# AC 2011-2100: THREE DIMENSIONAL SURFACE MODEL_FROM_LASER_SCANI OF PROVING GROUND ROAD

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# Three Dimensional Surface Model from Laser Scanning of Proving Ground Road

**Abstract:** This project goal is to creating a 3D surface model from scanning of an existing road proving ground for vehicle testing. The road surface has several different kinds of deviation features intended to test the vehicle for its stability and durability. An innovative laser scanning system, with two laser measurement sensors, has been designed, built, and used for this purpose. The two laser scanners, working in two mutually perpendicular planes XZ and YZ, scan and record distances and angles to the surface. This measured data is converted to a 3D point cloud data set using a scan matching algorithm. The point cloud data, thus obtained, is processed with special algorithms to construct the 3D model of the scanned road surface. The resulted precise 3D model of the road surface can be used for virtual simulation of the vehicles' performance and accelerated test. Education impact of this project is usage of the created model for simulation of the testing vehicle in automotive laboratory and research activities.

**Keywords.** three dimensional road model, road profile, laser measurement scanners

## 1. Introduction

Most of the automotive companies perform accelerated testing of trucks and cars in extreme condition, driving them on proving ground (Bosch, Ford, Chrysler, etc.). Durability roads used for testing the vehicles contain so called surface events, such as inverted bumps, cobblestones, resonance and undulating roads, chatter bumps, sine wave road; in addition there are gravel and cross-country roads[1]. This setup allow in short time to complete accelerated millage accumulation testing of the vehicles in worst case road condition. The cost of testing and failure rate is very high and results are difficult to predict before actual vehicle is tested. As a result there is increase in cost for redesigning and manufacturing of tested vehicles in case of failure.

We proposed a system for measuring and building of the three dimensional (3D) model of existing proving ground to be used for accelerated testing together with simulated models/environment of the vehicle. Although the model of the road can be simply designed as 3D model, the one created from scanning of the real proving ground will give results closely correlated to the actual driving condition.

There are numerous research and development dealing with road surface measurements. National Optics Institute created and inspection of the road surfaces with the laser scanners[2] that can measure 3D road profiles and a crack map of an actual pavement section. Another approach is digitizing of the road surface using multiple sensors[3] (3D laser-range sensors, video cameras, global positioning, GPS, and inertial measurement units). 3D road digital reconstruction from stereo images[4] or monocular video camera[5] have been used to build road maps or geometry of the roads. Some researches approaches generate road parameters (width, center line, etc) using available databases of laser scanning and terrain profile from public sources or commercial map providers[6]. All those surface measuring systems are suitable for normal road condition, but could not provide accurate scanning for proving ground. On the other hands there are many commercially available 3D scanners and coordinate measuring machine (CMM) used in industry that can scan with high accuracy and precision. They can only be used within the device work space and the speed of scanning is extremely slow. Handheld/portable scanning systems comprise similar limitation[7]. There are also companies that provide road surveying services for cracks, distress, rutting, and roughness of the road surface. The data and measurements are image based and does not have real 3D measuring values. In conclusion the existing systems cannot offer precise measurement to be used to create 3D surface model of proving grounds.

There are laser based systems exploited to create urban road models by scanning the horizontal and vertical profiles. These scanners were triggered with the odometer. For this purpose, the assumption made was that the two scanners are always in the same horizontal plane which is not correct[8]. The bumps, ditches make the vehicle vibrates, moves up and down so much that the data collected is inaccurate in road cross-section direction of measurements. The automobile odometers, used to measure the distance alongside the road, are not precise to the extent of the laser scanners. This is the reason that for this research project we design a system, with two laser scanners that use a reference plane created by the rail guides physically set on the ground, outside of deviation of the events.

