IDEA

Innovations Deserving Exploratory Analysis Programs

Highway IDEA Program

Advanced Methods for Mobile Retroreflectivity Measurement of Pavement Marking

Final Report for Highway IDEA Project 146

Prepared by:
Terry Lee, Leetron Vision, Concord, NH

July 2011

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

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Transportation Research Board

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ACKNOWLEDGEMENTS

This project was conducted in cooperation with the Center for Transportation Research and Education, Connecticut Department of Transportation and New Hampshire Department of Transportation. The authors wish to acknowledge the following individuals. Without their insight and assistance it would not have been possible to successfully complete of this research project.

- James M. Sime, P.E., ConnDOT, Manager of Research (retired);
- Mr. Bradley J. Overturf, ConnDOT, Division of Research, Transportation Photolog Supervisor;
- Robert Kasica, Conn. DOT, Data Collection Specialist;
- Vittorio P. Castro, ConnDOT,
- Scott Leslie, NH DOT, Data Collection Supervisor;
- Glenn E. Roberts, P.E., NH DOT, Chief of Research;
- Tobey, Reynolds, NH DOT, Senior Engineer;
- Eric Healey, NH DOT, Pavement Marking Supervisor;
- Robert Havey, NH DOT, Pavement Marking Foreman II;
- Charles Holzschuher, P.E. FDOT, Pavement Performance Engineer;
- Omar Smadi, Center for Transportation Research and Education, Ph.D., Research Scientist,
- Paul J. Carlson, Ph.D., P.E., Texas Transportation Institute, Division Head of the Operations and Design Division;
- Greg Schertz, P.E., FHWA, Retroreflectivity Team Leader,
- Inam Jawed, NCHRP-IDEA Program, Program Manager
- David R. Luhr Ph.D., WSDOT, Pavement Management Engineer,
- Jon Jackels, Minnesota DOT, ITS Program Engineer
- George Fearnley, SCORE Counselor

1 Executive Summary

To meet new Minimum Retro-Reflectivity Standards proposed by FHWA, State departments of transportation (DOTs) face a need for new ways to manage the maintenance of pavement markings. At the same time, most DOTs are experiencing reductions in resources, both in staffing levels and in their maintenance budgets. The Leetron innovation described herein offers a reliable solution to meet the new Retro-Reflectivity Standards and with fact-based condition data on retroreflectivity, as well as enabling DOTs to achieve cost savings in their pavement marking maintenance operations.

The objective of this project was to develop and demonstrate the use of a prototype mobile unit for rapid and reliable measurement of marked pavement reflectivity. This final report describes the results of efforts to design, build, and test a system to fulfill the requirements of this task.

The Leetron Mobile Retro-reflectometer Unit (MRU) is designed to address shortcomings of traditional handheld and MRU systems, primarily shortcomings in the handling of motion issues inherent in the mobile measurement process. The Leetron MRU invention provides an innovative method of tracking measurements in real time that mitigates the effects of road vibration and surface roughness. The Leetron method aims a laser at the center of the pavement marking and uses a feedback loop to readjust the aim point as the vehicle travels at highway speeds. Leetron researchers examined whether the new Leetron design would achieve a significant measurable improvement over other existing methods.

After research, conceptualization, and design, a prototype mobile unit was built and tested. The initial road test results demonstrated very good repeatability in the measurement parameters acquired under real time mobile conditions. This observation was made from an analysis of test results from June 2011. Note that the repeatability is in the range of 4% to 9%. Subsequent improvements and alterations in the tracking system resulted in repeatability improvements reaching a repeatability range of 1.5%. We feel that these results validate the basic technologies used in the Leetron MRU system. We are pleased to submit this evidence as proof of the expectations of many of the contributors and experts who are familiar with the concept and agreed early on as to the robustness of the principals involved, yet had some doubts about the practical application of these ideas.

Thanks to the NCHRP-IDEA program, we believe we have established proof of principle for our mobile system. Once we complete the last phase of testing and refinements early in 2012, we anticipate presenting a fait accompli of the Leetron MRU system that will set a new standard for mobile retro-reflectivity measurement, providing an accurate, repeatable and reliable machine and methodology that will benefit FHWA and State DOTs, and the motoring public they serve.

