Pavement Profile Scanner (PPS)

White Paper

Introduction

This white paper briefly describes the operation of the Phoenix Scientific Inc's (PSI) Pavement Profile Scanner (PPS) and discusses the improved data and operational performance and features derived from using this new technology. For more complete details, specifications, photographs and representative data, browse PSI's website. In particular, see the most recent Power Point Presentation.

The PPS is a single sensor that simultaneously measures transverse and longitudinal profile using the latest technology developed specifically for pavement testing. When compared to competing technologies in use today, the PPS produces more complete high-quality data, presents a much less obtrusive installation which is safer on the road, has performance potential for use beyond Rut and Ride, and is cost competitive and easily integrated onto existing test vehicles anywhere in the world. Options for Geodetic Position from a Navigation System consisting of an Inertial Measurement Unit and Global Position System (IMU/GPS), dual wheel path macro-texture, and bridge height integrated directly into the next generation units are being offered.

Rut and Ride Results from a Single Sensor

The PPS was originally developed for the Rolling Wheel Deflectometer (RWD) concept patented by Phoenix Scientific Inc. While an operational RWD has yet to be completed, the resulting technology has proven to be ideally suited to improve the way conventional pavement condition data such as Rut and Ride indexes are obtained. The RWD concept hinged on the ability to measure, essentially instantaneously, the profile of the pavement along a radial line long enough to reach from the center of a rolling wheel deflection basin out at least 1 to 2 meters past the deflected area. The resulting PPS measures a profile 4.3 meters long in 0.75 milliseconds, 1,000 times per second. This is accomplished by mounting the scanner, which has a 90 degree field-of-view, 2.15 meters above the pavement. By orienting the scanner so that it scans transversely across the pavement, each scan produces a transverse profile covering the shoulder and lane divider markings. The raw data consists of 943 points spaced at constant angle and these points are converted to Cartesian coordinates. The operator specifies the number and separation of the points to satisfy specific requirements.

High Quality Data

The PPS-2002 measures pavement profile using phase shift Laser Radar (Ladar) technology that has been optimized by PSI to yield the high data rate and high accuracy required for high resolution profiling at highway speeds. The PPS generates 1.258 million profile points per second with precision comparable to the best triangulation style lasers currently used today, however those devices operate at 1/20th the data rate. Hence, the PPS offers a nominal 20X performance improvement. The full benefit of this Ladar range measurement technology advantage has been brought to bear by combining it with optics generating a large laser spot and internally sampling at a high rate which is a multiple of the output rate while scanning with a rotating polygon. This results in performance that enables a single sensor to cover a full lane width, not just a narrow profile in each wheel path. Beyond superior profiling the Ladar digital implementation enables the PPS technology to measure the reflectivity of the pavement at each profile point.

Spot Size

Spot size is important in profiling pavement. If the laser spot is small relative to the pavement texture then the profile will include high frequency content not relevant to rut and ride. Systems based on the dominant triangulation sensors deal with this by averaging multiple samples. The PPS spot is 20 mm. wide in the cross-scan direction and 6 mm. wide in the scan direction. The 20 mm. wide scan line helps to reduce the amount of texture noise in each point of the measured profile.

Scanning

The PPS rotates a polygonal mirror with six sides at 10,000 RPM to quickly sweep the measurement spot across the full lane width. At 100 KPH, a new scan starts every 2.8 cm, although depending on the application, not every scan is recorded. Scanning turns a single ranging sensor into a multipoint measurement system that measures many more points over a wider area than is physically or economically possible with discrete triangulation sensors. All this is accomplished with a sensor that is well within the vehicle envelope, thereby eliminating the hazards of operating a rut bar that extends beyond the vehicle envelope. Furthermore, since the PPS is mounted 2.15 meters in the air, it would not be damaged by a fender bender accident, which could demolish a rut bar.

