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Road Environment Situation Detection Based on 2D LIDAR Sensor

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Abstract

Road situation detection system plays a significant role for many vehicle safety systems. The application of intelligent vehicles relies on various data of obstacle detection system. In the field of automotive era safety, the object detection methodology becomes the largest research area recently. According to its definition, intelligent vehicles present the ability of updating their maps based on various sensory inputs and permitting the vehicles to track continuously its position. However, conditions changes or when they arrive in unexplored environment, the intelligent vehicle have the capability of protecting its occupants. Road environment detection method is among of the most significant research fields in ITS (Intelligent Transportation System), and ALV (Autonomous Land Vehicle) recently. The analysis of road situation demands not only obstacle information at the present time but also provide a prediction of obstacle information at the future time. In fact, a skilled driver looks various seconds along the road and reacts accordingly. On the other hand, road preview methodology is very useful in control of suspension system and the driver assistance. The road preview is very important in accident avoidance since vehicle dynamics limits the vehicle in making speed or direction changes. In this paper the road model is composed by one bump and LiDAR sensor mounted on the car near the rear wheel. The model has been modeled in PreScan software and invoked in Matlab/ Simulink for analysis, the results from data analysis showed that the LIDAR sensor is able to detect the vertical road irregularities.

Keywords: *2D Lidar sensor, Road detection system, PreScan model.*

1. Introduction

LiDAR as it is named LiDAR is considered an abbreviation of Light Detection and Ranging (also called LIDAR, LiDAR, and LADAR) is an approach of survey that utilized to measure distance to reach the target by lighting up that target with a laser light[1]. The conception of LiDAR technology started in the 1970s, with early systems built in the USA and Canada [2]. Later in 1980s, LiDAR technology has been implemented in aircraft at to determine accurate models of terrain. The use of the technology in early years was blocked by its cost efficacy, complexity and poor geo-referencing. LiDAR devices are unique in that they take the consistent light energy within a very narrow beam, which generates pulses of very high peak intensity[3, 4]. The blue-green wavelength of LiDAR admits the penetration of clear moderately turbid coastal waters for bathymetric measurements and enables mainly near-infrared LiDAR to survey gaps in forest grasses to generate topographic map data for digital elevation models. In surveying geographic maps, LiDAR measurement systems use an exact clock that records the round-

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tour path time between reception of a reflected beam and the transmission ones [5]. LiDAR sensor is based on timely transmission light beam and reception of reflected light beam. According to operation principles, we find two models: pulse time-of-flight ranging and pulse time-of-flight ranging. As it is shown in the Fig. 1 below, in both systems LiDAR instrument is composed by transmitter and receiver. The transmitter transmits the narrow laser light. If the beam strikes an object, part of the incident beam energy is reflected, as demonstrated by the red arrows displaying a hemispherical radiation style. The receiver is situated near the laser; it is an optical system that takes the energy radiated back from the target object[6].

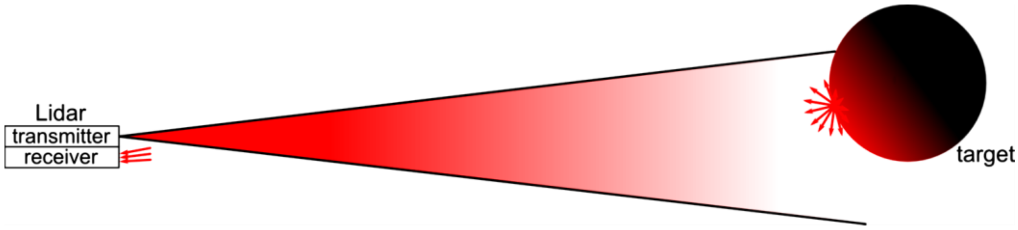

Figure 1: Operating principle of LiDAR sensor

The acquired signal is then processed to calculate the angle and distance from the LiDAR to the detected point of object. To process the range, the power of measured signal should be strong enough. In special case, the specific power ratio (SPR) is a useful number that characterizes which part of the emitted power is received per unit area at the receiver. The Specific Power Ratio (SPR) is important number for systems engineers to size the LiDAR. In the way from the transmitter to the target object, the light beam is diffusing with a lower angle (in the Fig. 1) above this angle is drawn much larger than a practical light beam sh). As the spreading is wide it provokes the reduction of laser intensity, if the distance increase the intensity become lower and it is denoting as geometric loss. The medium through which the light travels might assimilate or spread the light which presents a way loss that augment with the distance to the target. Table 1 shows the RP LiDAR specification.