2 Body

2.1 IDEA Product

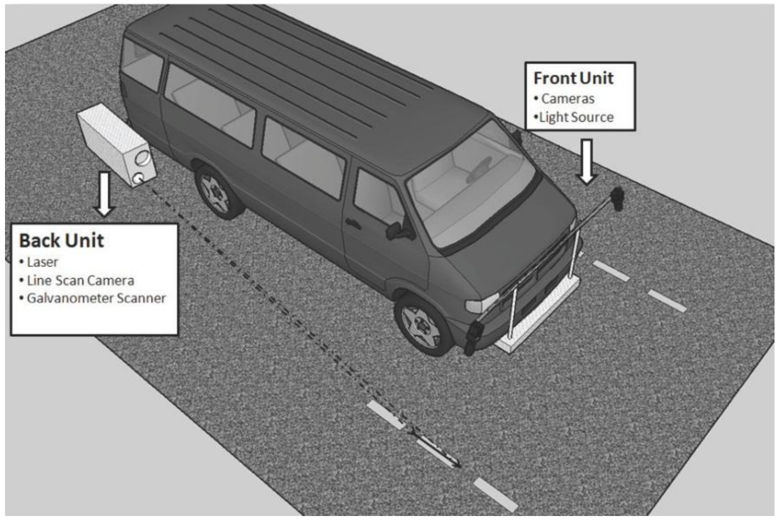

Figure 1 Leetron Mobile Unit hardware configuration overview

The product resulting from this research is a vehicle-mounted system for retro-reflectivity measurement on pavement marking.
Figure 1 shows a prototype unit. The system will meet the performance requirements of accuracy, repeatability, and reproducibility. Those variations are anticipated to be less than 10%. The system should be stable. It should be able to operate under a variety of road and environmental conditions, requiring only a simple daily verification procedure. This is a marked improvement over current competing MRU systems that require hourly calibration. And, as an additional benefit, only a single operator is required, as opposed to two personnel usually required by the existing competing MRU technology. We must also mention that this system is fully capable of simultaneously measuring two lanes of markings instead of one. In summary, the system is anticipated to provide accurate, stable, reliable, efficient, and simple operation, thereby providing a new level of cost effectiveness in the field of vehicle-mounted pavement retro-reflectivity measurement.

2.2 Concept and Innovation

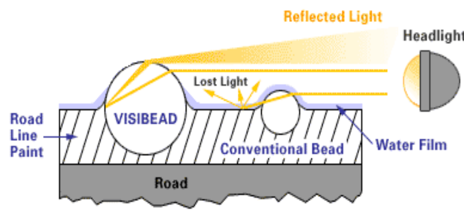

Figure 2 Retro-reflectivity concepts

Retro-reflectivity is a measure of how efficiently the pavement marking returns (reflects) light from the vehicle headlamps back to the driver as shown in Figure 2. To measure pavement marking retro-reflectivity, an international standard is recognized by the State DOTs and the FHWA, which uses “Standard 30 Meter Geometry” (see figures 3 below).

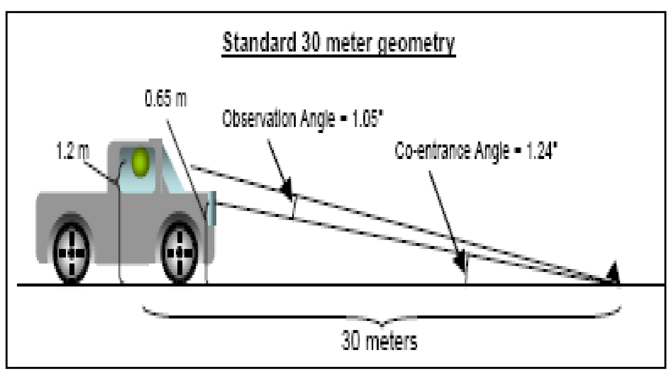

Figure 3 Standard 30 Meter Geometry

For manual system, small battery-powered hand-held devices with 30-meter geometry are placed on the pavement and readings are taken at spot locations by a technician. A mobile system introduces additional factors and conditions that will impact the measurements acquired by these devices. Four of those conditions with the greatest impacts are sunlight, vehicle dynamics, road profile and temperature.

Sunlight introduces variations in light levels that affect the projected light source of the retro-reflectivity measurement device. Vehicle dynamics (pitch, roll and yaw) affect the location where the light source meets the pavement marking and the target location where the imaging device is measuring. Road profile (vertical variations between wheel path and marking) also “moves” the light source and image device and impact targeting capabilities. Also, components of the light source and imaging device are typically temperature sensitive, where variations in air temperature affect measurements. Traditional MRU units use many methods to compensate for and overcome the influence of sunlight and temperature, but available MRU devices have been lacking in solid solutions that must dealing with the motion issues and road profiles in mobile units.

The proposed IDEA innovation leverages the latest proven technologies available today to provide a more comprehensive solution to all of the issues mentioned. The Leetron MRU device is relatively simple to understand - you point a laser light on to the pavement marking and keep it there with automated aiming-correction techniques built into the system, while the vehicle travels at highway speeds. With the laser staying on target pavement markings regardless of external motion influences, the system does not have to deal with the variations introduced by vehicle motion and road profile. Although easily stated, the actual implementation of the concept is complex and a key achievement of this IDEA project. The engineering challenge was to develop a robust real time tracking system that provides automated aiming-correction capabilities. For the reader not familiar with the principals involved, you have only to visualize the tracking system available to a fighter jet pilot. You no doubt have seen images on TV or in the movies (think Top Gun) of such a system locking on a target via computer adjusted radar and sensor tracking. The computer implements a feedback system that integrates the various changing parameters to track the target. In some ways, the roadway challenges we faced to make our reflectivity measurements were just as difficult, given the need for simplicity and cost constraints and the addition of such issues as vehicle-speed changes, low light-source projection angle (1.24 degrees) and variability of environmental conditions.

2.3 Investigation

2.3.1 Background

Being able to accurately and efficiently measure the retro-reflective condition of traffic control devices is becoming increasingly important for all agencies in the U.S. responsible for maintaining roads open to public travel. To guarantee a safer driving environment, the FHWA is establishing minimum retro-reflective maintenance levels for signs and pavement markings. The requirements for signs have been established and published in the MUTCD. The FHWA has completed their research on pavement markings maintenance retro-reflectivity levels and has begun to implement official rules for markings in 2009 to establish national minimum maintenance standards in the MUTCD.