Over Sampling

The PPS optimizes the profile precision by internally sampling 24 times faster than the output rate and averaging the results in high-speed electronics before the data is recorded. This process has the added benefit that the 6 mm laser spot width in the scan direction is effectively widened by sample averaging while scanning which tends to further eliminate the effects of pavement texture.

Reflectivity

The PPS Ladar function has been implemented with a sophisticated RF analog electronics front end followed by high speed digitization and signal processing using technology like that used in modern cellular telephones and GPS receivers. An important benefit of this approach is that in addition to profile, the PPS yields the reflectivity of the pavement at each profile point. Lane divider paint stripes are readily detected in the data. This makes it possible to register PPS profile data precisely to the pavement. This PPS capability overcomes one of the most often ignored limitations of current profile and rut bar systems which is that they provide no record of where the test vehicle was driven in the lane.

Transverse profile – Rut Measurement

The primary data from PPS is a profile 4.6 meters wide consisting of 943 points. The average spacing between points is 5 mm. For rut characterization and quantification purposes, this is essentially continuous data. This wide profile spans the average lane with margin to profile the shoulder condition (download PSI Shoulder/EOP Application Note 001 at http://www.phnx-sci.com/pages/info.html). The profile extent also spans any pavement lane stripes or fog lines which make it possible to measure the vehicle's transverse position in the lane and express the profile position relative to these features.

The PPS generates much more data than a conventional 3-, 5- or even 10-sensor rut bar. However, the PPS capability does not stop here, as the goal is not more data, but rather accurate assessment of the rutting condition of the road. The PPS processing software is capable of computing all the important rut indices as well as the 3- and 5-point rut bar results if there is a need to try to correlate the more advanced indices with historical data. Refer to "The Characterization of Transverse Profiles", April 2001 (FHWA-RD-01-024), item 7 on the LTPP web site: http://www.tfhrc.gov/pavement/ltpp/reports.htm.

For network level surveys, the software can produce rut index statistics over an operator specified interval. For project level activities where the goal is not just rut indices, raw or gridded profile data can be exported and used with other software such as geometric design programs for optimal resurfacing to minimize cut and fill.

Longitudinal Profile – Ride Measurement

While the continuous profile of the PPS scan brings highway speed rut measurement to a higher level of fidelity than ever before, the cost-effectiveness of the PPS technology is fully realized by processing the very same data for ride quality indices such as the International Roughness Index (IRI) and Ride Number (RN).

This is accomplished by processing profile points from successive transverse scans that fall along one or more longitudinal lines, most commonly one in each wheel path, in conjunction with double integration of vertical acceleration of the PPS to compute longitudinal profiles. This process is the same as that employed by all inertial profiling systems (GM technique). What is unique is that operator controls the number and transverse position of the profiles *after* the data has been collected. In contrast, systems in use today provide just one profile per laser, and the transverse position of the lasers and the vehicle path lock in the profile path. Slide 18 of the RPUG 2001 presentation, available on the PSI website, illustrates the data processing concept and sample profile line placement options.

A unique advantage of deriving longitudinal profile from transverse scans is that the effects of macrotexture can be further reduced by averaging a number of points over an operator controlled transverse width to generate the single point at each transverse profile station. An extreme condition that can be accommodated by this feature is longitudinal grooving in PCC. The typical triangulation laser, which has a small spot, tends to ride in and out of the grooving causing a very noisy profile and very large ride quality index values, where as averaging or fitting to the peaks over an 8 to 15 cm band would eliminate this noise. A sample profile is shown on Slide 24 of the RPUG 2001 presentation available on the PSI website.

For network level production jobs, the operator can process the data to generate just two profiles, one in each wheel path. For large production jobs, a specialized data storage option is available that minimizes the stored data volume by recording transverse profiles only at any desired longitudinal station interval, e.g. 1 or 15 or 25 meters, while the longitudinal profile data is stored only along the transverse offsets selected. As with rutting, for network level surveys, ride index statistics can be generated at operator specified longitudinal intervals, e.g. every 0.2 Km.