Table 1: RP LiDAR specification

Specification	Range
Distance range	0.2-6 m
Angular ranger	0-360°
Distance resolution	<0.5mm (1% of the distance)
Angular resolution	=<1°
Sample duration	0.5 ms
Sample frequency	>= 2000 Hz
Scan rate	5.5 Hz
Laser wavelength	785 nanometer
Laser power	3 mW
Pulse length	110 µs

LiDAR sensors are categorized into 2 types based to its application, terrestrial and airborne LiDAR. Airborne LiDAR scanning is applied when a laser scanner, while mounted to an aircraft during flight, generates landscape model in 3D. This application approach replaces old method of photo grammetry recently due to its high accuracy and ability to generate digital elevation models. One big benefit in comparison with photogrammetry is the capacity of detection of vegetation from point cloud model to generate a digital surface model which demonstrates ground surfaces such as paths, rivers cultural touristic area[7]. Terrestrial scanning of LiDAR is applied on the planet surface it can mobile or fixed. Fixed terrestrial scanning is mostly utilized in surveying applications, such as monitoring, classic topography, forensics and cultural heritage documentation. The 3D point clouds generated from terrestrial scanner remain the same compared with the digital image taken from the scanned area in location scanned. Compare to other technologies 3D model are provided in short time. Every point in the point cloud is provided the color of the pixel from the picture captured situated at the same angle as the laser light beam that generated the point[8].LiDAR devices are classified two main categories based on detection system and the way beams are transmitted; two dimensions LiDAR (2D) and three dimensions LiDAR (3D). In this study 2D RPLIDAR sensor developed by Robopeak, has been utilized to detect road surface irregularities as it is shown in Fig.2, below.

Figure 2: RPLIDAR sensor

RP LiDAR sensor is based on its low cost RPLIDAR 360° Laser Scanner is a good choice for 2D scanning LiDAR system. It operates 360 degrees laser scanning area detection range of more than 6 meters. Generated 2D point cloud data can be utilized in localization mapping and object environment modeling. RPLIDAR transmits modulated infrared laser signal and receive the reflected laser beams of object to be detected, the received beam signal is withdrew by RPLIDAR vision acquisition and the DSP embedded in RPLIDAR commences the processing of sampled data, output values are angle and distance between the RPLIDAR and the object The processed of data are outputted through a serial communication interface[9]. Tracking and detection of moving objects is a significant duty in autonomous vehicle and mobile robotics. The main benefits of RPLIDAR the way it transmits the light thus it operates independent of the ambient light. Day, night, or sunny, clouds unlight or shadows, it shows the same and best result in all conditions. RPLIDAR has a higher operation resolution than radar device and robust against interference.

2. Object detection methodology

Laser range scanners have been utilized to detect obstacle in many years ago, especially for navigation in harsh terrain. Laser range scanners work by scanning a laser over the area desired to measure, at each pixel, it takes a time to emit and receive data to the sensor. As the velocity of light is known, the distance to each pixel can be computed. Many laser range scanners also generate the intensity of the reflected signal at each pixel[10]. The brightness contradiction between vertical surfaces horizontal can be devoted in two coefficients, range and incidence angle. Suppose the spreading element of the laser reflection is plane surface, the laser reflectance beam is calculated with the equation below:

$$P_{return} \propto (\rho\cos\theta/z^2) \tag{1}$$

Where P return is defined as power in the reflectance laser pulse, ρ defines the actual surface reflectance (0≤ ρ≤0), θ denotes incidence angle of the beam with the surface and z is the range.

In this Fig. 3 suppose vertical object has the shape of square corners, θ angle varies between 0 and 45 degrees according to the rotations of the vertical z-axis. For horizontal surfaces at distances over 20m, however, θ can be varies between 87 and 90 degrees and should provide smaller return. Additionally, in the same scan line the points which hit the obstacle must be closer compare to the points of road surface. In some case, where the sensor beam is situated in parallel and obstacle height to the road surface, laser intensity must be non-zero only on obstacle pixels.