Measuring retro-reflectivity of pavement markings utilizing a MRU is anticipated to be not only the most efficient method, but also the safest work environment for both technicians and motorists. See Table 1 and consider the issues faced by a worker walking along a public roadway to take manual hand-held retro-reflectivity meter readings. Currently in the U.S., there is only one competing mobile technology providing MRU capabilities. The new innovative Leetron MRU technology described in this IDEA project has the potential to deliver improvements in safety efficiency, accuracy, and repeatability.

Table 1 Pavement Marking Retroreflectivity Measurement Methods

Pavement Marking Retro reflective Method	Safe?	Efficient?	Accurate?	Repeatable?
Visual Inspection	N	N	N	N
Hand-Held Device	N	N	Y	Y
Current MRU	Y	Y	N	N
Innovative MRU	Y	Y	TBD	Y

Successful field implementation of this system will provide these improved qualities to transportation agencies desiring to realize the advantages. Theoretically, better management of pavement marking retro-reflectivity will lead to safer nighttime roadways and safer driving conditions for all, with particular advantages for older drivers with night impaired vision. Without a doubt, the Leetron MRUs will lead to safer measurement conditions and produce rich data sources for analysis such as life cycle costs, QC reporting, and contractor compliance with warranty and performance-based contracts.

Measuring the many miles of pavement markings is difficult to do cost effectively using handheld retro-reflectivity meters, but is an objective measurement. Some DOTs will elect to use statistical sampling strategies with handheld meters. In an environment that is stressing operating cost minimization in government, manual methods are likely to be too expensive, especially considering that pavement markings will need to be measured annually in most cases. Visual inspections are subjective and inherently inaccurate, with repeatability problems, making a poor choice for DOTs that need to enforce performance guarantees and warrantees. As stated previously, the existing MRU is not sufficiently practical due to its inherent design limitations that have just begun to surface with increased usage. [1,2]

One major consideration always at the top of any civil organization's agenda is the potential for savings that could be realized by changing pavement-markings repainting schedules. Currently, many agencies assign a road a fixed repainting schedule based on factors such as traffic load, prevailing weather conditions, and the type of pavement markings. Some roads have bi-annual

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[1] Pike, A. Evaluating Factors that may Influence the Accuracy of Mobile Retroreflectivity Data Collection. Paper 09-0493, TRB Annual Meeting, January 2009.

[2] Fletcher, J. et al. Characteristics of a Calibration Standard for the Mobile Retroreflectometer Unit, TRB Annual Meeting, January 2009.

paint schedules, while others may see years of service between repainting. Generally, these fixed schedules are based on worst-case scenarios in order to guarantee compliance with minimum retro-reflectivity requirements. With the availability of real time retro-reflectivity data from the Leetron MRU, the roads that fall below the minimum requirement could be queued up for painting based on a priority schedule. Action on roads measured and shown to be in compliance with the required safety standards could be delayed in the repainting schedule. Such an arrangement has the potential to result in a safer environment and make for more effective use of available maintenance repainting budgets. Our preliminary study of the potential for repainting savings estimates that savings should be in the range of 5 to 20%. Appendix A details our calculation methodology for estimating cost savings in repainting budgets. Recent research from Kentucky [3] shows that it is not necessary to re-stripe many roads annually. The report indicates that nearly half of those striped had passing levels after two years. That represents a 25% potential savings of repainting costs if DOTs can identify with confidence those line stripes that do not need repainting. Considering that the annual US DOT pavement markings expenditures have been estimated to be approximately $1billion dollars, the potential for savings with the Leetron MRU device and adjustments to maintenance management methodologies are quite significant.[4]

2.3.2 Issues associated with the existing MUR

In the field of vehicle-mounted pavement retro-reflectivity measurement, our investigation began with an examination of issues associated with the only MRU system currently available. The list of issues we identified is summarized as follows:

1. MRU relies heavily on the level of experience and skill of users to collect reasonable data, thus the process is subjective.
2. Many user calibrations (up to 30 times a day) are required to minimize system sensitivities.
3. It is imperative that the vehicle load is kept as constant as possible during the process of data collection. Changes in the weight distribution within the vehicle cause a change in the measurement geometry. Therefore, operators must ensure that they and equipment remain in their original place/position during data collection. It isn't clear what the impact of fuel usage is on changes in weight distribution. [5]
4. In some areas, it can be time consuming to find a flat section of roadway for required system calibrations, which may reduce operator productivity. Flat sections of roadway are needed to ensure proper geometry for the calibration procedure.[6]

[3] Eric R. Green, Kenneth R. Agent. Evaluation of Pavement Marking Performance. www.ktc.uky.edu/Reports/KTC_08_21_SPR_330_07_2I.pdf

[4] Carlson, P.J., E.S. Park, and C.K. Andersen. The Benefits of Pavement Markings: A Renewed Perspective Based On Recent and Ongoing Research. Pending Publication in Transportation Research Record series. Washington, D.C., March 2009.

[5] Robert J. Benz, P.E. MOBILE RETROREFLECTIVITY BEST PRACTICES HANDBOOK. http://tti.tamu.edu/documents/0-5656-P1.pdf.

[6] Charles Holzschuher. Mobile Retroreflectivity Testing for a Pavement Marking Management System. http://www.dot.state.fl.us/Structures/DesignConf2006/Presentations/session52/Final-52Holzschuher.pdf

5. Some studies have observed retro-reflectivity measurement variation can be as much as 20% lower while in motion as opposed to those same measurements taken while stationary.
6. When roads are not being completely flat, changes in surface elevation affect the measurement.
7. The MRU system produces results that are temperature sensitive. The sensor, laser, and interference filter all appear contribute to the temperature sensitivity problem.

