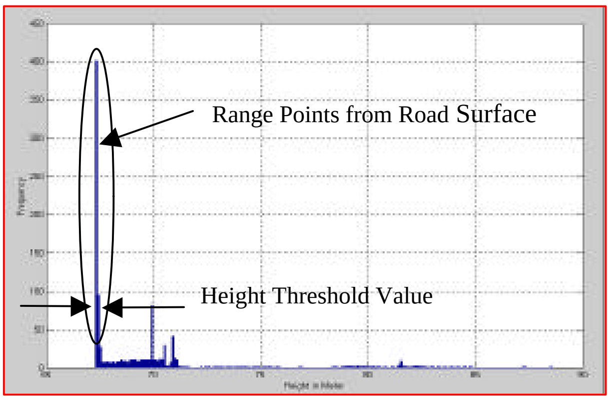


*Figure 5: Frequency analysis of height data*

the straight lines are used to create a 3-D road surface by creating a patch from a pair of neighboring straight lines. The results of road surface extraction are shown in figure 6(b).

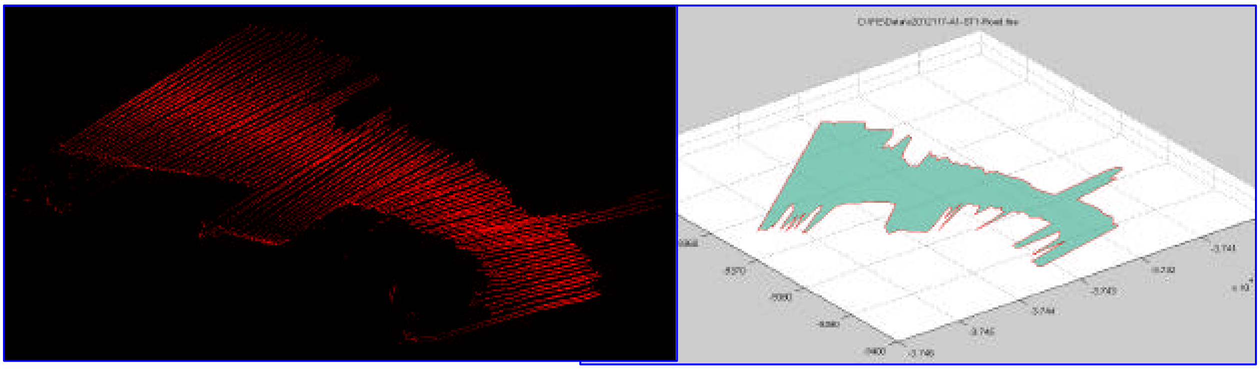

*Figure 6: (a) Selected range points from road surface (b) Road surface generated from straight lines fitted to points*

## 2.3 Scattered and Non-scattered Points Extraction

Extraction of building faces, trees and other features are done by separating scattered and non-scattered features. Points from natural features are scattered due to their irregular geometric shape, where as points from man-made features are generally not scattered as they have certain geometric shape. In order to analyse the scatterness of the points in three dimensions, we use range distance analysis given by equation 2.

$$d = \left(d_{n+1} - \left(d_{n+2} - d_n\right)/2\right) \quad (2)$$

where, $d_n$, $d_{n+1}$ and $d_{n+2}$ are the distance from the sensor position to the n$^{th}$, (n+1)$^{th}$ and (n+2)$^{th}$ range points on a scan line. Figure 7 shows the result of the analysis. We can clearly see the scattered distance value from the trees and quite smoother values from man-made features like buildings, walls and roads. The analysis also gives us clusters of points. Every transition between the smooth value and scattered value indicates either different features or discontinuity in the same feature (in case of spike like transition) due to location of features at different distance from the sensor or due to partly occlusion. A threshold value of +/-10cm and at least ten range points in any cluster is set for identifying the range points as reflections from building surface or wall or any other flat surface either vertically or horizontally oriented with respect to the sensor scanning plane. In order to classify each cluster into building surface or wall or ground surface like pavement (footpath), we have analysed the standard deviation (SD) of every cluster of points. The standard deviation analysis of X, Y and Z directions (coordinates) are done separately. Our hypothesis is that, points from building surface will have much higher SD value in Z-directions compared to X and Y directions. Similarly, a ground surface like footpath will have much higher SD value in X or Y direction compared to Z direction. Trees exhibit high SD values in all the three directions due to their scattered nature of range points. Various threshold values are set for the classification of features into building face points (points from vertical faces), ground feature points (points

