Unification of Roadway Surface Dimensional Measurements

Introduction

This white paper gives an overview current pavement measurement practices and the technology developed by PSI which is able to produce a dense accurate geodetic point cloud representation of pavements. From this foundation, the paper outlines the ways in which the various pavement measurement and analysis needs can be met by methods and software tailored to process the point cloud representation of the pavement surface. This concept, that a vast array of pavement data requirements can be satisfied with a single unified data structure, represents a major paradigm shift, the affects of which cut across multiple disciplines.

Current Practice Background

The methodologies for obtaining and handling the information required to support the design, construction and monitoring of roadways has evolved by separate distinct paths, focused on, and optimized for the specific application or task of concern.

The pavement life cycle begins with conventional survey methods, which are today being augmented by aerial lidar, to chart the **Pavement Route and Design** the geometry of the road bed. At this stage the concern is with accurate position in the legally recognized coordinate system (State Planes) to address issues of property lines and alignment with topography and connecting pavements. Once **Pavement Construction** commences, the work migrates to a local reference system general based on stakes put into the ground by the surveyors. Traditionally, the equipment followed string lines stretched between the stakes. Modern developments are replacing the string lines with laser levels, precision GPS, local topology measurements for feedback control of the paving process, where the emphasis is on construction of a pavement that will provide a smooth safe traveling surface for a long service life.

For example, **Pavement Condition**, which is concerned with the performance of the structural aspects of the pavement as it relates to service life and ride quality. Two most common measurements are of ruts formed in the wheel paths evidenced in the transverse profile of the pavement and the longitudinal profile that would be experienced by a person riding in a vehicle with a specified suspension from which a roughness index (IRI) is calculated. The rut calculations are not concerned with cross fall and hence do not address the impact of water buildup on the pavement and in the ruts. IRI is calculated from a profile that is filtered to remove spatial wavelengths less than 1 foot and greater than 200 to 300 feet, depending on the speed of the road. Further the single axis inertial sensors employed in the measurement only yield reliable measurements on straight roads. While this methodology has provided a way to track pavement degradation and perform relative comparisons for maintenance prioritization, the data is of limited use for studying vehicle pavement interaction dynamics in super-elevated turns and other geometries that are often the most dangerous parts of roadways. Also, since true elevation and surface orientation relative to gravity is not measured, this data is not useful for design and construction. Specialized measurements concerns the high frequency spatial profile of the pavement, generally referred to as texture, which is measured over very small percentages of the pavement surface by specialized sensors to address friction and tire noise and high-resolution imagery for automatic detection and classification of cracks, referred to as distress, robust automatic performance is the current quest in technology development.

Specialized pavements such as race tracks, vehicle manufacturer test tracks, and experimental test sections are built and characterized with exacting standards using sophisticated measurement systems that are not particularly practical for use on inservice roads which represent a vastly greater number of lane miles to characterize **Pavement Performance** and **Vehicle-Pavement Interaction**. Generally this work is segregated between the vehicle manufacturers and pavement engineers in terms of both the physical facilities and the measurement and analysis methods and focus of the work. Vehicle manufacturers generally instrument the vehicles extensively while pavement engineers instrument the pavement and use accelerated loading methodologies.