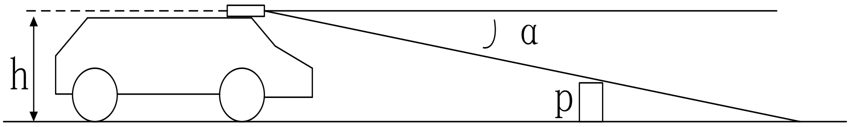

Figure 3: LiDAR sensor placed on the top of the vehicle

As indicated in Fig. 3 particularly, when the sensor is situated at a height h, with depression angle α, supposing a flat road, the expected road pixels to reflect intensity:

$$I_{road} \propto (\rho_{road} \sin^3\alpha / h^2) \tag{2}$$

Meanwhile, if the laser strikes a vertical obstacle of height p, the reflected intensity is expected as follow as:

$$I_{obs} \propto (\rho_{obs} \sin^2\alpha \cos\alpha / (h-p)^2 \tag{3}$$

Suppose road reflectance surface and obstacle are comparable, in the other word $\rho_{road} \approx \rho_{obs}$ Thus typical sensor height of 1m, obstacle height of 20 cm, and sensor depression angle of 1 degree it means that the LiDAR sensor is aimed at a typical look ahead distance of relatively 60 meters away the result showed that I_{obs} double greater than I_{road}. The big compromise between intensity is mainly based to the difference in the incidence angle. However this compromise between intensity is minimized significantly for harsh surfaces, it has nevertheless proven sufficient for detecting many non-lambertian obstacles[11]. Ensuring that road coverage present big advantages in obstacle detection mechanism. The scanning process must be frequent in order to make sure that all objects located in field of view are detected. Indeed, if coverage is not enough in a road environment, the detection system can sometime detect objects like retro reflector in the road and airborne debris or rain. To minimize the labeling variation these bright spots as obstacles, it is necessary to oversample, that is to sample more frequently than necessary for ensuring coverage alone. The over estimating factor is the number of scan line in which an obstacle of low height p will be shown. If vehicle is being driven at speed v, and getting line scans at a frequency f, hence, the oversampling factor n is

$$n = pf/(v \mathrm{tang}\alpha) \tag{4}$$

3. Model in PreScan environment

PreScan is a physics-based simulation platform which is based on sensor technologies like, LiDAR, GPS, camera and laser. It is utilized in the automotive era for development of Advanced Driver Assistance Systems. It is also widely utilized for designing, vehicle dynamics safety control, monitoring and evaluating vehicle-to-vehicle (V2V) model and vehicle-to-infrastructure (road, building) communication applications as well as intelligent driving applications. PreScan can be utilized from model-based controller design model in the loop (MIL) to real-time tests with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) systems[12]. The Fig. 4 indicates the road model in PreScan.

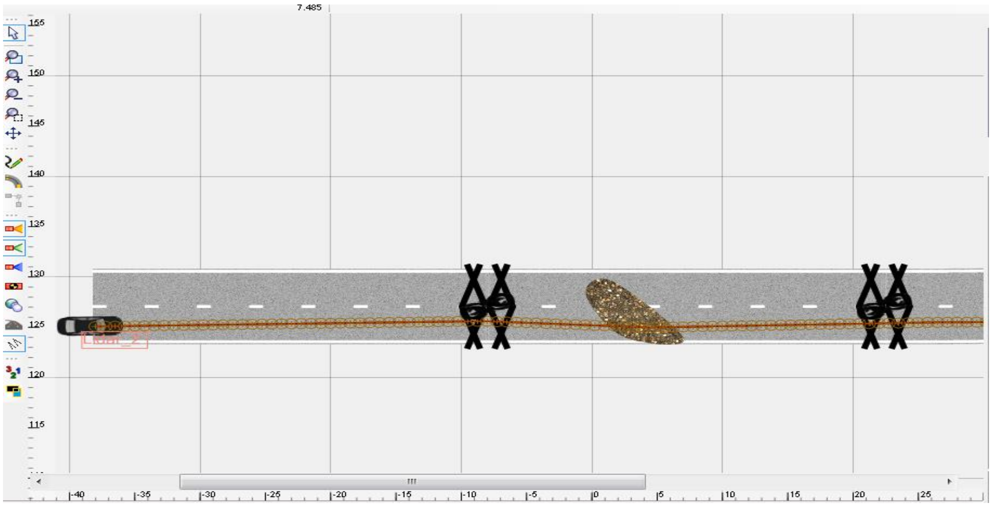

Figure 4: PreScan road model

Figure 5: PreScan road model view

As it is indicated in the Fig. 6, the PreScan model is composed by road, with bump, vehicle and LiDAR which is mounted on vehicle near the rear wheel.

