Proceedings of the
International Conference on Mechanical Engineering 2011
(ICME2011) 18-20 December 2011, Dhaka, Bangladesh

ICME11-RT-010

INFRARED ROAD SURFACE DETECTION USED AS AN ABS SWITCH

D. J. McGoldrick[1], J. S. Samuels[1], M. D. Humphry[1], K. J McManus AM,[1] and A.S Blicblau[1]

[1]Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, Victoria, Australia

ABSTRACT

Anti-lock braking systems (ABS) have significantly improved braking performance on sealed surfaces by preventing wheel lock up. However, a study conducted by the American National Highway Traffic Safety Administration (NHTSA) in 1995 found that ABS actually increased stopping distances on unsealed roads (e.g. gravel) for vehicles by as much as 25% over non-ABS vehicles. In lock-up conditions on loose gravel surfaces, the non- ABS vehicle formed a "wedge" of loose material in front of each wheel, which increased the braking force. With the increasing number of vehicles equipped with ABS on the roads, coupled with the high proportion of unsealed road surfaces worldwide, a system capable of detecting changes in the road surface from sealed to gravel which would provide a signal to disengage the ABS, could provide a significant advance in vehicle safety.

Keywords: Anti-Lock Braking Unsealed Roads, Safety.

1. INTRODUCTION

In an emergency, when a car is forced to stop suddenly, the wheels of a car are prone to ‘lock-up’. Anti-lock braking systems (ABS), which are fitted to the majority of cars on the market, release the pressure applied to the brakes, allowing the driver to maintain control and reduce stopping distance [1, 2]. The performance of ABS on sealed roads has proved to increase a driver’s chance of avoiding a potentially dangerous situation. However, experts in the field of automotive braking have also identified major limitations associated with the effectiveness of ABS on certain road surfaces [2-6]. The surfaces that present a major problem are those comprised of loose material such as gravel, sand and snow. When wheel ‘lock-up’ occurs on these surfaces a ‘wedge’ of loose material forms in front of each wheel, increasing the braking force. However, ABS eliminates wheel lock up and thus prevents the formation of a wedge. This feature is largely responsible for the increased stopping distances exhibited by ABS equipped vehicles on loose surfaces.

Several road surface detection systems have been investigated in the past. Systems include a laser coupled with a web cam [7], a distance measurement sensor [8], monitoring lights interaction with the road surface [5], tyres that measure external forces [9], a radiometer that monitors surface brightness [10], Polarimetrics [11] and Sonic detection [12].

Previous research conducted at Swinburne University produced two systems that monitor the tyre/road interface. One system combines a laser with a web camera linked to a visual basic program. It uses image analysis to monitor the reflection angle of the light off the tire/road interface. Another system uses an infrared distance measurement sensor run by a c-code via a handy board. The sensor is positioned in front of the rear wheels to constantly monitor the distance to the tyre/road interface. Any significant reduction in distance is then recognized by the sensor and it is then assumed that the change was caused by the buildup of a wedge. Both systems rely on accurately detecting a wedge of loose material in front of the tyres during a lock-up situation, which works in the laboratory but is difficult to achieve.

This paper focuses on an alternative road surface detection system that does not rely on detecting a wedge to discriminate between different surfaces. The system couples an infrared LED (Z-3235) [13] with an infrared light-to-voltage converting photodiode (Texas Instruments TSL262) [14] and monitors the scatter of light off different surfaces. The infrared band is chosen to reduce the effects of external light. Both units are extremely low in cost and readily available.

For this system, the LED and photodiode are mounted together in a small electronics box facing the road surface. When the sensor passed over a surface, a series of voltage values were recorded from the photodiode, and stored in an oscilloscope. The Discrete Fourier Transform of the values was calculated to generate the light spectrum for the surface. Light spectrums for different surfaces were then compared. These spectrums were used to provide information about the type of road surface.

2. EXPERIMENTAL

2.1 Apparatus and Procedure

The rig used consisted of a test trolley with the road surface detection unit mounted on a frame with four small wheels to allow for rolling movement. The detection unit was positioned 30mm above the simulated road surfaces', which are positioned on a large board, inclined at 3°. Upon release, it rolls at an average of 4.1km/h down the incline allowing the detection unit to acquire a consistent sweep over the simulated road surfaces. The two surfaces consisted of coarse gravel (20mm aggregate, unsealed) and cold mix asphalt (sealed) which are shown in Figure 1.