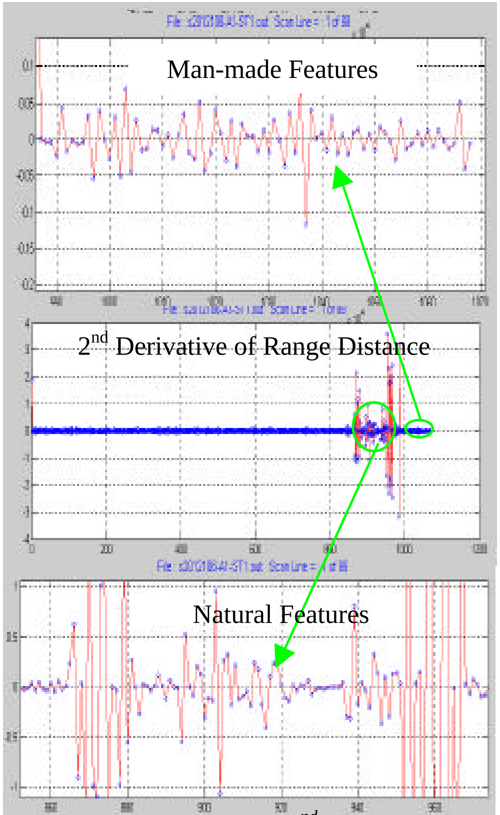


*Figure 7: Analysis of 2$^{nd}$ Derivative of Distance of range points for a scan line*

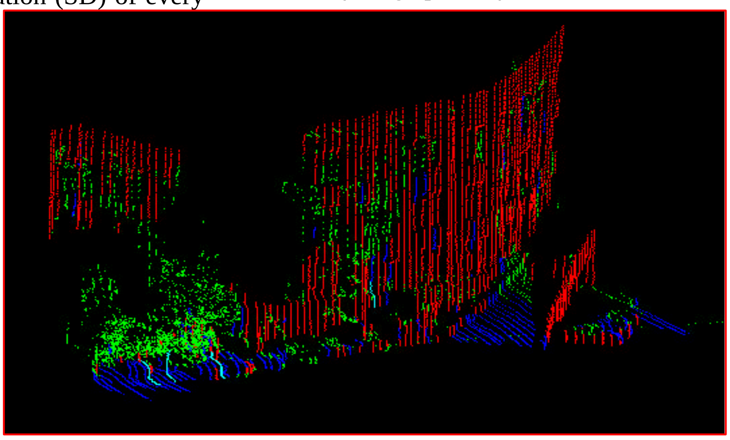

*Figure 8: Classification of laser Points. Red – vertically aligned points, Blue – Horizontally aligned points, Green – Trees (scattered points)*

from horizontal faces), points from trees and mixed classified points. The results from the pre-processing algorithm are quite promising for further successful classification of features. Figure 8 shows the result of the classification. Some scattered points (green color) are mis-classified into trees class though the points are actually from the building. The laser can pass through the glass in the windows. In this case, the laser points are reflected from the inner objects of the building and hence we get scattered points.

## 2.4 Building Face extraction

In order to extract building faces from range points, we have taken only the points that belong to vertically aligned points group, shown in red color in figure 8. These are the output of the extraction of man-made and natural features. Straight lines are fitted to vertically aligned points using robust least square method. The data analysis is done scan line by scan line basis. After fitting the line to each group of points, direction vector of each of the fitted line is computed. Beginning, from the first scan line and the first line segment, angle and distance between the lines to all the line segments in the next scan line are computed. This process is continued for all the line segments and a line connectivity table is created. The line connectivity table indicates which straight lines should be used to form a building surface. The result of this process is shown in figure 9. There are empty spaces in the 3-D model created for the building surface. This is due to the absence of laser point data on those areas either due to presence of windows or scattered data. The algorithm needs further improvement to cover these empty areas.

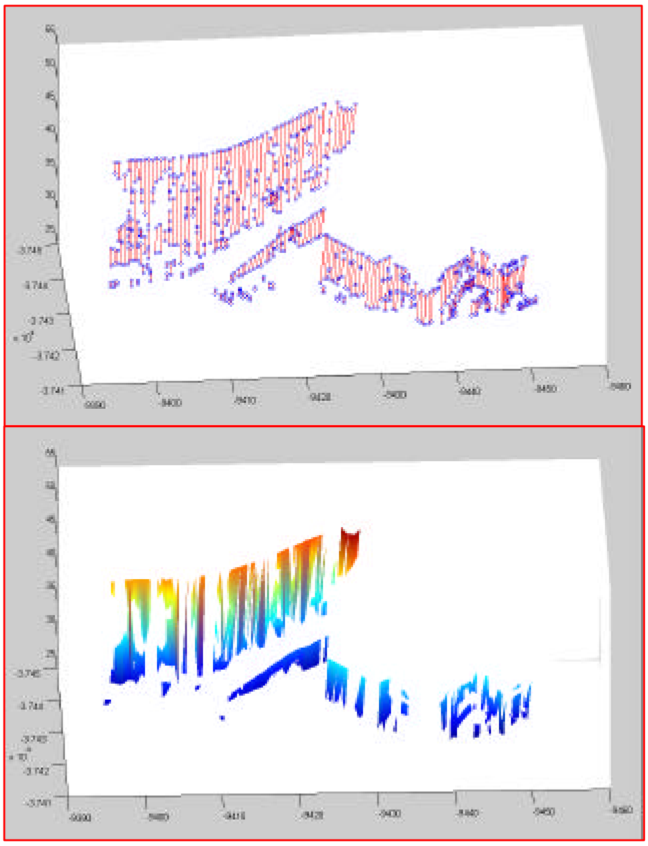

*Figure 9: Top : Straight line fitting to vertically aligned points, Bottom : 3-D patches created from line data*