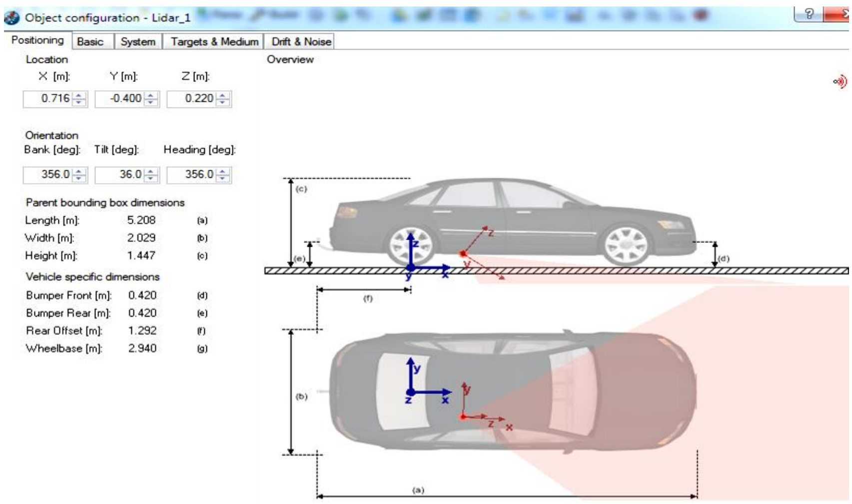

Figure 6: LiDAR sensor position on the vehicle

The position of LiDAR sensor on the vehicle is important in receiving the accurate raw data of the sensor. On this research project the LiDAR has been placed near the rear wheel, as it is shown in Fig. 6 in order to get the real data of situation of road. The road disturbance objects like, bumps, small holes, potholes and any kind of disturbance will be detected, before the tire passing through. The position of the sensor before the rear wheel shows a great potential to monitor the road profile via LiDAR sensor.

4. Road model in PreScan environment

Raw data of LiDAR sensor shown Fig. 7 and table 2 obtained from PreScan model are invoked in Simulink software and performed in various vehicle dynamic models as road excitation input.

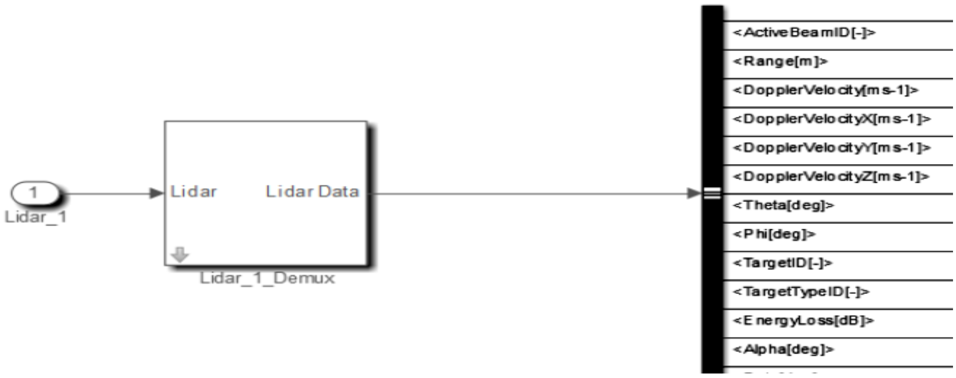

Figure 7: PreScan raw LiDAR sensor data representation in Simulink

Table 2: Description of LiDAR data

Signal name	Description
Active Beam ID	ID of the beam in the current simulation time step
Range[m]	Range at which the target object has been detected
Doppler Velocity [ms^{-1}]	Velocity of target point, relative to the sensor, along the beam
Doppler Velocity X/Y/Z [ms^{-1}]	Velocity of target point, relative to the sensor, along the beam, decomposed into X, Y, Z of the sensor's coordinate system
Theta[deg]	Azimuth angle in the sensor coordinate system at which the target is detected
Phi[deg]	Elevation angle in the sensor coordinate system at which the target is detected
Target ID[-]	Numerical ID of the detected target
Target Type ID[-]	The Type ID of the detected object
Energy Loss[dB]	Ratio received power / transmitted power
Alpha[deg]	Azimuthally incidence angle of LiDAR on the target object
Beta[deg]	Elevation incidence angle of LiDAR on the target object

