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Concept of Operations (CONOPS)

Jorge A. Prozzi
Christian Claudel
Andre Smit
Praveen Pasupathy
Hao Liu
Ambika Verma

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Ambika Verma

TxDOT Project 6873: True Road Surface Deflection Measuring Device

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Performing Organization: Center for Transportation Research The University of Texas at Austin 1616 Guadalupe, Suite 4.202 Austin, Texas 78701	**Sponsoring Organization:** Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, Texas 78763-5080
Performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.	

Introduction

A Concept of Operations (ConOps) document describes the likely operation of a future system in the terminology of its users, providing important information for the development of that system. This particular ConOps includes identification and discussion of the following aspects:

1. Why the system is needed?
2. System overview
3. Operating principles
4. Different aspects of system use including operations, maintenance, and support
5. When the system will be used, and under what circumstances?
6. How and how well is the needed capability currently being met by existing systems in Texas?
7. Scenarios illustrating specific operational activities involving the use of the system
8. Additional features

Why the system is needed?

Measuring pavement surface deflection under a moving wheel with high fidelity is challenging and cannot be accomplished today at a speed necessary for network-level applications. Pavement deflection measurements began more than 60 years ago with the development of the Benkelman Beam as part as the WASHO Road Test. Engineers have long recognized the usefulness of pavement deflection measurements to evaluate and monitor pavement response and existing pavement structural conditions by means of backcalculation of layer moduli. The Texas Department of Transportation (TxDOT) has been, and continues to be, one of the leaders in using deflection data (TxDOT operates the largest fleet of falling weight deflectometers in the US) as well as in developing and implementing devices used to measure pavement deflections and other in situ properties. Two recent examples of TxDOT supporting the development of new devices are the Rolling Dynamic Deflectometer (RDD) and the Total Pavement Acceptance Device (TPAD). These devices, however, do not measure pavement deflection under a standard axle load and they operate at very low speeds, making them unsuited for network-level work.

All continuous (or quasi-continuous) pavement deflection measurement devices have loading systems that move along with the measuring vehicle. Two major differences exist between these devices: 1) some deflection sensors move along the pavement at the speed of the device while other sensors are stationary on the pavement as the loading mechanism moves past the sensor, and (2) the speed along the pavement ranges from very slow to fast.

The goal of TxDOT Project 0-6873, *True Road Surface Deflection Measuring Device*, is to develop a measuring device for project- and network-level studies that continuously moves along the pavement at speeds above 10 mph.

System overview

To address the needs highlighted above, the research team will develop a True Road Surface Deflection Measuring Device. We use the term *true road surface deflection* because current systems, which claim to measure deflection at highway speeds, do not measure actual deflections but merely some index or indicator of pavement deflection. Figure 1 provides the schematic of the system developed in Phase 1 of this project.

The setup consists of a rigid beam that is attached to a tractor-trailer; two distance-measuring lasers heads are attached to this beam, with this configuration:

- The front laser head is used for monitoring the pavement far away from the deflection bowl.
- A second, back laser head monitors the deflection bowl itself.
- In Phase 1, a third laser (not shown in figure) was used to establish the beam's relative position.

The operation principle is very simple: the front laser measures the distance from the beam to the undeflected surface while the back laser measures the distance from the beam to the deflected surface under the wheel. The difference between these two measurements will be the deflection. The relative position of the beam needs to be known, requiring the addition of a third laser head or the use of a high-precision gyroscope. During Phase 1, the first option was pursued. For Phase 2, we will employ a ring laser gyrometer in conjunction with a third laser head to improve the accuracy of the system and account for any potential deformation of the beam.