Topology Mapping and Crack Measurement

Another option is to produce a topology map of the pavement with a uniform grid of elevations and optional reflectivity. Using 3rd party software a 3-dimensional image of the pavement surface can be constructed. A sample of this is the topology of the "PSI" letters shown on the first page of our technology brochure available on our website at: http://www.phnx-sci.com/pages/info.html. Here, the reflectance has been mapped onto the surface topology.

PPS customers are developing their own custom software to take full advantage of this data. A major focus seems to be to combine the 3D scanner data with high resolution line scan pavement images to address crack automation.

Operational Features

Easy Installation

The 54 Kg PPS is easily shipped worldwide in the reusable container provided with the PPS. The PPS can be installed on just about any vehicle. All that is required is a secure framework with a platform for the PPS and 6 bolts.

Unobtrusive Installation

Perhaps the single most fundamental feature of the PPS is that it is compact and mounted high above the bumper, eliminating all the burdens caused by conventional rut bars. It does not protrude outside the vehicle envelope causing concern for passing traffic and fixed obstacles. It does not interfere with towing a vehicle in need of service. It is not vulnerable to fender bender damage.

Simple Interface

The PPS was designed specifically to make it easy for anyone to interface the PPS with other subsystems such as line scan pavement imaging systems. The PPS provides three digital lines that allow the operator to 1) control collection of scans, 2) Insert event flags, and 3) input Distance Measurement Interval (DMI) pulses that allow absolute control of PPS operations and coordination with other subsystems.

Simple Operation

The PPS is design for direct operator control or control by another computer. After the operator starts the scanner, then data collection is a simple matter of switch operation, manual or automatic. The data quality can be monitored, but the system is fully automatic and requires no adjustments.

Full Lane Coverage – Data Registration

The ultimate benefit of the PPS full 4D (profile plus reflectivity) coverage of the entire lane will ultimately be realized as industry's experience with this new technology matures. However, the PPS coverage immediately solves the question of where in the lane the vehicle has driven and where derived results such as rut depth comes from. With a rut bar, there is no record of where in the lane the sparse data was collected. Since it is impossible to drive the same path twice, especially a year later, rut bar data that cannot be registered to the position in the lane, yields results whose comparison over time my well be degraded. With the PPS coverage to the lane markings, the results can be reliably correlated.

Self-calibrating

The PPS performs and internal calibration with every scan. No field calibration is ever required. However the system does provided several features that allow easy field verification of performance.

Extensive and Extensible Processing Software

The PPS comes with turnkey software not just for operation of the scanner, but processing of the data for rut and ride. The PPS software also provides features allow the profile data to be exported for processing by customer developed applications.

Potential Applications

While the PPS provides the core of a highway speed rut and ride measurement system, the technology has potential that will be exploited as application experience and feedback from users is amassed. The following applications are some examples of capabilities that are under consideration and/or development. The important point to understand is that a PPS-2002 purchased today will be capable for these expanded applications with only upgrades to the software and firmware.

Longitudinal Profile in Stop and Go Traffic

Inertial profile measurement (GM technique) requires operation at a constant speed greater than some minimum value. The digital filter used to limit the long wave content requires a lead-in segment at least as long as the long wave cutoff, nominally 100 meters. By mounting the scanner so that it scans longitudinally, successive scans can be processed by aligning them to previous processed scans by using the overlapping profile data as an alignment guide. Repeating this process iteratively generates a longitudinal profile without the use of an accelerometer. The process is speed independent. The vehicle does not need to maintain a constant speed. Operating at variable speeds or stopping at intersections would not be a problem. See the graph in the middle of page two of the Technology Brochure. Profiles scanned longitudinally at intervals one foot apart are seen to agree with the rod and level survey results. This process would support ride measurements through intersections, which are often the segments with the roughest ride, since the vehicle can stop without loss of profile continuity.