To analyze the data given by LiDAR sensor, two parameters will be used: range (r) and theta angle (θ).Road profile in PreScan is calculated based on equations below

$$Z_{road} = r * \cos(\theta) \tag{5}$$

$$X_{road} = r * \sin(\theta) \tag{6}$$

Where Zroad denotes the road heights, r defines the range at which the target object has been detected, Xroad denotes road distance. Fig.8 shows the simulation results.

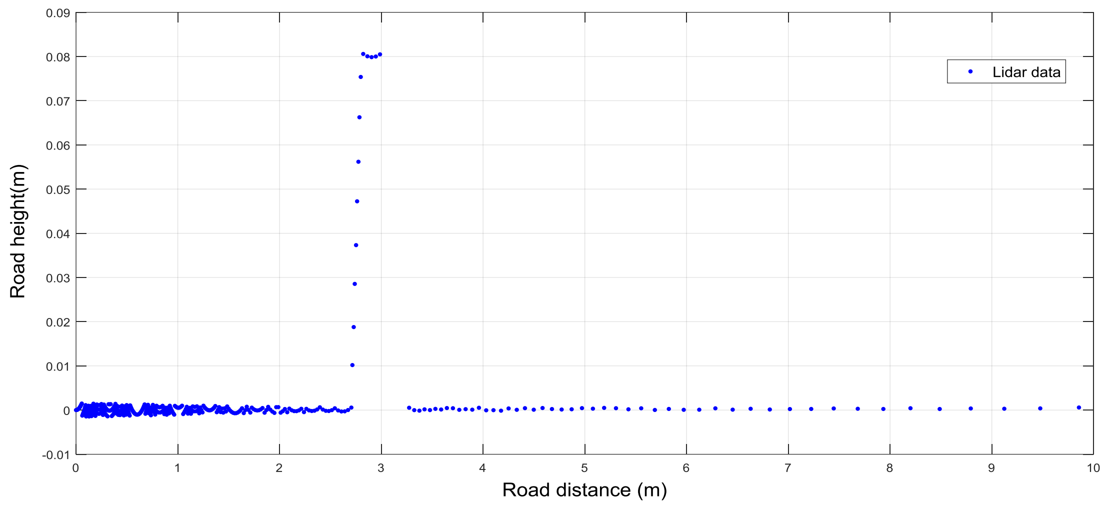

Figure 8: PreScan LiDAR sensor road data

By using curve fitting of data points the road profile is obtained as it is indicated in Fig. 9 below.