Usage of two set of high speed laser scanners have been proved in various applications to provide adequate precision and speed. For example, measuring of objects and determine their position, monitoring the areas, detect the obstacles, etc., played a major role in the developing an vehicle guidance system for the autonomous ground vehicles competing in DARPA grand challenge; this allowed successful moving vehicle autonomously for 132 miles over desert terrain[9]. Similar system implemented for Google driverless cars is using multiple sensors: radars, video cameras and laser scanners[10] (LIDAR). Both these system allow unattended driving with main goal to travel to designation by avoiding obstacles using sensor and advanced computational algorithms. While the accuracy of measurements is sufficient for driving purpose it is not accurate enough to be used for precise modeling and building of 3D surface road models. In the case of the proving ground there is a requirement to achieve a high fidelity of the models and simulation so the evaluation results are as close as possible to the real situation. In case of fast moving objects over the ground, such as vehicle tires, even fraction of the inch movement can cause significant bouncing and vibration of the car body. Therefore our goal was to measure the deviations of the proving ground with maximum precision (+/- 5mm) achievable by the measuring with laser scanner. On the other hand, going to extreme higher precision would result to very slow rate of measurements, thus optimal speed and precision was the goal of this project.

## 2. Design of the scanning device for proving ground

### *2.1 Proving Grounds events*

The Bosch Automotive Proving Grounds was selected as a testing track for measurements, evaluations, and results. Based on the actual measurements, we found that the test tracks events width is between 10 foot and 17 foot wide and has very uneven surface made for testing the trucks and cars. Each event of the proving ground tracks is built for specific purpose and provide different load on the testing vehicle.  For example, frame twist bump is an event used to test the vehicle for the deflection in the frame. Such events are: staggered bumps, shown on the Figure 1, and impact bumps event, Figure 2, have same dept or high but are set at different distance. The cobble stones, Figure 3, provide driving conditions similar to river bed. Another section called the undulating road has undulating profile section alongside the road.

Figure 1. Staggered Bumps

Figure 2. Impact bump

Figure 3. Cobble Stones

*2.2 Design of measuring platform*

Proving ground has many event deviations. Therefore, to move the measuring scanner smoothly, related to a reference surface, the measuring platform wheels need to be outside of this uneven surface. Even if wheels move on the ground, out of the uneven surface, they still follow the surface terrain and irregularities; if there is a bump the wheel will go up and so will do the scanner; if there is a gap, crack wheel will go down as well. To create a perfect reverence plane for the measuring platform a simple rail system, placed outside of the measured events, was designed. It has two functions, first to provide smooth tracks that establish a reference plane, and second to provide guidance for smoothen, straight movement of the wheels and the platform.

A special measuring platform/trailer was designed and built to move the scanners smoothly over the testing track and measure and record data accurately. The trailer is light, yet rigid, easy to assemble and disassemble for transportation, and allow measurement of track with different width. Depending on the width of the event across the testing track the distance between the wheels is adjustable from 10.5 foot to 17.5 foot in the interval of 6 inches.