Transverse Macrotexture

Pavement profile in the 3 to 30 mm spatial wavelength band, which is often referred to as macrotexture, is measured to evaluate tire noise, asphalt aggregate/binder performance and traction. This is usually measured in the longitudinal direction with a high-end triangulation pavement laser using a 1 mm spot. The FHWA ROSAN Project is leading this type of work. PSI is developing an improved non-scanning laser for that program. However texture profile only in the longitudinal direction does not give insight to the cross-lane variation in texture. It is possible to develop specialized firmware for the scanner that would perform a scan periodically that consisted of 2x or even 4x the number of points in the standard scan. This is possible because of the high internal rate that the scanner actually samples the data (24x the output rate).

Joint Faulting

The discontinuity at *skewed* transverse joints can be extracted from the normal transverse scan because they are at different angles. This is illustrated on Slide 24 of the RPUG 2001 presentation available on the PSI website. In fact the joint fault can be measured at a number of positions across the transverse joint. The number is determined by angle between scan and joint and vehicle speed.

Joint Load Transfer

The scanner could be mounted to scan longitudinally just beside the rear loaded axle of a truck with a heavy load such as a water or dump truck. By examining successive scans as the loaded axle passes over the joint, the joint fault size could be extracted and plotted. Contact PSI for a white paper on this concept prepared for the California Department of Transportation.

Status

Two prototypes were developed for the USACE Waterways Experiment Station. They have been working since 1997. Several extensive field tests have been completed with the prototypes: WESTACK in 1997, LTPP sites in Arizona in conjunction with RPUG 1999, NAPA Track testing in conjunction with RPUG 2000 followed by State DOT demonstration tests in Nashville, Tennessee and Ames, Iowa. Then in the fall of 2001 USACE-WES performed the first network level production job with one of the prototypes, surveying over 1,800 miles of the California Forest Road Network.

During the period from 1997 when the prototypes first became operational to Fall of 2000, PSI made several upgrades to the electronics, firmware and software to improve the performance and operability of the PPS. The first production scanners were placed in service between October 2002 and July 2003. They are now operating on three continents. Contact PSI for references.

The PPS consists of all solid-state electronics, some optics, and a motor/bearing assembly to scan the polygon. The assembly is very durable. However the electronics are modular and field serviceable and PSI is able to control and troubleshoot scanners remotely over the Internet. The combination of reliability and serviceability combine to dependable operations.

Options in Next Systems

An incremental evolution of the digital core electronics of the PPS under development for the next units is designed to provide flexibility to expand the interfaces of the scanner. This effort lays the foundation for the following options.

Geodetic position and pavement slope

An inertial measurement unit, Global Positioning System (GPS) receiver and Differential GPS HF receiver will be integrated into the scanner and the data interleaved with the profile data. It is likely that a navigation processor may be placed in the system to minimize post-processing requirements. Pavement grade and cross fall will be derived from the IMU.

Dual Wheel path Macro-texture

Texture measurement involves 64 KHz sampling with laser spot size less than 0.5 mm to characterize the roughness of the pavement between 1-30mm. PSI is developing a non-scanning sensor to perform these measurements. It seemed natural to provide two channels into the scanner data stream to include two texture inputs, one for each path. The inputs will accommodate PSI's texture laser or a Selcom Optocator

Bridge Height

This option adds an upward looking laser spot ranger to measure the height from the scanner to an overhead structure. Of course the scanner is already measuring the height to the pavement.

Conclusion

The Pavement Profile Scanner is a revolutionary new technology developed specifically for testing pavements. PPS technology was proven during 5 years of prototype testing and operation. The first set of production units went into service between October 2002 and July 2003. They have proven to be very reliable. The PPS provides better rut and ride data, with an installation that is safer to operate and much less vulnerable to damage, all at a price that is competitive with existing technology. Future units offer options for integrated measurement of geodetic position, grade and cross-fall, macro-texture, and bridge height, all from a single system without any integration effort required. Furthermore an investment in PPS technology lays the foundation for more advanced pavement testing as operational experience and customer needs lead to the development of software for other applications such as edge or shoulder deterioration, cracking, faulting, texture, bridge height, etc. The PPS technology is the future of modern pavement testing.