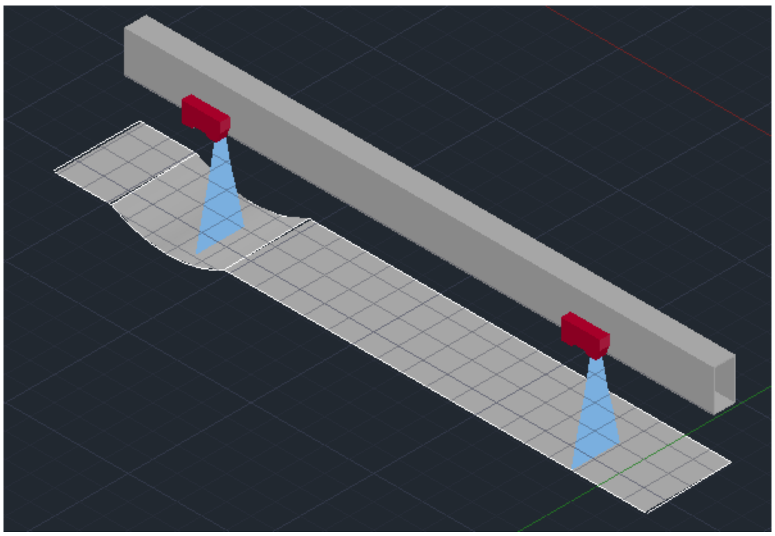

Figure 1: Schematic of current system with two laser heads

Note that this system (as tested in Phase 1) allows only the maximum deflection to be measured. In Phase 2, we will use six lasers: two for monitoring the position of the beam and four for determining four points in the deflection bowl. For Phase 3, any number of laser heads could be added. The final number of laser heads will be decided between the research team and TxDOT personnel based on cost-benefit considerations.

Due to the texture of the pavement, a point distance measurement would be associated with a significant uncertainty, on the order of several millimeters. Current systems overcome this problem by averaging the distance measure over several feet and, therefore, they cannot get a point deflection. To overcome this limitation, our system will take measurements using a line scanner that can monitor a large number of points in the transverse direction to identify features that can be used by all lasers to obtain an absolute distance measurement. The lasers used can scan 800 points in the transverse direction. Both lasers will scan about 4 inches in the transverse direction and 1 inch in the longitudinal direction, producing a 3D image of the undeflected and deflected surfaces.

Another advantage of the line scanner is that it provides additional data for matching the positions through their transverse scan patterns. This capability is extremely important in practice, since we have to precisely estimate when both lasers are above the same exact point in space. This could not be achieved with a point laser, because the vehicle cannot drive on a perfectly straight line with deviations smaller than the laser spot size.

Operating principles

The data processing algorithm of the proposed system is schematically represented in Figure 2 and consists of the following steps:

1. **Data Acquisition**: as the vehicle with the attached beam travels over the pavement, both laser heads shown in Figure 1 continuously monitor the distance from the beam to the pavement surface at the undeflected and deflected positions, respectively.
2. **Dead Pixel Filtering**: due to the nature of the technology and the dynamic nature of the test, noise, outliers, and missing points will arise. These points will be removed by dead pixel filtering.
3. **Median Filtering**: this step will remove the relative position of both heads from a true horizontal datum or reference point.
4. **Mean Value Correction**: this step determines the mean distance of each head to the pavement surface.
5. **Tilt Correction**: due to the dynamic nature of the measurement, the heads can potentially tilt differently during data acquisition, which needs to be corrected.
6. **Cross Correlation**: during this process, both images (from the front and back laser heads) are matched and the difference is obtained. This difference will represent the actual deflection (Figure 3 provides an example).