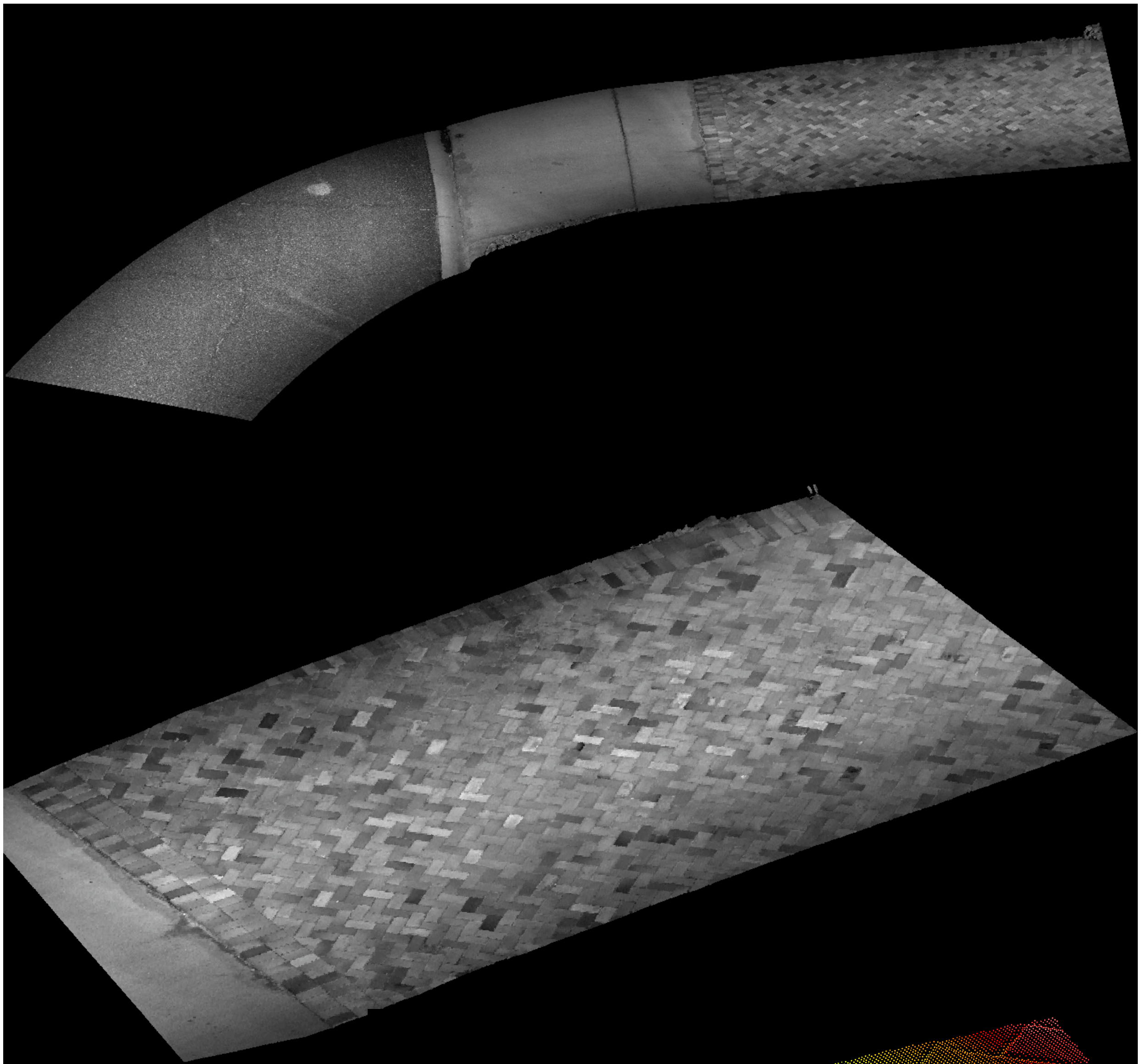
PSI Technology

Phoenix Scientific developed a laser scanner with unprecedented speed and accuracy to implementation a concept patented by PSI for a Rolling Wheel Deflectometer (RWD). This product is called the Pavement Profile Scanner (PPS). The very small RWD niche market did not embrace the PSI approach and after 18 years has only resulted in a few experimental systems manufactured by others. The greater potential for the PPS was realized as a replacement for the conventional Pavement Condition products generically referred to as Rut Bars and Inertial Profilers. The migration of the industry to the use of the rich data provided by the PPS and other high point density profile technologies has been slow in part because of the complexities presented by high resolution full lane width data which revels the actual drive path and the diverse anomalies in real world pavements.

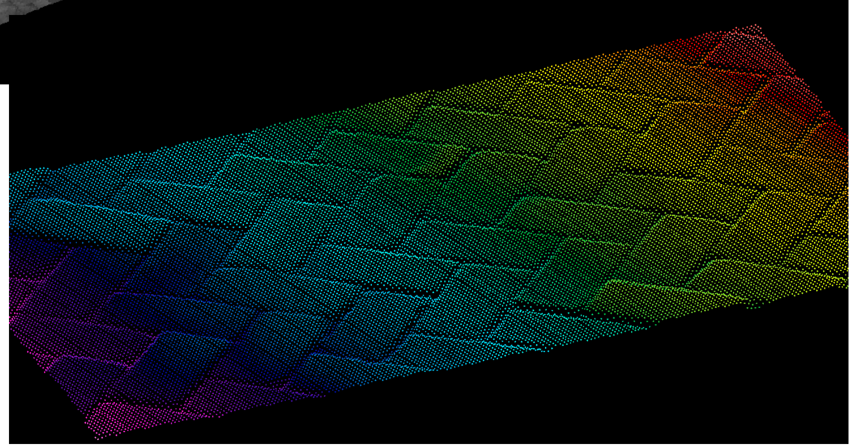
In 2005 PSI integrated the PPS data with an inertial/GPS navigation system and developed software to transform the spatially dense scan points into Geodetic coordinates much as aerial Lidar systems operate. The initial purpose was to obtain problematic road topology on a road that was always too busy to close, not to mention the cost and danger, so that the pavement conditions could be reproduced as a test road by BMW for tuning suspension systems design.