## 2.5 Pole Extraction

The extraction of utility poles is based on the following assumptions:

1. The utility poles generate independent straight lines
2. The poles are nearly vertical
3. The poles have a minimum height
4. The bottom of the pole should not be above the road surface.
5. The pole should be in front of the building or wall surface

The above assumptions also impose the limitation on automated extraction of poles. Assumption 1, limits the extraction of poles if they are just next to the building or wall surface. A threshold distance value is set to identify independent straight lines. The independency of the line is tested by computing the vertical center distance between the lines. A threshold value for tilt angle is set to identify whether the line is vertical within the tilt angle or not. Sometimes, the bottom portion of the pole is hidden by plants or smaller objects. In this case only the upper portion is captured. Thus another threshold value is set to check the location of the bottom portion of the pole. If the bottom portion of the pole is above certain height from the road level, it is selected as a pole but with a question mark in

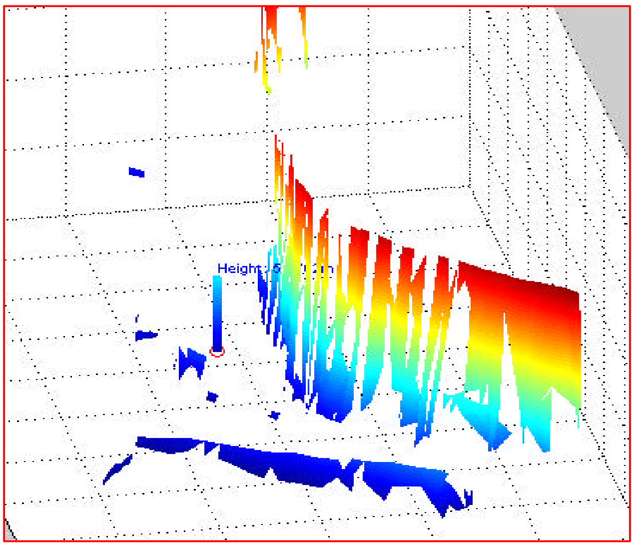

*Figure 10: Extraction of Pole. This data has three poles but only one could be extracted as the other two are next to the building surface.*

database. This needs a manual look at the data (image) and hence the decision is to be made manually. The laser data may or may not contain points reflected from the poles. The pole object is usually smaller (in terms of diameter, a few centimeters) and the capture of these smaller objects depends on the vehicle speed. The vehicle speed determines the along track resolution of the laser data. We have captured poles when the vehicle is driven at about 30 km/hr (along track resolution is about 40cm). When the vehicle is driven at 80km/hr, very few poles are scanned. Figure 10 shows the result of pole extraction.

## 2.6 Tunnel Extraction

Tunnels are extracted by visually analyzing the data at the moment. A look at the laser data can clearly indicate the portion of the tunnel in the data as this portion of data are more or less homogeneous except a few points reflected by some objects inside the tunnel like guard rails. Figure 11 shows point data of a portion of tunnel and it's 3-D mesh surface model.

# 3 CONCLUSION

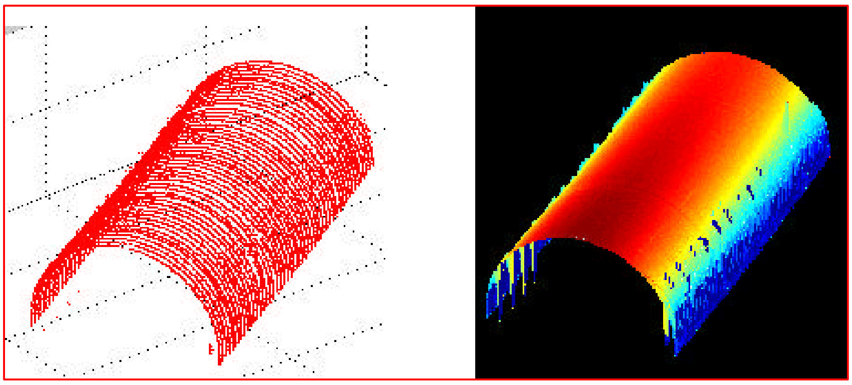

*Figure 11: Extraction of Tunnel and it's 3-D mesh model*

We have developed some algorithms for the extraction of features or classification of features from range data. The features include road surface, building surface, trees (classified as scattered points), utility poles and tunnel. The algorithms for road surface and pole extraction are satisfactory. Building surface extraction algorithm has to be improved to fill up the empty spaces. Trees have to be modeled for 3-D visualization. The number of polygons should be minimized without affecting the actual shape in modeling the tunnels. The future work includes the development of algorithms for extraction of static and dynamic features like parked and moving cars, extraction of cables and other utility and traffic facilities.

We feel that 3-D data generated from this type of mobile mapping system in future will supplement for development of 3-D GIS database.

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