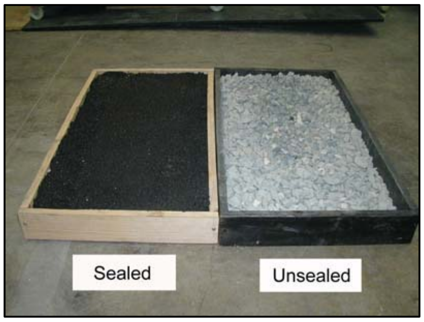

Fig 1. Simulated Sealed and unsealed Road surfaces.

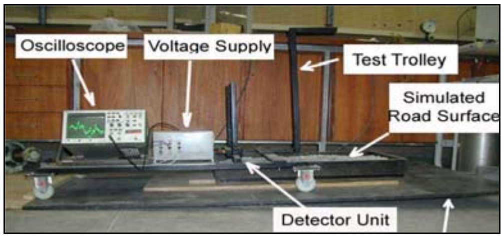

Fig 2. Test Rig for road surface detection.

The apparatus can be seen in Figure 2, which shows the relative layout for experimental work of dry and wet sealed and unsealed road surfaces. A schematic diagram of the road surface detection unit for both gravel and bitumen is s shown in Figure 3.

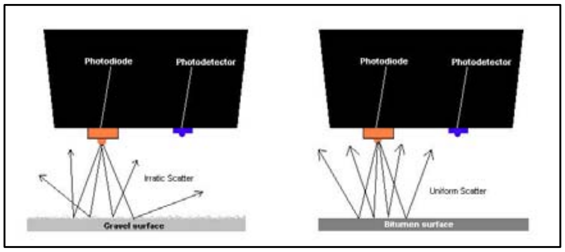

Fig 3. Schematic diagram of the road surface detection unit.

The oscilloscope, power supply and RS-232 cable were wired up to the Road Surface Detection Unit, as per apparatus (Figure 4)

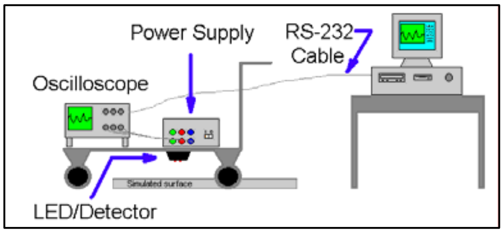

Fig 4. Road surface detection unit test rig setup schematic.

The oscilloscope was adjusted to the settings shown in Table 1:

Table 1: Oscilloscope Settings.

Settings	
Trigger Mode	Single
Sec/Div	$200\text{x}10^{-3}$
Volts/Div	$5\text{x}10^{-3}$
Sampling Frequency	1000Hz

To begin a pass the test rig was moved to the start position of the inclined test ramp. The rig was then released from the start position of the ramp allowing it to roll over the test surface. Upon release of the test rig, the oscilloscope was manually triggered and the voltage values recorded. The values were then downloaded onto the PC via the RS-232 cable and stored as a comma separated variable (CSV) file. This process was repeated 30 times for wet gravel, dry gravel, wet bitumen and dry bitumen. It is a general rule in probability that 30 samples give a 95% confidence interval for standard deviation. The voltage values for each surface were then averaged in MATLAB [15] and spectral analysis was conducted to estimate the power spectral density of the values for each.

2.2 Spectral Analysis

Matlab version 5.3 was used for spectral analysis. The analysis consisted of converting the time domain data to frequency domain using the Fourier Transform method. Computer programs use an algorithm that simplifies the process known as the Fast Fourier Transform (FFT). The (FFT) of the data was generated using the spectrum command. This command estimates the Power Spectral Density (PSD) of the signal using Welch's averaged periodogram method [16]. The signal is divided into overlapping sections, each of which is de-trended and windowed, then zero padded to the specified length [14] . Windowing helps to remove the recurring features that clutter an FFT and make interpretation difficult. The recurring features are often caused by surrounding noise generated from sources such external light and electrical devices. The result of applying these spectral analysis techniques is a Power Spectral Density curve that is characteristic of the road surface.

Samples of output for the time domain signal for both the sealed and unsealed roads are shown in Figures 5 and 6.