It's obvious that the existing system is unstable. It also shows that any height variation on the system has a large impact on measurement accuracy. To understand this impact, we examined the relationship between vehicle movements to retro-reflectivity measurement.

2.3.3 Relationship between vehicle movements to retro light intensity

In the following section, we examined the expected light intensity variations caused by vibration, tilt and road profile. Figure
5 illustrate the scenario where motion from the vehicle causes the device to lift and tilt. Also, the scenario when road profile is lower. Table 2 shows the calculations for light intensity variation.

Lifts

In the case of lifts caused by typical bounces on a vehicle as it travels, a 10mm bounce "up" causes the light source to point at a location 460 mm further away from the vehicle. Based on the inverse square law (see figure 4 on the left) for light intensity verses distance the light intensity at the intersection point is calculated to be 8.6% lower(see lifts in Figure 5 and table 2). The same amount of distance-related light-intensity variation applies when the light reflects back to the imaging sensor (camera). Therefore the total light intensity is expected is to be twice this value or 17.2% lower.

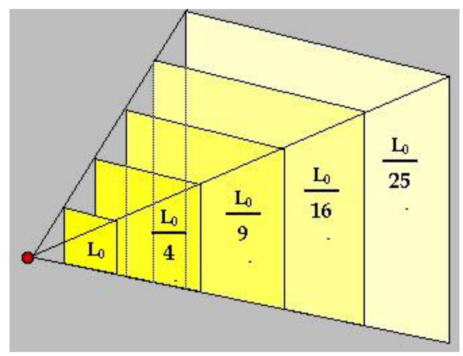

Figure 3 Light intensity verses distance. As distance from the light source increase, the light intensity decrease follows the inverse square law.

Tilt

Tilt represents a condition where the vehicle is not level relative to the road surface. In our example, we assumed that the vehicle is tilted up by 0.05 degrees (the front moves up by 10 mm while the back remains the same and this causes the tilt). Based on calculations similar to those for the effect of lift, the 0.05 degrees of tilt causes the distance illuminated to be 880 mm further away from the target area, and the total light intensity is expected to be 30% lower.

Road Profile

Since the wheel path and the pavement marking area are less than 2 feet away, we did not initially expect height differences between the two areas. Practical application of the system soon showed a problem but investigation revealed the height difference was not the cause. We found that the practice of “crowning” the road to facilitate runoff of water to the roadside was an issue. To examine and accommodate this crowning effect, we assumed that the pavement marking area is 10 mm lower than the wheel path area. The variations will be the same as a lift of 10 mm. The light source is 460 mm further away which results in 17.2% lower light intensity.

The assumption used in this calculation is based on typical road conditions. On secondary roads where the road is not as smooth, variations are expected to multiply. It is easy to conclude that the combination of these three conditions have tremendous impacts on retro-reflectivity measurements. Any MUR system will need to have a solution to solve these issues. Averaging and defocusing are the two methods used on the existing systems. The averaging method does, as you would expect, accumulates and averages a stream of measurement results. The assumption is that the errors will average out over time. The defocusing method is based on defocusing the image on the image sensor. With blurry images, the variation on light intensity created by the variables is less pronounced. Both methods will lessen the variations, but without solving the primary issue and with compromising of the accuracy of the results.

Table 2 Light intensity variation under geometry variation

Conditions	**Amount**	**Unit**	**Distance to Intersection**	**% of Light Intensity variation at intersection**	**% of Light Intensity variation at light sensor**
Initial		Mm	10,000		
Lifts	10	Mm	10.462	-8.60%	-17.20%
Tilted	0.05	Degree	10.88	-15.00%	-30.00%
Lower Profile	10	Mm	10.462	-8.60%	-17.20%