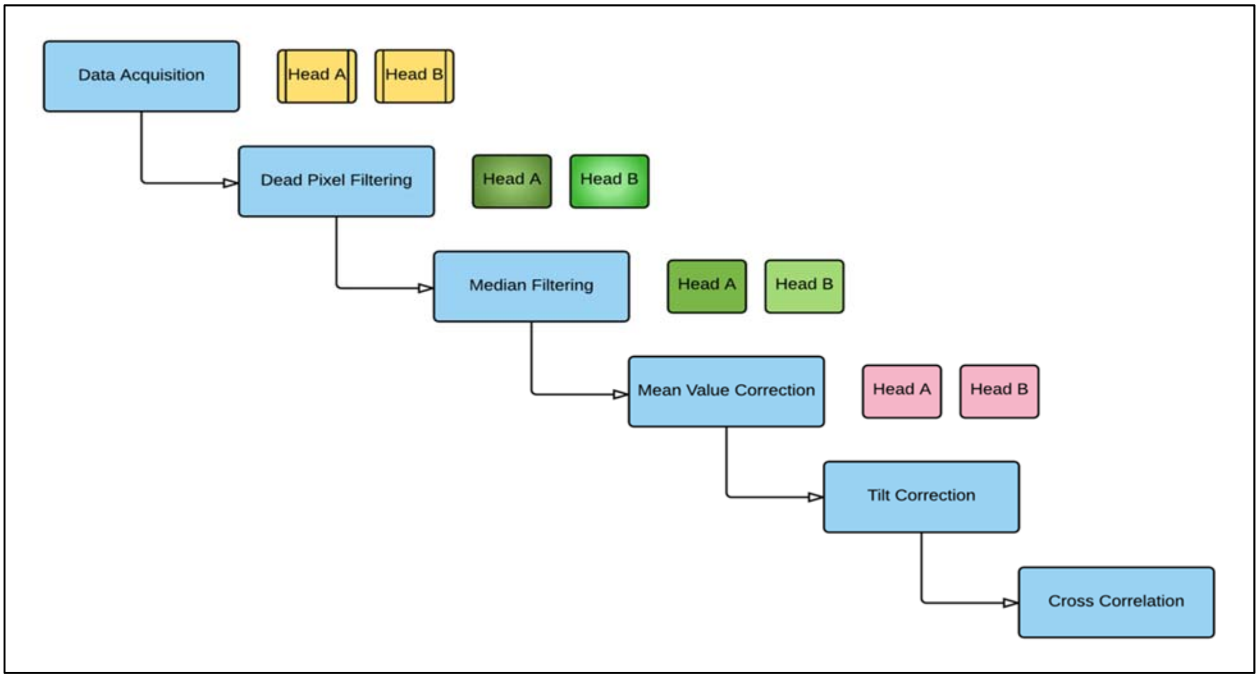

Figure 2: Schematic of data processing algorithm

Figure 3 represents the results of the sixth process (cross correlation), showing actual measurements over a 300x450-pixel area after the filtering and correction steps. The cross correlation was very high and can visually be verified in the figure (Head A and Head B). The third (rightmost) panel of the figure shows the difference, or actual deflection. This level of accuracy can be achieved only by the scanning laser heads used in this project, which are safe Class 2 lasers. Table 1 summarizes the main operating characteristics of these laser heads. Our goal is to achieve measurements with errors of less than 50 microns (two mils).

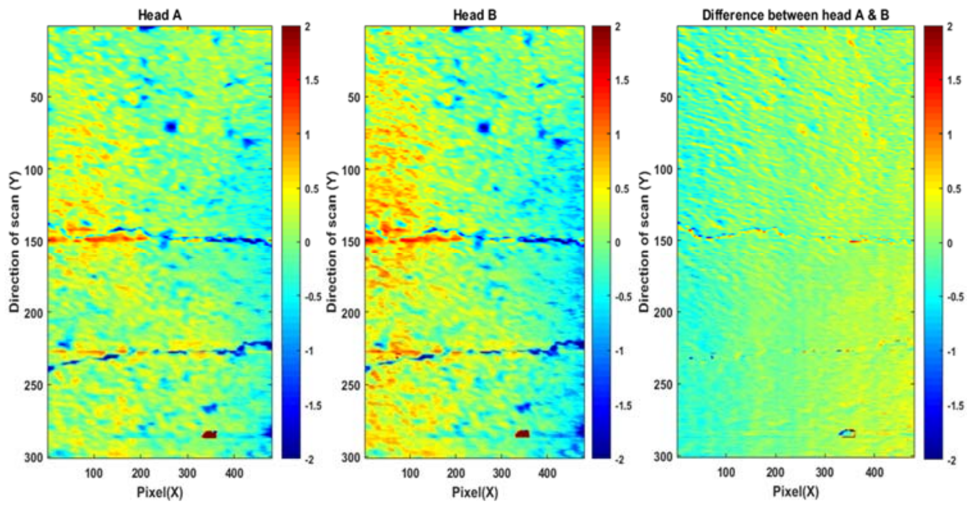

Figure 3: Principle for calculating actual deflection

Table 1: Laser Sensor Characteristics

Measurement range	Vertical axis nominal: 300 mm Vertical axis range: 155 to 445 mm Horizontal axis nominal (transverse to travel direction): 110 to 240 mm Horizontal axis range: 180 mm
Repeatability	Vertical axis: 5 microns Horizontal axis: 60 microns
Wavelength	405 nm (visible beam)
Laser class	IEC60825-1, FDA(CDRH), Part 1040.10*1 Class 2 Laser Product
Output	4.8 mW