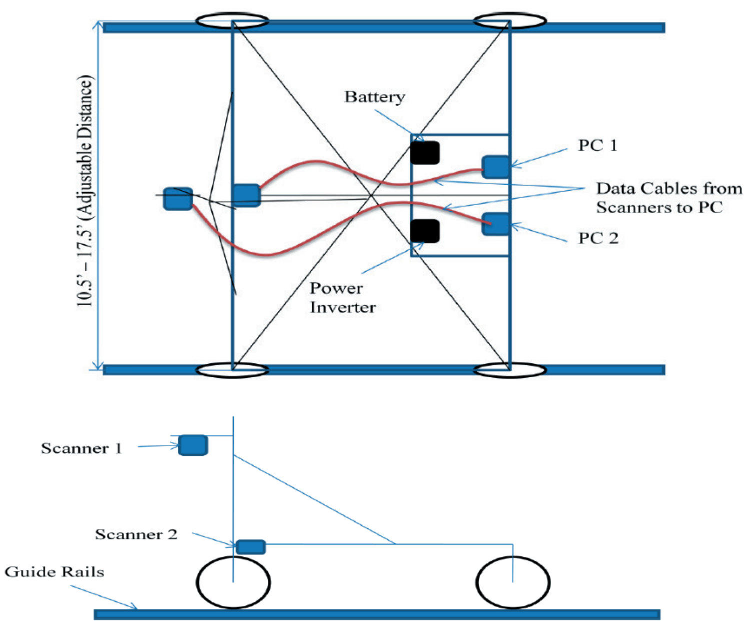


Figure 4. Trailer with scanners, rail and computers

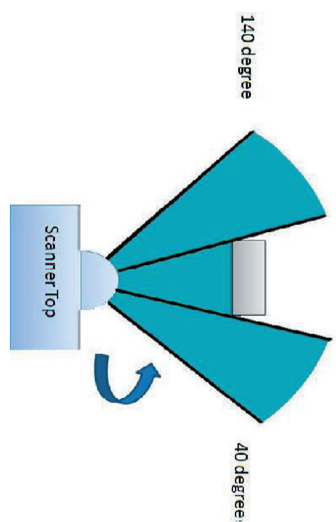


Figure 5. Scan span of 100 degree with resolution of 1/4 degree

The guiding, round profile, rails are placed on both sides of the road flat surface and four wheels with concave round profile ride on them. This set up provide smooth and steady motion of the measuring platform over the reference plane defined by the rail guide system, see Figure 4. Depending on the needs the guide rails length can be adjusted between 20 to 80 feet, alongside the road. It can be easily extended or shifted for longer road section, thus providing unlimited length of measurement. The guide rails system is light-weight, can be carried and adjusted by a single person.

There are two laser scanner fixed on the front side of the measuring platform. The first scanner, measuring across the track, is placed on an elevated platform supported by a triangular mounted structure on the trailer. This allows to increase the precision of scanning angles, so that even a 100 degree scan the whole width of the event can be covered. The height of the scanner from the ground is also made adjustable to accommodate scanner area for wider or narrow track, if needed. The second scanner, measuring alongside the track, is bolted to the frame of the trailer. At the back side of the platform, processing equipment (two computers-PC1 and PC2) and power source (deep charge battery with inverter) are set up in protective box, covered from elements. Both laser scanners are connected to the computers with data serial cables.

## 3. **Methodology**

### *3.1 Laser measurement system*

Two Sick laser scanners (LMS 291-S05) have been selected for scanning the road profile precisely. These scanners use a serial interface to communicate with the computers, which controls them and are uses the same time to record the scanned data.

These scanners have an angular resolution of a half a degree, when it is configured to measure 180 degree; angular resolution can be set to quarter degree when the scanner is configured to scan 100 degree (range from 40 to 140 degree). The former configuration yields 361 data points in a single scan while the later 401 data points. The pictorial representation of the scan angles is shown in Figure 5. Scanners have measurement distance resolution of +/ -5mm in the whole scan range of 180 degrees. The angular resolution of the scanner, which scans the cross sectional profile of the road, is set to 0.250 to get more data points and better precision.

### *3.2 Measuring Platform with scanners*

The measuring platform with both scanners, profiles of the scan lines for each scanner and directions are shown in Figure 6. One of the scanners on the trailer scans in the XZ plane across the trailer. The other scanner scans YZ plane along the length of the trailer, perpendicular to the track. After the system is setup in place and ready to scan, the two laser scanners are started simultaneously. Each scanner gives a reading every second. The measured data from the scanners is recorded in the computers. The pitch of the successive scans patches depends on the speed of the trailer. The speed of the trailer is maintained constant, depending on the accuracy needed.

