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Investigation of an Optical Method to Determine the Presence of Ice on Road Surfaces

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Abstract. This report contains a review of alternative techniques to determine the presence of ice on road surfaces, ranging from passive, in-pavement technologies, through various remote sensing technique. A technique which we dub Polarized Reflectance Infrared Signature Method (PRISM) is argued to offer the best potential, based on a variety of criteria, to include relevance to both vehicle- and roadside-borne measurements. The PRISM technique uses differences in measured near infrared reflectance between ice, water and dry road due to absorption, in addition to the effect of polarization to discount the contribution of specular (i.e., mirror-like) reflectance off the front surface. An additional proof of concept experimental increment of work to investigate PRISM is recommended as a first step, to be followed by a prototype to test the device in real and icy highway situations. Two increments of future work are envisioned: conduct of a proof of concept test as originally planned, and if the concept is proven build a prototype.

Key Words. Ice Detection, Remote Sensing, Discrimination, Near Infrared, Polarization, Road Weather Information.

Executive Summary. This document reports on findings from a short term exploratory development project to determine the feasibility of a roadside or in-vehicle remote ice sensing system to differentiate localized roadway traction states (i.e., provide knowledge of dry, wet, or icy road surface conditions). We call this technique the Polarized Reflectance Infrared Signature Method (PRISM), and it uses differences in measured near infrared reflectance between ice, water and dry road due to absorption, in addition to the effect of polarization to discount the contribution of specular (i.e., mirror-like) reflectance off the front surface to minimize ambiguities in discerning different absorption characteristics.

Potential applications include a sensor mounted over an ice-prone bridge to indicate the certain presence of ice to motorists via a changeable message sign. An adjunct application would be to employ a camera-like sensor to provide Caltrans maintenance crews with a means to spatially discriminate ice patches from non-icy roadway sections; in this manner, the success of de-icing operations could be guaranteed. Another implementation of PRISM could be in the form of a low cost non-imaging sensor mounted forward of the front wheels to forewarn the driver of localized traction states, then provide both a driver warning to prompt situational awareness, and a “smart assist” to begin the application of traction control countermeasures. In this manner, subsequent driver-initiated braking or control would have already been prompted and automatically in process by the time the driver reacts to complete the action.

Finally, an AHS extension would be to fully automate wheel or engine torque traction control, given combined PRISM sensor and in-vehicle true speed/longitudinal slip inputs. Using inter-vehicle or vehicle-to-roadside communications, the first encounter with a local ice patch could be communicated to both the following vehicles (intra- and inter-platoon) and to the roadside maintenance and operations authority.

Prior to a detailed description of PRISM, pros and cons of competing systems such as in-pavement systems, or other remote techniques such as temperature-, acoustically-, or even different NIR absorption-based systems are discussed. We conclude that PRISM represents the most promising method – if it can be shown to be feasible and cost effective. Therefore, a follow-on activity is being planned to conduct the experiment and provide a report assessing the technical feasibility of the principle.

1.0 Introduction

This report is organized as follows: Section 1 (Introduction) summarizes the motivation and overview of the project, Section 2 (Summary of Results) provides the original objectives and modified outcomes, Section 3(Alternate Techniques) reviews other ice detection methods, and Sections 4 (PRISM: Principles and Theory), 5 (Conclusions and Recommendations), and 6 (Future Work) focus on the primary method of determining the presence of ice on road surfaces. Section 7 contains references.

This project was designed as a short term exploratory development to determine the feasibility of a roadside or in-vehicle remote ice sensing system to differentiate localized roadway traction states (i.e., provide knowledge of dry, wet, or icy road surface conditions). The impetus was to provide an efficient sensing component to a vehicle- or infrastructure-borne anti-icing strategy, and ultimately, to allow for more efficient winter operations on California highways.

We dub this method the Polarized Reflectance Infrared Signature Method (PRISM) to connote the basic physics of the technique; the PRISM technique is optical and utilizes the polarized reflectance from the near infrared (NIR) portion of the spectrum[1]. It is based on the differences in measured reflectance between ice, water and dry road due to absorption, and it uses the effect of polarization to discount the contribution of specular (i.e., mirror-like) reflectance off the front surface to minimize ambiguities in discerning different absorption characteristics. As such, PRISM is conceived to overcome various deficiencies in ice detection techniques, namely, in-pavement systems, or other remote

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[1] Note that the NIR is close to visible wavelengths, and although low cost Si photodiodes and CCD arrays are not sensitive in this regime, relatively cheap solid state (e.g., InGaAs) detector-based NIR sensing systems are readily available. The intent of the PRISM technologies is to detect ice within "reasonable" costs, so conventional thinking which considers infrared detection to be expensive is circumvented by utilizing NIR effects. The NIR detectors differ greatly from mid- to long-wave "thermal" infrared band detectors, which are considerably more expensive, unreliable, and have shorter MTBF statistics.

techniques such as temperature-, acoustically-, or even different NIR absorption-based systems.

