AC 2008-2782: MEASURING AND MODELING OF A 3-D ROAD SURFACE

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Laser Scanning and Modeling of a 3D Road Surface

Abstract

The aim of this research is to create 3D model of an existing road surface and build with special deviation features used for vehicle testing. For the purpose of this project a special scanning system using two laser measuring scanner was designed and built. Data from the two laser scanners, scanning in two mutually perpendicular planes XZ and YZ are recorded and then converted to 3D point cloud data using the scan matching algorithm. From the measured point cloud data, the 3D model of the road is created by the application of special algorithms and data processing. This precise 3D model obtained can then be used for simulating and testing the vehicles’ performance, for their dynamic stability and durability.

Keywords. 3D Road surface model, road profile, laser scanning

1. Introduction

Digitizing of a road surface using images has been tried using multiple sensors [1]. There have been only few researches dealing with road parameters (width, center line, etc) using laser scanning and terrain profile from available databases from the public databases or commercial map providers [2]. There are commercially available 3D scanners and the 3D coordinate measuring machines that can scan individual objects. Though these machines can scan with high accuracy and precision, they are very slow and cannot they are limited to scan objects only within the volume of their workspace. There are several hand held/portable scanning systems that can be used for scanning objects, still they have limit volume range and are not suitable for extended range scanning such as road surface scanned [8]. Commercial companies which offer road surveying services provide data such as pavement distress, rutting, cracks and roughness of the road most of which is image based data [6][7]. To the authors knowledge there is no existing system that can scan and provide precise 3D surface model of the proving ground road surface.

Measuring with 2D laser scanners have been exploited in various ways by the researchers. They have been used to measure the objects and determine their position, monitoring the areas, detect the obstacles for the autonomous vehicles, etc. In addition, they have been used for collision control and have also played the major role in the vehicle guidance system. The laser scanners in this research are used to scan the 3D profile and create the 3D surface model of the road surface.

Two laser scanners can be used to create the 3D model of the indoor environments. The two scanners rotate continuously to record the data which was then processed to get the 3D model [4]. Though this research was able to create the 3D model of the indoor environment, it did not create the surface model of the floor. In another research two laser scanners have also been used together to explore the indoor and outdoor environments in addition to 3D mapping [5]. Similar system were exploited to create the urban model by scanning the horizontal and vertical surface profiles of surrounding buildings. 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 always valid [6]. The ride over bumps, ditches, etc., cause vibration tot the vehicle, as
well as unaccounted movements up and down, therefore the data collected contain errors and could not be used for small deviation. On the other direction of measurement, the odometers used could not meet the precision of the scanners. After analyzing the problems with the existing measuring system a new concept of measuring device moving on the reference plane created was designed and built for the current research.

This paper discusses an approach to create the 3D road surface model of the proving ground testing track with an accuracy matching the resolution of the scanner.

1.1 Building the laser scanner system

Two Sick Laser Scanners (LMS 291-S05) have been selected for scanning the road profile precisely. These scanners use the serial interface to communicate with the computer that controls it and uses the same to record the scanned data.

These scanners have an angular resolution of 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 1. Scanners have measurement resolution of +/-5mm in the whole scan range of 180 degrees. The angular resolution of one of the scanner which scans the cross sectional profile of the road is set to 0.25° to get more data points and better precision.

1.2 Testing track and trailer design

The proving ground testing track has events varying from 10 foot wide to 17 foot wide with very uneven surface made for testing the trucks and cars. An event is the section of the track that is built for some specific purpose. Ex. Frame twist bump is an event which is used to test the vehicle for the deflection in the frame. Figure 2 shows a couple of events of the testing track. The section of the track in Figure 2a is called the staggered bumps and the one in Figure 2b is called the cobble stones. These two are just a few of many events of the track. Each event of the track has varied height, depth and width. The widths of the events vary from 10.5 foot to 17.5 foot.
The testing track is not all flat surface that can be measured easily with conventional tools such as ruler, tape, etc.. One of the track has cobble stones as can be seen in Figure 2b, there is another section called the undulating road where the track has a undulating profile. There are several more sections each one having different deviation, shape and profile.

Figure 2a. Staggered Bumps

Figure 2b. Cobble Stones

For this reason, a special trailer was designed to move the scanners smoothly over the testing track and record accurate and precise data while scanning. The trailer built was light, yet rigid, easy to assemble and disassemble for transportation and the most important thing is that the distance between the wheels is adjustable from 10.5 foot to 17.5 foot in the interval of 6 inches. Depending on the width of the event of the testing track, the trailer is adjusted.

The two scanners are fixed rigidly on the trailer. The first scanner is elevated several feet above the ground and placed on a platform supported by a triangular mounted structure on the trailer, so that even a 100 degree scan can cover the whole width of the event. The height of the scanner from the ground is also made adjustable. The second scanner is fixed rigidly to the frame of the trailer.

The wheels move over the self-guiding rail guides. The rail guides are placed on the flat, smooth surface on the both side of the road profile which will allow steady motion of the trailer over the reference plane defined by the rail guide system. The guide rails are very light and can be carried and adjusted by single person, the length can vary from 20 to 60 foot long and can be easily extended or shifted for longer road section.