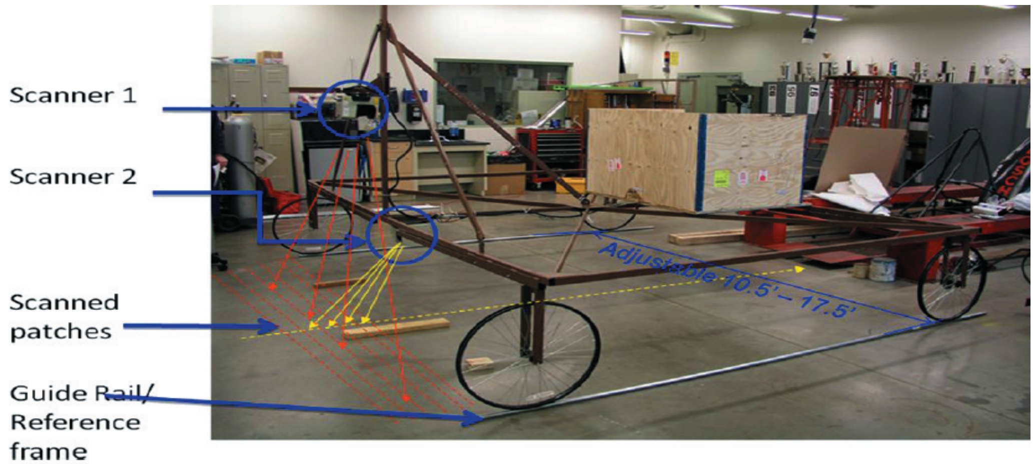


Figure 6 Trailer with scanners: adjustment and imaginary lines of scanned path

*3.3 Processing measured data*

Each of the scanners itself, provides 2D measurement of the road. Using scan matching algorithms these two 2D data sets are processed to 3D coordinate point XYZ or so called point data cloud when. This 3D data or the point cloud data set is filtered to remove the outliers. The data thus obtained is now processed to reduce the noise and errors.

Refined point cloud data is used to create mesh surfaces. A schematic flowchart the operation of the laser scanner measuring system is shown in Figure 7. Further this data and surfaces are processed to extract basic features, if obtainable. All regular features such as plane, cylinder, and cone can be extracted. In case of irregular surface the data is fitted to the spline surfaces. The type of the surface created is NURBS surface (Non-Uniform Rational B- Spline). Feature extraction gives a high quality representation of the road profile. Finally the desired 3D data format is obtained after solid model/3D surface translations/conversions.

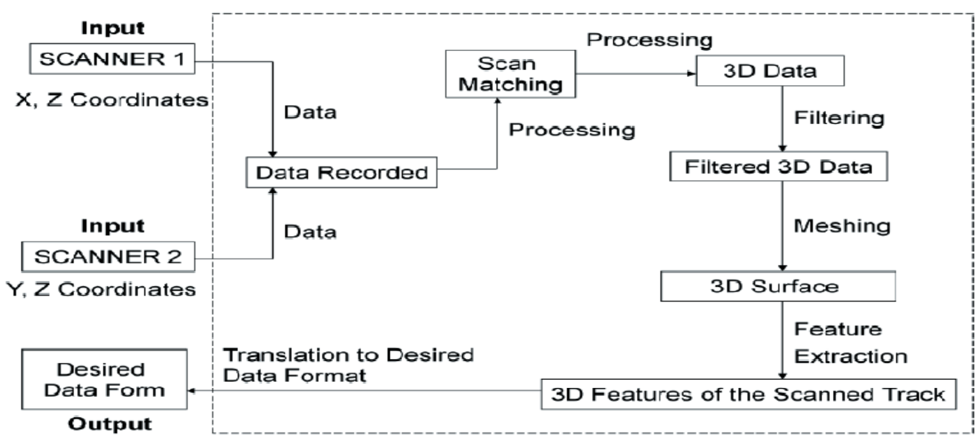


Figure 7 Schematic diagram of data process of road scanning system

## 4. Results and discussion

This section discusses the results obtained in the experiments performed. A few experiments were carried out in the indoor laboratory environment before the actual data acquisition was performed at the Bosch proving ground test site in New Carlisle, Indiana.