These competing systems are discussed in this report, with pros and cons of each described; however, the main focus of the report will be the principle and envisioned application of PRISM.

In order to conceive how PRISM would work, it is useful to consider several applications. Once such application would be a sensor mounted over an ice-prone bridge to indicate the certain presence of ice to motorists via a changeable message sign. An adjunct application would be to employ a camera-like sensor to provide Caltrans maintenance crews with a means to spatially discriminate ice patches from non-icy roadway sections; in this manner, the success of de-icing operations could be guaranteed.

Another implementation of PRISM could be in the form of a low cost non-imaging sensor mounted forward of the front wheels to forewarn the driver of localized traction states, then provide both a driver warning to prompt situational awareness, and a “smart assist” to begin the application of traction control countermeasures. In this manner, subsequent driver-initiated braking or control would have already been prompted and automatically in process by the time the driver reacts to complete the action.

An AHS extension would be to fully automate wheel or engine torque traction control, given combined PRISM sensor and in-vehicle true speed/longitudinal slip inputs. Using inter-vehicle or vehicle-to-roadside communications, the first encounter with a local ice patch could be communicated to both the following vehicles (intra- and inter-platoon) and to the roadside maintenance and operations authority.

2.0 Summary of Results

The original intent of this project was to conduct experiments to verify this discrimination technique, but this could not be completed. Problems first arose due to difficulty in obtaining a NIR spectrometer supplier to meet spectral sensitivity requirements and who would also lease the instrument for this one-time and relatively low-budget experiment. Once a supplier was found, only a short-term rental could be arranged. The spectrometer's PCMCIA data acquisition card failed early in the experimentation process, then the term of the rental expired as the instrument was being sold. The instrument was returned to the supplier and not available for the subsequent term of this project's period of performance.

Hence, the work performed in this project was mainly comprised of an investigation of the principles and theory of conducting this type of discrimination technique. Alternate ice detection techniques used in road surface condition applications were investigated, and these are discussed. The conclusion, however, is that PRISM represents the most promising method – if it can be shown to be feasible and cost effective. Therefore, a follow-on activity is being planned to conduct the experiment and provide a report assessing the technical feasibility of the principle.

3.0 Alternative Techniques

Several methods have been applied toward the general category of road surface condition sensing, ranging from the "tried and true" through various novel techniques. They can be categorized as either passive in-pavement sensors, or remote sensing techniques. Passive in-pavement sensors can measure pavement temperature, moisture, or both. Remote sensing techniques can be further categorized as acoustical or optical, with optical sensors subdivided into spatial profile-, temperature-, and absorption/reflection-measuring types.

3.1 Passive In-Pavement Sensors

An example of a passive sensor is the SCAN FP 2000 Roadway/Runway Sensor manufactured by Surface Systems, Inc (SSI). The SCAN FP 2000 measures pavement temperature, presence of moisture, and depth of solution. From these measurements, the percent of ice/solution, freeze point (defined as the temperature at which the solution, and not just water alone, will freeze), and the relative percent solid ice/solution is inferred. The SCAN FP 2000 was potentially envisioned to be part of a Roadway/Runway Weather Information Systems (RWIS) product purveyed by SSI, where sensor inputs would by incorporated into a weather and pavement condition forecast. The RWIS is also marketed to the CVO community as a comprehensive weather and pavement condition planning and advisory tool called TravelCAST.

The major difficulty in using the SCAN FP 2000 – or other passive in-pavement sensing devices – is that its measurements apply only to the solution that lies directly over the sensor head; in the case of the SCAN FP 2000, this constitutes a circular area with a 13.3 *cm* diameter. Road surface conditions can be quite localized with the presence of grades, crowns, potholes, and potentially highly variable sources of subsurface thermal masses (i.e., bridges). It is cost-, computationally-, and in many cases, structurally prohibitive to place a dense network of passive sensors in an attempt to capture this spatial variability; moreover, to do so may require densities approaching several *cm*/device. Hence, in using a passive sensing system, inaccurate mapping of ice on the roadway will occur, and some localized hazardous ice patches will not be detected.

3.2 Remote Sensing Techniques

Acoustic Technique

One aspect of the Porsche participation in the PROMETHEUS project was to determine the roadway/tire friction potential. In deriving a technique, the overall problem was decomposed into influencing variables, one of which was the identification of road surface wetness and another, the road texture [1]. These were inputs into an algorithm to determine the coefficient of friction associated with dry pavement, and with wet pavement, various water depths and the presence of snow or ice. Although the specific parameters used to acoustically identify road surface wetness and texture were not published, the basic phenomenology was described, namely, that a characteristic acoustic signal emanates due to water splashes from the wheel to the arch liner. The signal can be measured with accelerometers installed near the rear axle hubs, and mapped according to frequency. The signal characteristic is a function of water depth, and although not stated explicitly, probably to snow or ice.