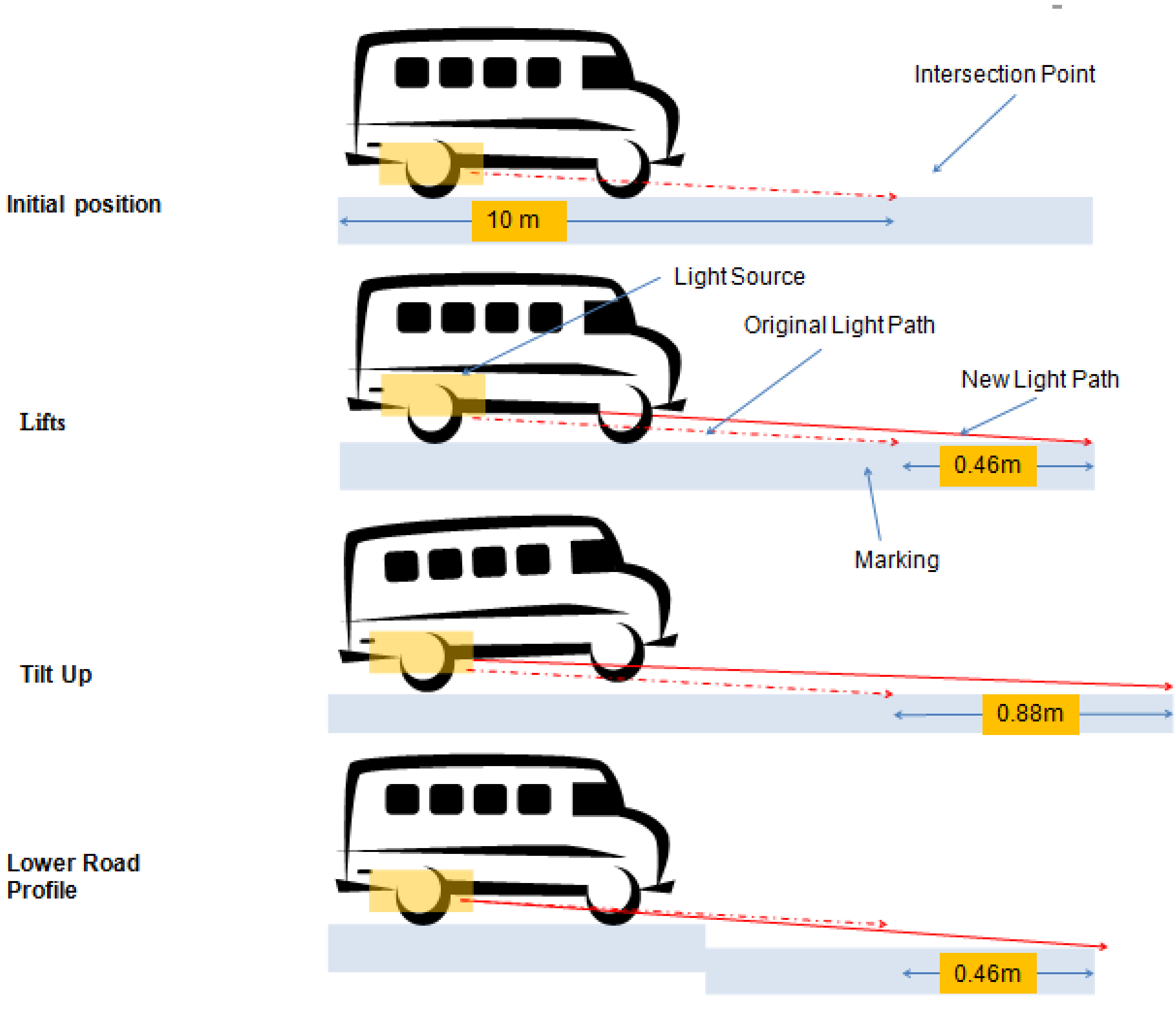

Figure 5 Geometry variation effect on light intensity

2.3.4 Solution

It appeared to the Leetron design team that to build a stable system, a solution was needed to compensate for the variations introduced by motion. Variability of the sensor position relative to the target is unavoidable in practical driving conditions, being caused by the aforementioned factors. All efforts to control and minimize motion will at best create only a marginal improvement in variance. Even if the movement is controlled, the road profile variation will still need to be addressed. Ergo, the solution developed by Leetron under this project is to point the laser at the center of pavement marking and to continually adjust the aim to keep it on target. As stated, by keeping the laser pointed at the same distance, the variables and their effects on the measurements are minimized. As a result, the retro-reflectivity measurements are independent of the motion and road profile variation. The question is whether it is possible to keep the laser aimed at the marking center as the system travels at highway speed.

2.3.5 Tracking System

The difficulty is not in pointing the laser at the center of the pavement marking; the hard part is keeping it there as the vehicle travels at highway speed. As is typical with any new engineering ideas, at some point the inventors realize that full analytical investigation of a theory, regardless of how promising it seems on paper, does not guarantee the expected results in the real world. We knew that feasibility had to be determined by the execution of the idea. We therefore knew we had to build and test the system on the road. To this end, Leetron built a system consisting of the following...

1. A front unit consisting of a camera for location information.
2. A back unit consisting of a laser, image device and light path adjustment (re-aiming) devices.

The sequence of events is as follows:

1. The Camera from the front unit identifies the location of pavement marking.
2. The Camera from the front unit identifies the location of the laser on the pavement.
3. The location information is used to determine the target location for the back unit and calculates the adjustment needed to aim the laser at the target point on the pavement marking.
4. The Laser from the back unit projects a laser onto the pavement marking.
5. The Light bounces back from the glass beads (imbedded in the pavement marking) to the back unit.
6. The imaging device uses optical filtering to reject sunlight yet allows the laser light to pass.
7. The image device measures the amount of light bouncing back.
8. A transformation system converts the light intensity to a retro-reflectivity value.
9. As the vehicle travels, the laser will not stay on the target (center of pavement marking) due to one or a combination of the flowing factors: bounce on the road, sway from driving and pavement profile variation, etc.

10. To keep the laser on target, the system repeats the steps between 1 and 9 to continually re-aim the laser.

How well the Leetron MRU system performs is dependent on this critical tracking system. To keep up with the sway and bounce at highway speed, the tracking system needs to be fast. We determined that a cycle time of 80 cycles per second (80 Hz) would be fast enough to keep the laser aimed at its target. This means that each cycle acquires an image, processes that image for location information, calculates the needed movement to compensate for positional offset resulting from motions and finally repositions the aim of the light source. With this fast cycle time and robust movement control mechanism, our tracking system is performing above expectations. At highway speed, the laser acquires the target and stays centered during the many variable conditions. The Leetron MRU aiming system is to achieving successful performance under real highway conditions.

2.3.6 Imaging System

A critically important component of the system is the imaging hardware. This measures the light retro-reflectivity from the pavement marking. The Leetron MRU imaging system utilizes the latest technology components to provide the continuous measurement input required. These components can continuously capture lines at the rate of 2000 lines per second. At highway speeds, this high capture rate allows the Leetron MRU to produce a continuous stream of measurements at 15mm intervals. A way of visualizing this is to think of drawing a continuous line along the center of the pavement marking. This line would represent the area the system is measuring for retro-reflectivity. Figure 6 on the right illustrates the difference between the existing and the proposed system. This continuous measurement is the basic building block for accurate and repeatable retro-reflectivity measurement.