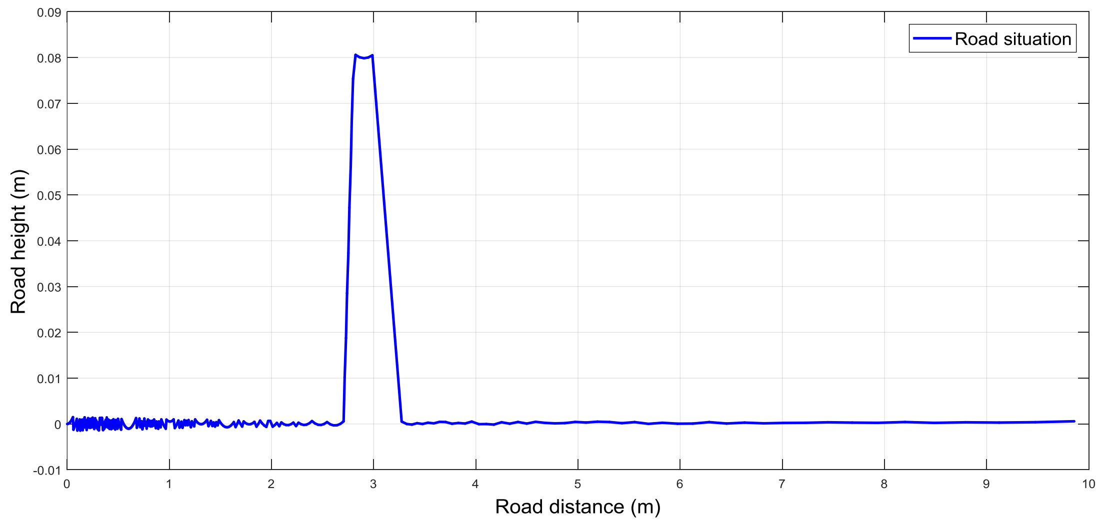

Figure 9: Road bump in PreScan

5. LiDAR data acquisition

To make LIDAR operation, wiring must be connected to communication interface of host system (microcontroller or computer). LiDAR sends the data via TX communication Port and Receive data via RX port as shown in Fig.10. The data are sampled continuously. Host system gives command to the LiDAR to configure the operation of the sensor, for example checking the health of sensor, start scanning, stop scanning, by sending different package of hexadecimal data as it is shown in the table 3 below.

Table 3: Hexadecimal LiDAR data package

Action	Hexadecimal package
Scan	0x20
Stop	0x25
Reset	0x40
Force to scan	0x21
Get information about LiDAR sensor	0x50

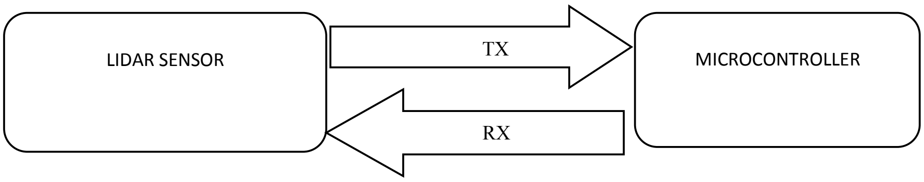

Figure 10: Serial communication protocol

The microcontroller sends data package commands through serial port. When the data are sent, LiDAR sends backs a package of bytes corresponding to range of object and the angle of reflectance beam. If the start string is successfully transmitted, the sensor will begin spreading data through RS232. The sensor transmits data sequentially as the scans through 180°. It means when the LiDAR is configured to scan 180° with resolution of 0.5° the first data point which was sent will correspond to 0°degree, the next will equal to 0°, degree plus resolution angle 0.5°, the following will be 1°, and so on. This means that the resolution serves as range of scan. Every range data measured is sent in the form of two bytes. The measurement unit of are mm for distance and degree for angle. The code in Fig.11 is based on data acquisition from LiDAR sensor; it has been developed in codewarrior software, the output of code is the distance to obstacle and azimuth angle of object and reflectance beam.

```
#include  "robopeak.h"
void turnto(rplidar_response_measurement_node_t t[],unsigned int c){
  unsigned int i;
  for(i=0;i<c;i++){
    if(t[i].distance_q2!=0){
      //angle[(unsigned int)angletmp]=angletmp;
      distance[(unsigned int)((t[i].angle_q6_checkbit>>1)/64.0f)]=(t[i].distance_q2)/4.0f;
    }
  }
}
void clean(void){
  unsigned int s;
  for(s=0;s<MAX_SCAN_NODES;s++){
    local_scan[s]=cleaner;
  }
  for(s=0;s<MAX_BUF_NODES;s++){
    local_buf[s]=cleaner;
  }
}
Bool cmd_scan(void)
{
  scisend(0xA5);
  scisend(0x20);
  return(TRUE);
}

Bool cmd_stop(void)
{
  scisend(0xA5);
  scisend(0x25);
  return(TRUE);
}

Bool cmd_health(void)
{
  scisend(0xA5);
  scisend(0x52);
  return(TRUE);
}

Bool cmd_info(void)
{
  scisend(0xA5);
  scisend(0x50);
  return(TRUE);
}
```

Figure 11: Serial communication codes

Conclusion

This paper has illustrated the road detection methodology using LiDAR sensor, type of LiDAR sensors, specifications and data acquisition approach. The road model is composed by one bump, LiDAR sensor and car have been modeled in PreScan software then, invoked in Simulink for data processing. By applying the data acquisition methodology, the results of PreScan scan model showed that LiDAR sensor performs well in the detection of vertical road surface. The data gotten from this model can be utilized in suspension of vehicle to predict the shock absorber the road environment (bump, pothole and road irregularities) or warning the vehicle driver about the road environment.

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