Different aspects of system use, including operations, maintenance, and support

As part of Phase 3 of the project, the Center for Transportation Research (CTR) will develop a prototype device that will be used to test the concept in the field and make the necessary adjustments to ensure the system will meet the project objectives. However, during Phase 2, the project team will also develop a commercialization plan at TxDOT's request. The commercialization plan will include recommended strategies for involving the private sector on the production of a commercial version of the system, address intellectual property rights aspects, and synthesize considerations for the provision of services with the device. TxDOT requested this plan as the Department seems to be moving away from the business of developing, operating, and maintaining complex pieces of equipment that involve rapidly changing technologies.

Different classes of user, including operators, maintainers, and their different skills
At the end of the project, TxDOT will have two possible options: 1) the equipment will belong to TxDOT and will be owned, operated, and maintained by TxDOT personnel from the Maintenance Division, or 2) the equipment will be built and commercialized by a vendor, and operated and maintained by a consulting company that will provide services to TxDOT and any other interested agencies. Partnership agreements between CTR, TxDOT, and a third-party private partner will also be considered. Note that the system is making use of Class 2 laser systems, so they are safe and require no special handling or training.

When the system will be used, and under what circumstances?

The system will initially be used as a project-level tool for measuring pavement surface deflection, performing backcalculation of layer moduli, and contributing to rehabilitation design. This will provide a period for establishing and getting familiar with the new technology as well as addressing any potential problems encountered in the field that were not encountered during the development phase. After approximately two years of field experience, a second (and possibly a third device) could be manufactured. With two or three devices in full operation, TxDOT will be able to monitor the entire Texas road network on an annual basis. This will be the first device in the world capable of covering such an extensive road network on an annual basis while still providing the accuracy of project-level analysis. Unlike other current systems, this system will measure actual deflections rather than providing an index or an indicator that correlates with actual deflection. Therefore, the deflection measurements will be used for backcalculation of layer moduli.

How and how well is the needed capability currently being met by existing systems in Texas?

As mentioned earlier, two different devices are currently available in Texas to measure pavement deflection under a moving wheel load: the RDD and the TPAD. These devices, however, have some significant limitations in terms of speed that make them unsuitable for network-level measurements.

Rolling Dynamic Deflectometer (RDD): The RDD was developed by CTR in the 1990s under TxDOT's research program and has been used for about 15 years as a valuable tool for project-level pavement deflection under a dynamic vibratory load. The RDD applies a static hold-down force combined with a dynamic sinusoidal force applied to the pavement surface with two loading rollers while continuously moving along the pavement. An array of rolling sensors is used to continuously measure the induced dynamic pavement deflections.

This truck-mounted device moves along the pavement at a speed of about 1.0 mph, so it is used only for project-level studies. Each of the rolling sensors consists of a three-wheeled cart supporting a vertically oriented velocity transducer (geophone) with a 2-Hz resonant frequency. An electro-hydraulic loading system is used to deliver the dynamic forces to the pavement. The array of rolling sensors is positioned on the pavement along the longitudinal centerline of the truck, beginning midway between the loading rollers and extending ahead of the rollers. Due to the close spacing between deflection measurements, the RDD is an irreplaceable device for monitoring joints in jointed concrete pavements. To date, it is mostly used for airport pavements.

Total Pavement Acceptance Device (TPAD): The multi-functional TPAD was developed through TxDOT's research program by a joint effort between CTR and the Texas A&M Transportation Institute. The objectives of developing this device were to integrate multiple testing functions into one piece of equipment and to increase the speed along the pavement. The TPAD provides these functionalities: 1) RDD,

2) ground-penetrating radar, 3) GPS, 4) pavement surface temperature, 5) digital video imaging of pavement and right-of-way conditions, and 6) a distance measurement instrument to obtain longitudinal survey distances.