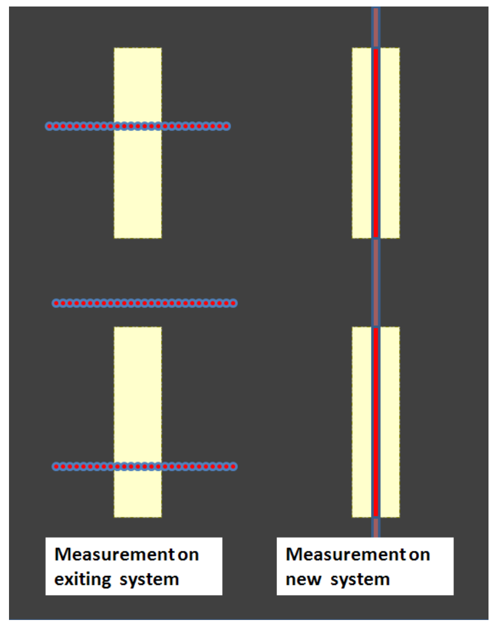

Figure 6 Measurement technique of Leetron MRU is on the right. Competitor's approach is on the left.

2.3.7 Calibration System

One of the design goals for the Leetron system is to avoid the need for frequent calibrations. A system requiring frequent calibration indicates that the measurement method is not stable. To build a stable system, Leetron used comprehensive calibration procedures embodying thousands of calibration points. These calibration points are used to provide a knowledge base that allows the system to react to and handle various scenarios. The Leetron approach to system calibration is to perform one comprehensive calibration during system installation instead of the hourly calibrations of the competing MRU. When operating in the field, a simple daily procedure is used to verify the system is working normally. Since it is not practical to calibrate thousands of points manually, an automated calibration system was developed. The calibration system uses a sample strip moved in horizontal and vertical directions during the process of calibration.

2.3.8 Temperature Control

Temperature control is another function that had to be accounted for in the system to achieve stability. The design accommodates all sensitive electronic components in a stable temperature environment. To keep the size of the back unit small, the system uses a temperature control unit (heating/cooling) located remotely inside the van. Flexible ducting is used to transfer air to the external units.

2.3.9 Results

The project was performed in two stages. Work in Stage 1 focused on designing and building a prototype lab unit capable of measuring retro-reflectivity from sample strips and a calibration system. Work in Stage 2 involved developing, assembling and testing the mobile retro-reflectivity unit mounted on a vehicle.

Lab Unit (Stage 1)

The objective of the lab unit was to build the basic hardware and software structure and demonstrate that the system was capable of retro-reflectivity measurement of pavement markings in stationary mode and a controlled environment.

After the lab unit was built, a test was performed to determine the measurement capability. The test used 12 samples with a retro-reflectivity range from 200 to 1100 candelas per lux per square meter (cd/lx/m2). A New Hampshire DOT LTL2000 Retro-reflect-o-meter was used to provide the handheld data for comparison with the Leetron data. The Leetron MRU measured the same samples. As indicated in Figure 7, the results compare favorably. When compared to the handheld unit, the average standard deviation is 2.64% on the Leetron unit. The data also indicates that the device is repeatable with an average standard deviation below 1.5%.

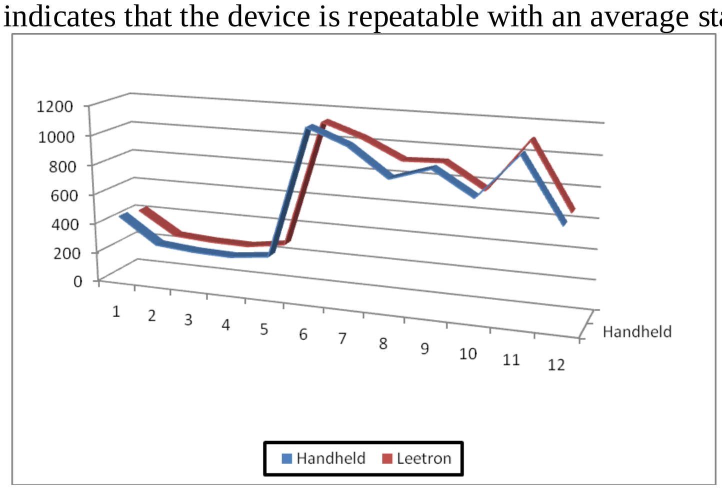

Figure 7 Retroreflectivity measurement on 12 samples between handheld and Leetron unit

Mobile prototype Unit (Stage 2)

Figure 8 Leetron Prototype Mobile Unit.

The transition from lab unit to mobile unit was more complicated than anticipated. First, we began to discover and quantify the effects of sunlight variation, various other conditions on pavement markings such as wear, tire marks, cracks and markings scraped off (by snow plows), etc. This created a better understanding of the challenges for the location identification processes (aiming). Second, the road profile (vertical variation on road) variations and the attendant effects on the system measurements were much greater than what we initially anticipated. We soon discovered the limitations of the lab unit design in a practical environment. Leetron developed a totally new mobile-unit design incorporating and improving on the critical tracking method.

Road Tests

The initial road test of this new improved system was performed in June 2011. It consisted of measurements taken at speeds of 40 MPH and 60 MPH.