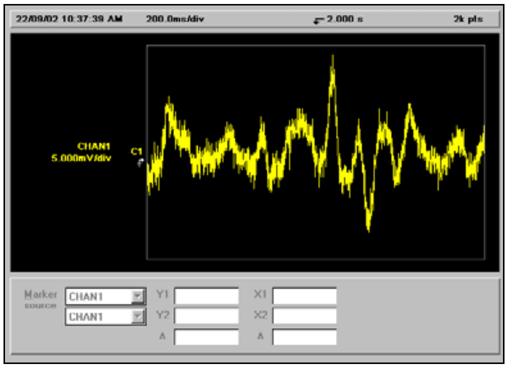

Fig 5. Sample of signal output for unsealed roads

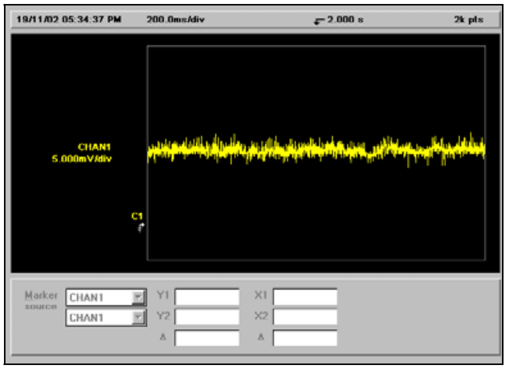

Fig 6. Sample of signal output for sealed roads

3 RESULTS AND DISCUSSION

The following gives a summary of the results obtained from spectral analysis of the test data. The graphs displayed (Figures 7 and 8) are the averaged power spectral density curves generated from 30 tests for each road surface. The graphs show a comparison between sealed and unsealed surfaces.

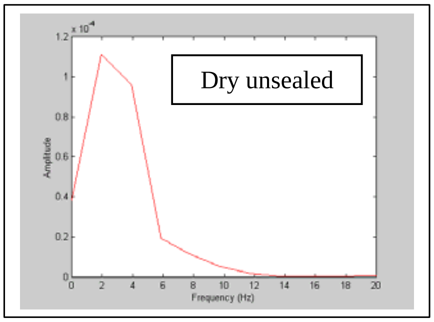

Fig 7. Power spectral density of reflected light from dry unsealed road surface frequency scale 0 - 20Hz

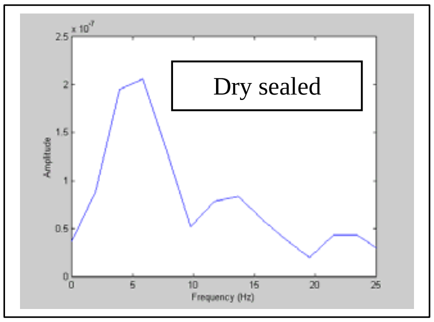

Fig 8. Power spectral density of reflected light from dry sealed road surface enlarged amplitude and frequency scale 0 - 20Hz

It appears that there is frequency peak for both surfaces below 15Hz, which is relatively larger than any other peaks at higher frequencies. This suggests that both surfaces have similar reflectivity properties. The results depicted in both figures also show the considerable difference in amplitude. In comparison, the amplitude for the dry unsealed surface is larger by a factor of 10^3. The variation can be attributed to the differences in surface texture. The unsealed surface is noticeably rougher than the sealed surface therefore it is expected that it would reflect the light in a more non-uniform manner due to its rough nature, while the smoother sealed surface would produce a more consistent reflection. The results suggest that an increase in surface roughness results in increased amplitude.

3.1 Wet Roads

Figures 9 and 10 show the PSD for a wet unsealed surface and a wet sealed surface. Once again, a difference exists between amplitude as was seen in the dry state. However, in this case the unsealed surface is only larger by a factor of 10. This is possibly caused by the change in colour of the unsealed surface when wet. Upon application of moisture, the surface became increasingly darker likening it to that of the sealed surface.

Figure 10 displays increased amplitudes at frequencies of up to 80Hz. This feature indicates an increase in reflectivity of the surface. A large difference can be seen when the PSD for the wet sealed (Figure 9) is compared to that of the dry sealed (Figure 8).

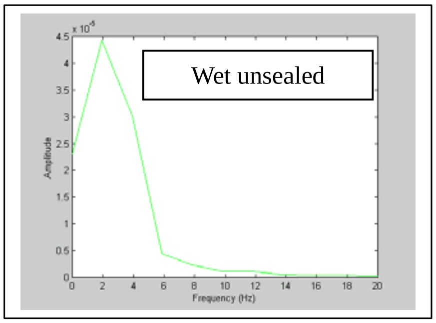

Fig 9**.** Power spectral density of reflected light from wet unsealed road surface enlarged amplitude and frequency scale 0 - 20Hz

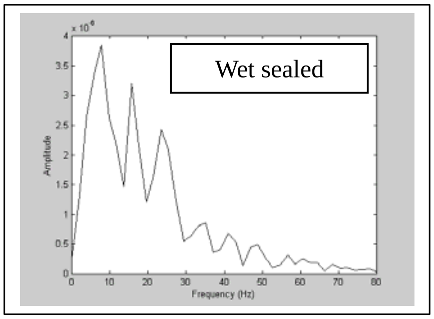

Fig 10**.** Power spectral density of reflected light from wet sealed road surface enlarged amplitude and frequency scale 0 - 80Hz

The fact that water pools on bitumen and has a much higher reflectivity than bitumen or gravel is the most likely explanation for this. The porous nature of the gravel may be responsible for minimizing the amount of water pooling on the surface therefore reducing the amount of any significant change in the reflective properties. These results suggest that this system is not only sensitive to changes in surface texture but also colour and moisture.