But it soon became clear that this type of mobile survey could provide the required data for road design and construction, while having minimal impact by eliminating lane closures, reducing the time required over conventional surveys, and drastically reducing the time for surveyors to be on the highways and in harms way. Now that construction grade mobile survey has become operational, the fundamental richness of a dense, accurate point cloud in Geodetic coordinates has laid the foundation for a unified data structure that can support the various disciplines concerned with measurement of the pavement surface.

The following scan of a brick driveway is a sample of an accurate high density point cloud. The data was collected by International Cybernetics PPS and PSI's Navigation System and the point cloud images were create with the Eartheye Viewer.

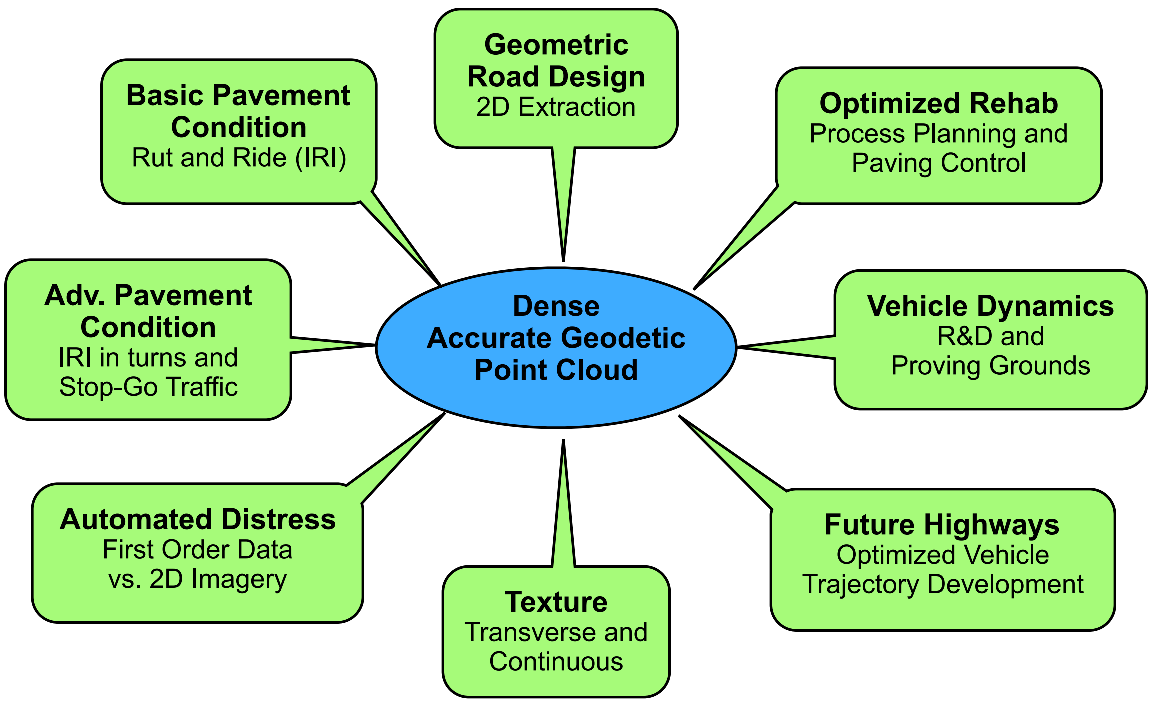


The top two images are lidar return displayed as gray scale. They are not images produced by a camera system. The lower image is color coded elevation.