Figure 9 shows the result from the 40 MPH road test. Measurements were taken along a one mile long track and were reported at 0.1-mile intervals. The road was painted over 9 months ago. It went through one snow season. There are signs of

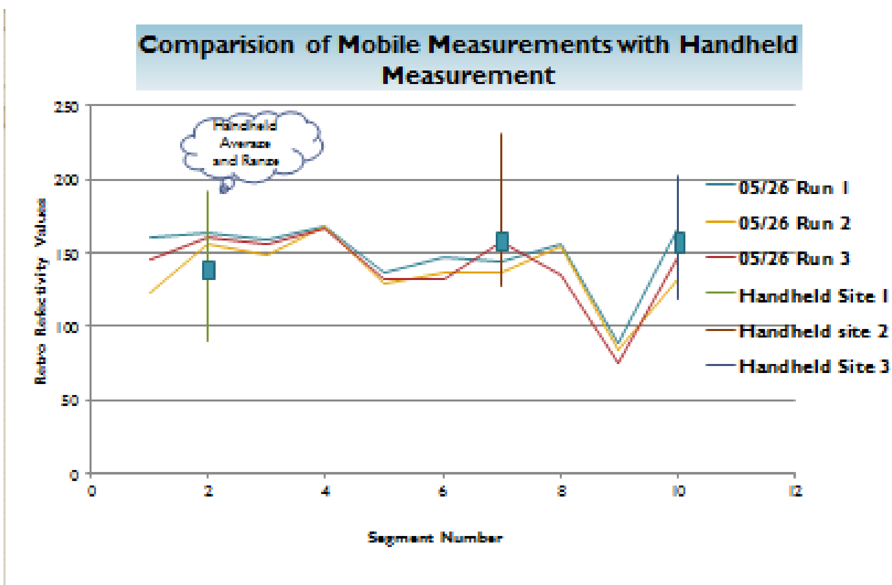

Figure 4 Comparison between mobile and handheld on 40 MPH road

pavement marking paint scraped off by snowplows. The graph on the three runs indicated good repeatability, and the standard deviation is 9%. The graph also shows that the measurement corresponds well to manual measurements taken on the sites.

Figure 10 shows the results from the 60 MPH road test. This was taken along a 3.5-mile segment and was reported at 0.1 mile intervals. Pavement markings were more than six months old and had experienced one winter season. There are signs of pavement marking paint scraped off, presumably by snowplows. The graph on the two runs indicated good repeatability at 4%.

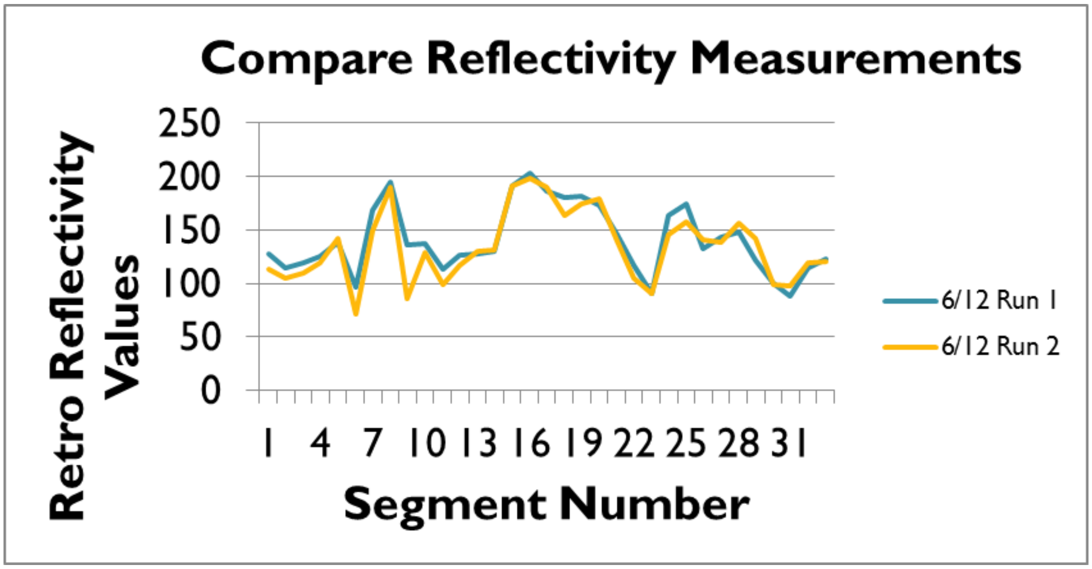

Figure 5 Repeatability Road Test at 60 MPH road

Since the initial road test, more refinements have been implemented. The latest road test shows the repeatability at 1.5% as recorded in Figure 11. At this time, we do not have the comprehensive data set to indicate the system accuracy on road test at this time.