3.2 Wet Sealed Roads vs. Dry Sealed Roads

Figures 9 and 10 show the effects of water on the sealed surface and unsealed surfaces. As discussed above, the reflective properties of water that pools on the surface are most likely responsible for the increased amplitudes at frequencies up to 80Hz. This information is quite useful given the fact that a vehicle performs differently under braking on wet and dry sealed surfaces

3.3 Wet Unsealed Roads vs. Dry Unsealed Roads

Figures 7 and 10 compare the output for a dry and wet unsealed surface. Both curves display increased amplitudes within the same frequency range, however, the magnitude of the amplitudes differs slightly. The wet unsealed surface has a smaller amplitude, which is most likely brought on by the darkening in colour when wetted. Unlike sealed surfaces, a means of distinguishing between wet and dry gravel is not essential, as it does not affect how a vehicle will react under heavy braking in any significant way. Therefore, the similarity in the spectral densities for both conditions does not pose as a problem as it is not critical to distinguish between the two.

3.4 Road Surface Characterization

As a means of translating the data, a ratio has been assigned for each differing road surface. This figure has been calculated by dividing the sum of the power between 0 and 49Hz by the sum of the power between 50 and 250 Hz. Except for Wet sealed, the majority of power in the spectral densities for each surface lies between 0 and 50 Hz. Through doing this, it is possible to assign a numerical range that may represent a certain surface. Table 2 presents a list of ratio ranges that could be indicative of the road surface

Table 2**:** Road surface frequency ratios and ratio ranges

SURFACE	**RATIO**	**RANGE**
Dry Unsealed	20.8027	>15
Wet Unsealed	9.6377	8-15
Wet Sealed	3.0190	1-4
Dry Sealed	0.3360	<1

4. LIMITATIONS OF THE SYSTEM

The following gives a summary of the possible limitations associated with the system and its implementation onto a vehicle.

- To be fitted to a vehicle, the surface detection unit would have to operate at a distance of around 300mm from the road surface. All testing was conducted at a working distance of 30mm.
- Obstructions to the light source or sensor such as dirt and mud could weaken the signal causing an incorrect diagnosis of the road surface.
- Dynamic testing of the system to simulate real life driving conditions i.e. suspension movement and accelerations have yet to be validated. The effect of these variables on the spectral density curves for each surface is, to date, unknown.

The road surfaces used for testing represented two extremes of surface texture. The gravel was extremely coarse in comparison to the relatively smooth bitumen. Naturally, intermediate unsealed road surfaces will provide different spectral feedback and therefore need to be investigated thoroughly. Throughout the world, road surfaces vary greatly, and other variants of road surface such as sand, snow and mud need to also be investigated.

Results shows that wet and dry gravel produce a similar outcome. However, wet and dry bitumen produce curves that differ quite considerably. This can be explained by the change in reflectivity properties of the surface in the presence of water. As well as surface texture, the system also exhibits the capability to detect changes in colour and reflectivity

5. RECOMMENDATIONS

This investigation has demonstrated that an IR light source coupled with an IR receiving photodiode can generate power spectral density curves that can be used to distinguish between different road surfaces. However, future work needs to be conducted to validate that the system is capable of producing positive results under driving conditions and over a wide variety of road surfaces. Further testing is required for different grades of gravel, sand, mud and snow. Throughout this investigation, the surface materials used represented the two extremes of road surfaces. Bitumen surfaces that have deteriorated over time and become rough produce a spectral density that closely resembles a gravel surface. However, at the other end of the scale, fine sandy surfaces may produce spectral densities similar to that of a sealed surface.

Significant improvements can be made to the electronics of the system to improve its performance. Noise in the signal proved to be a problem throughout the investigation. A possible solution would be to integrate an oscillator and demodulator into the circuit. Through setting up the system to oscillate and receive light at a high frequency, the effects of noise would be eliminated.