Initially, the system was tested in laboratory condition to optimize the procedures and verify the measured precision, see Figure 7 and 8. For example, three wooden planks were placed on the floor and scanned. Top surface planes and bottom plane were fitted using fitting procedure of CAD software CATIA, then a solid model was built by extruding the top surface to floor plane. To verify the accuracy of the measurement the distance between these two planes was measured and compared with the height of the wooden plank. The measurement results were excellent; the measurement precision +/- 5 mm was exactly the one specified by manufacturing company for the Sick lasers. Several other tests with unstructured events were performed and the result showed that the surface models obtained were very close to the tested surfaces. Thus our conclusion was that NURBS surface extraction from filtered data is the best way to proceed with actual measurements.

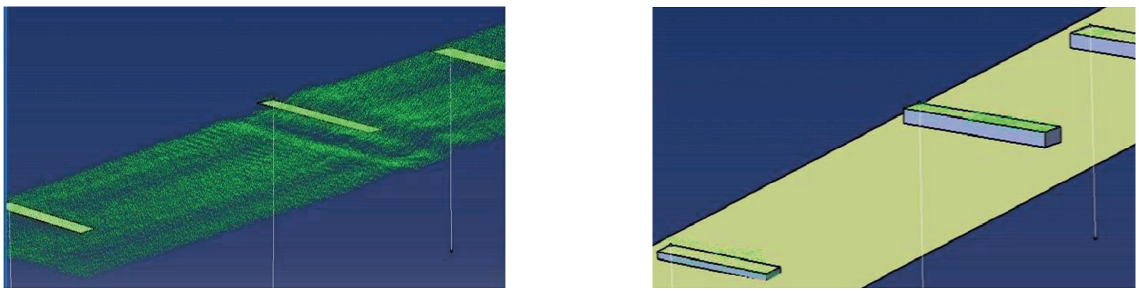

Figure 8. Recognition of top- plane of the wooden planks in the experimental setup (left)
Solid model of rectangular block feature extruded from planes (right)

Later, many scans were completed on the Bosch proving ground, altogether almost two linear miles of event of scanned data was obtained. Different event were scanned and surface models were acquired. For example, Figure 9 shows a section of the scanned cobble stone event. The length and the width of the event scanned are about 70 feet and 10 feet, respectively. The surface model built is in close agreement with the event scanned. The point cloud model in Figure 9 (left) is the filtered point cloud data. Filtered point cloud data is the data without the outliers and reduced noise. In most cases, there are a lot of redundant data and sampling allowing to obtain a precise model (right) of the scanned surface. The point cloud data show a number of horizontal empty places that indicate that the increased pitch as a result of either too fast speed of the scanner movement or scan matching capture has failed for the consecutive scans. As the process requires that the next scan data is compared to the previous data those irregularities are compensated. It is always preferred to have a small pitch value because it increases the quality of the data and the model based on these data.

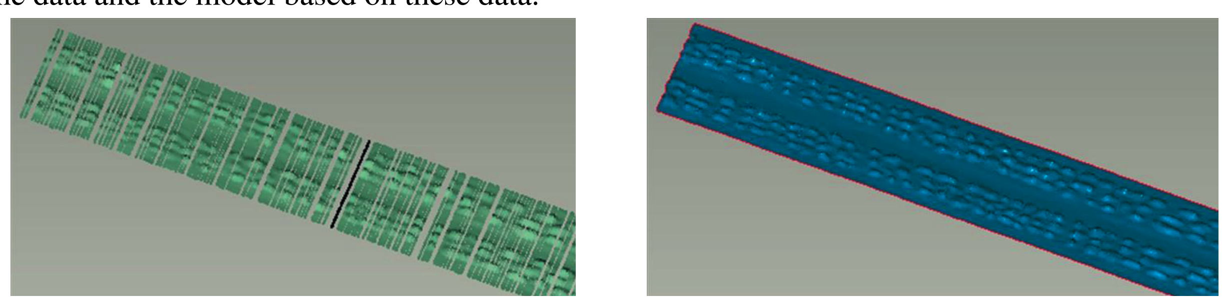

Figure 9 Point cloud data (left) and 3D surface model (right) at cobble stone event

The result of the section of the impact bumps event of the proving ground is given in Figure 10 shows. This scanned event is 12 feet wide and 32 feet in length. The height of the bumps is about one inch.