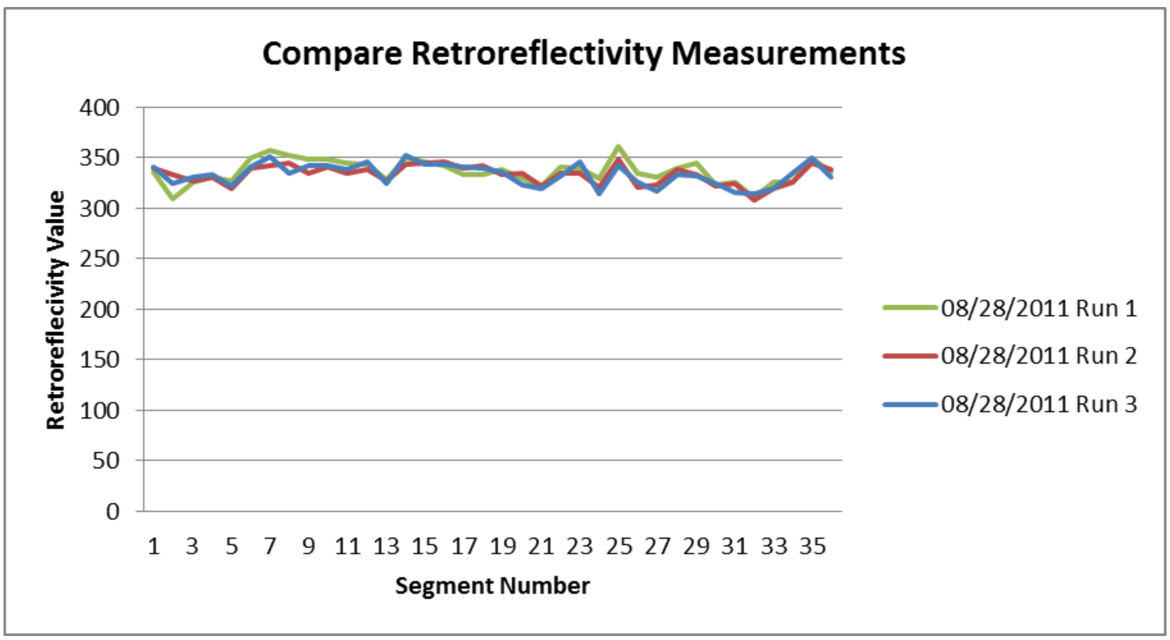

Figure 6 Repeatability Road Test at 60 MPH after refinements

However, initial accuracy test results indicate retro-reflectivity measurement results from Leetron MRU are within the design expectation of 10% accuracy. At current view the final accuracy for the system should be under 5%.

2.4 Plans for Implementation

With the success of the prototype development and the success of the latest model of the system, the project team is confident in the system's ability to continue to improve and set new standards for retro-reflectivity measurement. More engineering and financial resources are being employed toward the commercialization of the unit. . Currently, a beta production version is being designed and built incorporating design changes that provide a more robust solution and will handle a wider variety of marking and environmental conditions. Components in the system have been upgraded to higher performance products optimizing system reliability. Also, additional functionalities will be added to accommodate the needs of a final production model. Once the Leetron system is fully proven, the researchers will explore all the options for commercialization. Since quality is the key to the success of this project, the team expects that direct manufacturing and support would be the natural progression of events. To illustrate and study the potential benefits of the system, the team is looking for opportunities to partner with FHWA and state agencies on pilot projects. One avenue to help customers realize the benefit of the new innovations without committing any capital investment would be to provide a data collection service. The service would build on reliable and efficient data quality and data collection. The team believes that a customer will be able to save sufficiently on repainting strips while keeping American roads safer.

3 Conclusions

It goes without saying that in the current economic environment, there is no state agency that is not interested in achieving savings. Where highway safety is concerned, resources have to be allocated to satisfy federal requirements. The Leetron imaging system provides a faster, more cost effective method and business plan to minimize expenditures without compromising safety to satisfy the Federal requirements. It does so by providing a leap forward in the technology used. Since Leetron MRU measure two lines in a single pass, as compared to one line per pass with other MRUs, the measurement rate will be double. The field production rate of a Leetron MRU is anticipated to be on average of 70% higher. Since the Leetron MRU does not require hourly calibration, nor does it need to be relocated from side to side on the vehicle, we anticipate the measurement rate may be up to 20% higher. Also since the Leetron MRU is designed to operate by one person verses two on traditional system we estimate the operation cost could be lowered by as much as 20%. The research done thus far demonstrates the success of the system and leads to confidence in offering a business plan to assist governments in achieving their roadway requirements by implementing this standard in providing accurate measurement results and data for both primary and secondary roadways. Leetron is ready and eager to work with partners to assist all transportation agencies to realize the benefits of this new and unique invention.

4 Appendix A: Cost saving on repainting budget Estimate

Table 3 Estimate Cost Saving on Repainting Budget

	Service Life (months)		Pavement Marking Cost			Cost for MRU	Estimate Extend Life	Saving before MRU Cost	Saving after MUR Cost	Typical % Saving On Pavement Marking
	Month		$/ft.							
Material	**Typical**	**Range**	**Typical**	**Range**	**$/Mile**	**$/Mile**	**Months**	**$/Mile**	**$/Mile**	
Waterborne paints	12	09-36	$0.06	$0.02 - $0.20	$317	$15[7]	2	$52	$37	11.90%
Thermoplastic	26	12-40	$0.32	$0.08-$0.85	$1,690	$15	3	$281	$266	17.80%

- The above table shows potential saving by utilizing MRU for waterborne paints and thermoplastic. For waterborne paints, 11.9% of saving can be realized based on estimate average life extension of 2 months. For Thermoplastic, 11.9% of saving can be realized based on estimate average life extension of 3 months.

[7] Commonwealth of Kentucky mater agreement, Retroreflectivity Data Collection, http://transportation.ky.gov/Maintenance/Documents/Master%20Agreements/Final_MA_605_1100000852_Retroreflective%20Data%20Collection.pdf