Although optoelectronics prove to be very successful in achieving the aims of this investigation it is believed that other areas exist that could be developed to compliment this system. An area that could provide information regarding the roads surface is road noise. Changes in surface texture provide an audible change in noise when traveling in a vehicle. It is possible that road noise data could be compared to information gained from the system used in this investigation to provide an accurate diagnosis.

6. CONCLUSION

The investigation has looked at the effectiveness of using infrared light to distinguish between a sealed and unsealed road surface. Using an Infrared LED coupled with an Infrared receiving photodiode the system analyses the amount of scatter off the roads surface and operates independently of the tyre/road interface. The two surfaces analyzed comprised of coarse gravel and smooth bitumen both in their wet and dry state. The generation of averaged power spectral density curves through spectral analysis from 30 sets of time domain data has produced curves that display individual characteristics representative of the surface. Power ratios taken between different frequency bands have produced numbers that can be used to accurately distinguish between the different surfaces. In comparison to the systems investigated in previous years, this unit displays potential for providing accurate results when adapted to a vehicle.

Although further testing on different surfaces is required, the monitoring of infrared light scatter off different surfaces is a viable basis for further research into improving a vehicles braking performance over a range of different road surfaces. This system has the potential to diversify the modern braking system, improving its performance on a wider range of road surfaces.

7. REFERENCES

1. Bosch, R., *Conventional and Electronic Braking Systems for Passenger Cars*, ed. R.B. GmbH. 2003, Cambridge MA 02138-1804 USA: Bentley Publishers
2. Metz, L.D. and R.R. Scheibe, *Use of ABS in Emergency Brake-and-Steer Maneuvers*, in *SAE International Journal of Passenger Cars- Electronic and Electrical Systems*. 2009, SAE International.
3. Beyer, C., H. Schramm , and J. Wrede, *Electronic Braking System EBS - Status and Advanced Functions*, in *International Truck & Bus Meeting & Exposition*, . 1998, SAE: Indianapolis, IN, USA, .
4. Eddie, R., 1994, "Anti-lock Brakes on Snow and Ice". Society of Automotive Engineers: 47-49.
5. Elman, E., *Novel cost-effective remote ice detection system allows extensive deployment*, in *Transport Research Arena Europe* 2008: Ljubljana.
6. Austin, L. and D. Morrey, 2000, "Recent advances in antilock braking systems and traction control systems ". Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 214(6): 625-638.
7. Korolis, J., et al., *Image analysis applied to discriminate between sealed and unsealed road surfaces*, in *7th International Conference on Urban Transport and the Environment for the 21st Century (Urban Transport VII)*, L.J. Sucharov and C.A. Brebbia, Editors. 2001, WIT Press: Lemnos Island, Greece. p. 681-690.
8. McManus, K.J., et al., 2003, "Real-Time Detection of Unsealed Surfaces During Skidding". Transportation Research Record: Journal of the Transportation Research Board, 1819A / 2003: 237-243.
9. Cheli, F., et al., 2010, "On the impact of 'smart tyres' on existing ABS/EBD control systems". Vehicle System Dynamics, 48(1): 255-270.
10. Tabuchi, T., S. Yamagata, and T. Tamura, 2003, "Distinguishing the road conditions of dry, aquaplane, and frozen by using a three-color infrared camera". Proc. SPIE 5073: 277.
11. Finkele, R., 1997, "Detection of ice layers on road surfaces using a polarimetric millimetre wave sensor at 76 GHz". Electronics Letters, 33(13): 1153-1154.
12. Valenti, M., 1996, "Sonic ice detection". Mechanical Engineering, 118(1): 10-12.
13. Digi-Key, *Z3235-ND*, O.E.I.-I. Div, Editor. 2011, DISPLAY HMI TFT COLOR 5.7: Thief River Falls, MN 56701 USA
14. Farnell. *TAOS - TSL262R-LF - PHOTODIODE, SENSOR, L/VOLTS*. http://au.element14.com/taos/tsl262r-lf/photodiode-sensor-l-volts/dp/1182351?Ntt=TSL262 2011 [cited 2011 10 August].

15. Mathworks. *MATLAB-Signal Processing Toolbox* 2011; Available from: http://www.mathworks.com/products/signal/demos.html?file=/products/demos/shipping/signal/spectralanalysisobjsdemo.html.
16. Smith, J.O. *Spectral Audio Signal Processing*,. 2008 [cited 2011 30th August]; October 2008 Draft,:[Available from: http://ccrma.stanford.edu/~jos/sasp/, .

8. MAILING ADDRESS

Address for contact.
A.S.Blicblau, Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, Victoria, Australia 3122.
Phone : 61392148531.
E-mail : ablicblau@swin.edu.au