Unified Dimensional Data Structure

Given the ability to acquire and manipulate a dense accurate geodetic point cloud of the pavement surface, we now for the first time have the potential to support the data requirements for nearly the full range of data required throughout the pavement life cycle. This can be accomplished by developing data handling software to extract and analyze the point cloud data along the lines suited to each unique requirements as shown in the cloud diagram below. Each application is discussed briefly below somewhat in the order that associated activity and development were initiated or is likely to be pursued.



Basic Pavement Condition calculations for Rut and Ride were implemented by PSI by 2004. The Ride module supports up two 32 longitudinal profiles as user specified offsets. The Rut module provides options for all the modern rut algorithms as well as the 3 and 5 point methods for grandfather purposes. PPS customers have and continue to implement there own post-processing more directly integrated to there Pavement Management Systems (PMS) design.

Texture is typically measured by single spot lasers 0.5 mm in diameter sampled at 64 KHz, one in each wheel path. This presents a limited sample showing only the worn condition in the wheel path. By analyzing the transverse scan for texture, the condition in the wheel path can be compared to that in between and outside the wheel paths, which would be closer to the original condition other than for changes due to weathering. This concept was explored by TRL beginning in 2006: TRL_Texture_Scanning_Rpt_200608.pdf.

Vehicle Dynamics R&D, Pavement Interaction and Proving Grounds using PPS has been pioneered by the Vehicle Terrain Performance Laboratory (VTPL) at Virginia Tech. VTPL not only measures they point cloud but also measure the vehicle dynamics and perform research concerning the mathematical representation on the pavement topology and vehicle dynamics. VTPL also delivered a PPS system on an Army HUMVEE to the U. S. Army RDECOM-TARDEC Motion Base Technology Team.

Geometric Road Design has been a field that has been dominated by traditional survey and 2D flat drafting. The engrained systems and methods have proven very difficult to transition into the 3D world. However the point cloud tools support reduction of the data into the 2D information required. PSI initiated this type of work in 2008 by filling in the aerial liar survey or an interstate project with survey grade accuracy on the roadway: 2009 Mobile Survey Overview

Optimized Pavement Rehabilitation refers to Asphalt paving method which involves grinding off high spots and and filling low areas with multiple passes of the paver between stations derived from analysis of the existing topology. Then a final skip mill followed by a uniform continuous lay not only produces a very smooth pavement, but precise grade, cross fall and elevation are readily accomplished. Precision mobile survey can provide the data required for planning, tracking progress and final acceptance.

Advanced Pavement Condition encompasses classes of programming that build on several features of the unified point cloud representation. The validity of traditional 3, 5 and even 10 point rut bar data is dependent upon the trajectory driven by the driver as the data does not revel the position of the vehicle relative to the wheel path. The full coverage scanned point cloud clearly shows lane markings and pavement boundaries thereby enabling processing to automatically center the rut algorithms in the lanes. Valid IRI with the tradition "GM or inertial technique" method is obtained only from straight level roads at a nominal constant speed, whereas these results can be derived from the point cloud which may have been measured in stop and go traffic and can be derived in turns and super-elevated turns since the point cloud was measured and aligned to gravity with a 6 degree of freedom inertial measurement unit.

Automated Distress has been the"Holy Grail" of Pavement Condition assessment. High resolution line scan imagery is the dominate data source, but this is inherently 2D and thus not a first order parameter. The inherent 3D nature of the dense accurate point cloud is the ultimate first order data. Current technology is able to produce the required transverse resolution and technology in the pipeline will be able to match the longitudinal resolution to that in the transverse orientation.

Highways of the Future will include infrastructure to supply timely information concerning weather, traffic and pavement condition and safe speeds to vehicles that will be driven semiautomatically and eventually in a fully automatic mode. The unified dense accurate geodetic point cloud is the foundation from which information concerning not just optimum safe operating speed, but acceleration and deceleration profiles and other handling details. A related problem would be development of optimum tuning of vehicle suspension elements. A more immediate application is in the field of automotive sports, i.e. race cars.

Summary

By necessity, this white paper has covered a vast range of measurement processes and applications at a very summary level, however for those working in one or more of the areas identified, the paper shows that each areas needs can be satisfied by tailored software and processing applied to a single unified data structure, the dense accurate geodetic point cloud, such as those being produced by systems employing PSI's optimized pavement profile scanner, the PPS.