The continuous testing speed of the TPAD is 2.0 to 3.0 mph, which, at this time, still places it in the realm of project-level studies. Above this speed range, the signal-to-noise ratio becomes unacceptably large. The principle of the TPAD pavement deflection measurements is the same as the RDD, so 2-Hz geophones are used as transducers.

Scenarios illustrating specific operational activities involving the use of the system

The systems currently available are either ***network-level*** (they do not measure actual deflection but an index that is an indication of actual deflection and, therefore, cannot be utilized for backcalculation of layer moduli) or ***project-level*** (they measure actual pavement deflection but at very low speeds or statically, and therefore are not efficient for network-level application). The system being developed under this project has unique characteristics that will make it a network-level device with project-level accuracy and precision. We are aiming at measuring deflections at 10 mph and an accuracy of 50 microns (or 2 mils). Furthermore, the system will measure actual deflection, so it can be used for backcalculation of layer moduli and rehabilitation design. This assessment is based on the following operational assumptions:

- The Texas network consists of approximately 90,000 center-lane miles.
- The system will operate 5 days/week with an effective working day of 7 hours/day.
- Assumed service and breakdown downtime: 4 weeks/year
- Total operating hours per system: 1,680
- If TxDOT operates two such devices working three shifts a day, the total operating hours will reach 10,080.
- Minimum required speed: 8.9 mph
- Our target is 10 to 12 mph with the laser operation at 4 kHz.

This operational speed is ten times faster than the RDD and five times faster than the TPAD. Therefore, the entire Texas highway network could be covered annually operating two devices at three shifts per day, or three devices operating at two shifts per day, or six devices working only one 7-hour shift.

Finally, it should be noted that the 10 to 12 mph operational speed was demonstrated as feasible with the laser sensors operating at 4 kHz. These laser heads are capable of operating up to 64 kHz—therefore, there is the potential to increase the speed, in principle, by eight times.

Additional features

The Phase 1 system consisted of two laser heads (Figure 1) and a third head (not in the figure) that was used to determine the position of the beam relative to a reference (the undeflected pavement). For Phase 2, we will incorporate a ring laser gyrometer to obtain the position of the beam with very high accuracy and in real time. In addition, we will add three additional lasers at the back, enabling us to obtain four points of the deflection bowl as opposed to only obtaining the maximum deflection. A schematic representation of this system in presented in Figure 4.

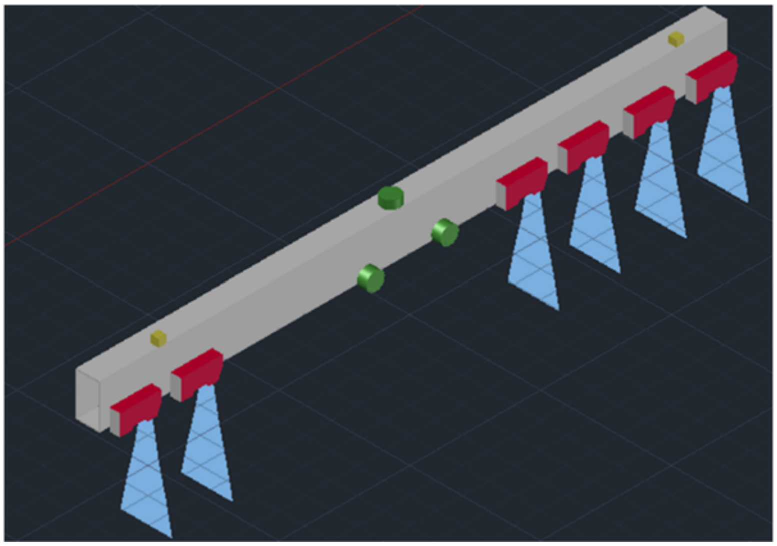

Figure 4: Enhanced device for Phase 2

As indicated earlier, the research team will provide TxDOT with a unique piece of equipment that could be used for network-level surveys but will have project-level accuracy. TxDOT will have the option to build, own, and operate the equipment or to establish a partnership with CTR and a third-party manufacturer for the fabrication and commercialization of the equipment and with a consultant who would provide the service of monitoring the entire Texas network on an annual basis.