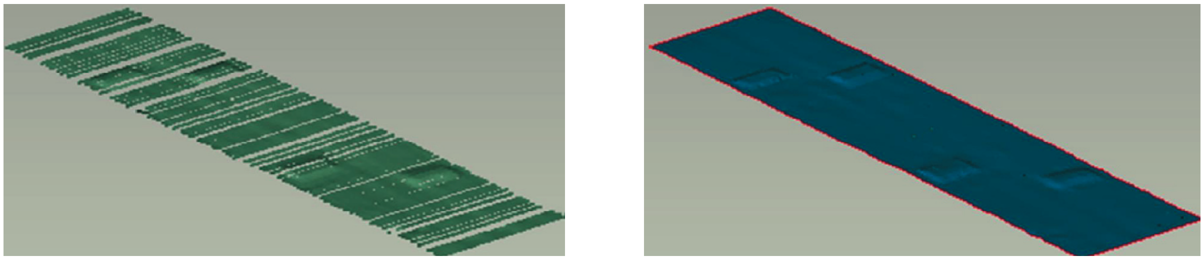

Figure 10 Point cloud data (left) and 3D surface model (right) at the impact bumps event

Another point cloud data set and the surface model of the staggered bumps event are shown in Figure 11. The event size is 11.5 feet wide and 45 feet in length. The bumps are 6 inches high. The staggered bumps are different from the resonance road and impact bumps. These bumps have a flat surface on the top and the edges are inclined to touch the road surface creating a smooth bump. This is the reason the bumps have better image quality.

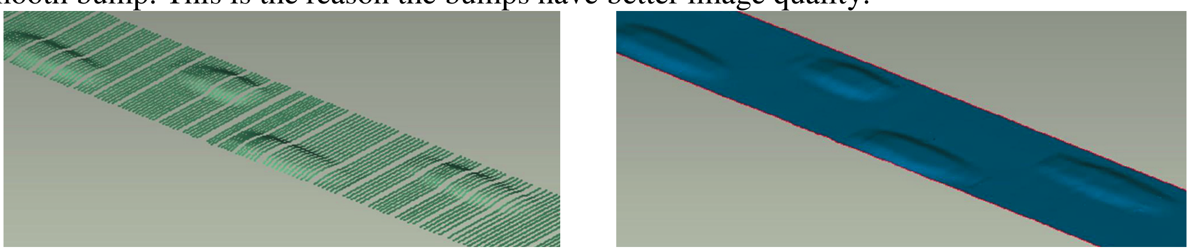

Figure 11 Point cloud data (left) and 3D surface model (right) at the staggered bumps event

In addition, inverted bumps and adulating road events were scanned. The inverted bumps are ditches with a depth of about 1 inch. The length of the event is about 50 feet and the width of the event is 13.5 feet.

As part of the project surface models were exported to simulation software and successfully used for accelerated testing of the vehicle performance. Further, using elevation values form GPS data, obtained mainly from Google earth, a 3D Google earth model was created and used for demonstration and presentation purposes.

## 5. Conclusion

The laser scanning system was successfully built and tested to scan and create the 3D road surface model from actual proving ground road. Specially designed algorithms were used to recognize and build the basic features, while for the more complex event surfaces, NURBS fitting was applied to create the surface model. The results show very close match between measured surfaces and the actual precision achieved by these measurements was found to be within the laser tools manufacturing specifications +/-5 mm. Created surface models were successfully exported to STL (stereolithography file format) and other 3D data formats including the one required by the simulation software used to test performance of vehicle on the proving ground. Future improvements could include obtaining of terrain, GIS, and GPS data alongside with data from the scanner system that will allow the terrain elevations to be added to the measured track 3D model and build a complete 3D model of the track. Education impact of this project is application of the created model for simulation of the testing vehicle in automotive laboratory and research activities.

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