The trailer has a special box to accommodate and carry a car battery, a power inverter, two laptops and few tools for assembling/disassembling and those needed during the measuring process. The line diagram of the trailer set up is shown in Figure 3.

2. Methodology

Once ready to scan, the two laser scanners are started simultaneously and the data from the scanners is recorded in the computers. The scanner gives a reading once every second. The speed of the trailer is supposedly constant and depending on the accuracy needed, the speed is maintained. The pitch of the successive scans depends on the speed of the trailer. Figure 4 shows the picture of the trailer with the scanners and the profiles of the scan lines. One of the scanners on the trailer scans and records the data in the XZ plane or in other words, it scans along the
width of the trailer. The other scanner scans and records the YZ plane or along the length of the trailer.

![Figure 3. Trailer with scanners and computers](image)

Each of the scanners on the trailer gives the 2D information about the road profile, which when combined together using the scan matching algorithms gives the 3D data. Figure 5. shows the picture of the trailer with the scanners and the imaginary scan lines. 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.

![Figure 4. Trailer built showing the scanners and the imaginary lines of scanned path](image)
Refined point cloud data will then be used to create the mesh surface. This data is then processed to extract basic features if obtainable. All the regular features such as plane, cylinder, and cone can be extracted, while irregular surface are fitted to the spline surfaces. The surface created with splines is NURBS surface (Non-Uniform Rational B-spline). Feature extraction will give a high quality representation of the road profile. A schematic flowchart how the laser scanner measuring system operates is shown in Figure 5.

![Figure 5. Data processing diagram of the road scanning system](image)

3. Results from measurement and building of 3D model

This section shows the experimental results obtained by placing three wooden planks on the floor in the indoor environment. Figure 6 shows the multi-view of the imported scanned data. Figure 6a shows the close up view of one of the feature from the scanned data. Figure 6b is the top view of the raw scanned data. Figure 6c shows the side view of the same data and the Figure 6d shows the front view of the scanned data.

It can be observed from of Figure 6d. that the vertical faces of the plank look tapered. This is because of the way the scanner scans the data. Depending on the position of the feature, there are two possible outcomes of the vertical faces. The first outcome is that they are completely missing / invisible. The second possibility is that one side of the vertical face can appear in the scanned data as a tapered face while the other side remains hidden under the shadow of the top plane of the feature. This is corrected by using the feature extraction algorithms and other data processing methods. The next step is to extract the bottom feature or the plane itself on which the planks were lying. The floor or the bottom plane is extracted and has been shown in Figure 7c.
Next, the top plane is extruded up to the bottom plane to create the feature put up in the experiment setup. To verify the accuracy the distance between these two planes is measured and compared with the height if the wooden plank. The results were found to be satisfactory with the measurement accuracy between +/- 5 mm. This is shown in Figure 7d.

Figure 7a shows the filtered 3D data of the experimental setup. Nice smooth looking point data is possible after the noise and the errors are reduced.

As said earlier, only planes, cylinders, cones, spheres can be extracted; the top planes of the wooden planks have been extracted first and this can be seen in Figure 7b.
Figure 7. Scanning data processing and results
a. Isometric view of the scanned data, b. Recognition of top-plane of the wooden planks in the experimental setup, c. extracted top and the bottom planes, d. planes extruded to acquire the rectangular block feature.

Figure 8a, 8b and 8c show the result of measurements of cobble stones, chatter bumps and undulating surface structures. Those surfaces are measured in an indoor environment for the purpose of experimenting/testing the accuracy and capability of the system.
4. Conclusion

The laser scanning system built helped to create the 3D road surface model from actual road. The algorithms recognize and build the basic features while for the other features, NURBS have been implemented to create the surface model. This surface model created can also be exported to other 3D data formats including the one required by the simulation software’s to test performance of vehicle on the road. In the near future we will use GPS along with this scanner system that will allow us to add the terrain elevations to the track 3D model and build a complete 3D model of the track.
5. References

1. Si-Jie Yu, Sreenivas R Sukumar, Andreas F Koschan, David L. Page and Mogi A Abidi; 3D reconstruction of road surfaces using integrated multi-sensory approach; Optics and lasers in Engineering; Volume 45, Issue 7; July 2007; Pages 808-818

2. Carsten Hatger, Claus Brenner, Extraction of Road Geometry parameters from Laser Scanning and existing Databases, Proceedings of the ISPRS working group III/3 workshop `3-D reconstruction from airborne laser scanner and InSAR data’, Dresden, Germany, 8-10 October 2003

3. Oliver Wulf, Kai O. Arras, Henrik, Christensen and Bernardo Wagner; 2D Mapping of Cluttered Indoor Environments by Means of 3D Perception; Proceedings of the 2004 IEEE International Conference on Robotics & Automation; New Orleans, LA; April 2004; Pages 4204-4209

4. Sebastian Thrun Wolfram Burgard Dieter Fox; A Real-Time Algorithm for Mobile Robot Mapping With Applications to Multi-Robot and 3D Mapping; Proceedings of the 2000 IEEE International Conference on Robotics 8, Automation; San Francisco, CA; April 2000; Pages 321-328