The vehicle structure figures prominently in determining the presence of water. Hence, this technique must be uniquely tuned to each vehicle and tire, and it may be suitable for in-vehicle sensing provided by OEM's and *not* infrastructure-based sensing. Additionally, as mentioned above, the detection of ice by this technique is a tenuous inference in examining the literature and may not be true; moreover, the error bounds and costs associated with this technique are unknown.

Optical Sensors: Spatial Profiling

An optical spatial filter/sensor has been applied by investigators from the OMRON Corporation in Japan to distinguish five road surface conditions: dry and wet asphalt, fresh and trampled snow, and black ice [2]. The principle of operation is an empirical correlation between reflected intensity and particle size, where measured data is mapped into a two-dimensional space defined as overall intensity vs. a lumped low/high-spatial frequency quotient. Each of the five road surface conditions corresponds to clusters in regions within this two-dimensional space. An additional advantage to the spatially resolved measurements is that the time for spatial features to traverse the entrance aperture slit resolution element is recorded, and true vehicle velocity is measured. This could be essential in determining wheel slip – and therefore the friction coefficient – but this consideration is not mentioned by the authors.

Errors in road surface classification arising from this technique are unknown, as the data samples collected to implement the algorithm are not extensive, and the effects of loose asphalt, potholes, expansion joints, or other surface discontinuities is unknown. This technique will require artificial illumination if used in the look down mode employed experimentally, especially if used at night or during inclement weather. This technique is impractical for any roadside-based measurement, as the 2 *mm* spatial resolution (which we derive from the published spatial filter characteristics) could not be achieved with even modest (i.e., several meter) ranges necessitated by mounting the sensor on an electrolier.

Optical Sensors: Temperature Measurement

A method of indirectly determining whether temperatures are conducive to icing is by optically thermometry by means of a relatively cheap infrared detector (e.g., pyroelectric or thermopile element)[3]. Thermal imaging is not necessary, but could be accommodated via a considerably more expensive array. A variety of techniques could be employed, ranging from a relatively straightforward radiance-to-temperature calculation from Planck's Law, assuming a blackbody or graybody. Because knowledge of surface emissivity is a problem with varying road surfaces, a two-wavelength pyrometry technique could be employed.

The RoadWatch Warning System from Sprague Controls, Inc is one on-vehicle system, whose primary market is for trucks. It is mounted on a mirror bracket and probably uses a single-wavelength thermography technique. The Mobile Surface Temperature System Model 994A by Control Products, Inc. is a competitive product based on the same principle. Additionally, an industrial single-wavelength pyrometer, including processing software, can be purchased for as little as $690 from Omega Engineering, Inc; many other vendors are also in this market.

To our knowledge, the more accurate two-wavelength pyrometry has not been applied for ice detection purposes, but a simple technique is purveyed by the NASA Lewis Research Center, and it is also available for laboratory purposes under the name of ThermaViz by Stratonics, Inc. The ThermaViz product provides a thermal image displayed in temperature units, which would be highly useful in mapping the presence of ice.

The major problem in employing a temperature-based technique is that the threshold of detection for ice is a road surface measurement predicated only on a temperature measurement corresponding to freezing point of water, which may not correspond to the existence of ice due to the following reasons:

- there may not be significant moisture on the road surface;
- there might exist some ice mixed with cold water (as in a cold point ice bath, similar to those commonly used in laboratory experiments as a way to establish a freezing point);
- there could be some contamination – the extreme being salt or deicing fluids – which would lower the freezing point, possibly significantly; and
- the temperature measurement could be inaccurate, especially if two-wavelength pyrometry is not used.

Optical Sensors: Absorption/Reflection Techniques

Two methods of applying principles of absorption and/or reflection were employed by the Darmstadt Technical University and Stuttgart University of the PROMETHEUS Tyre/Road-Friction-Monitoring-Group to discriminate ice from water: NIR absorption spectroscopy; and light emitting diode (LED) reflectance [4].

The use of NIR absorption spectroscopy is quite similar in principle to the PRISM discrimination technique, which is described in Section 4.1 of this report. The Darmstadt/Stuttgart researchers took advantage of the difference in absorption properties of water and ice by ratioing the two full-width-half-maximum bands, at approximately 1.40 – 1.44 μm and 1.46 – 1.52 μm, to yield a discriminant between the two states, given illumination by a standard quartz-halogen light source embedded in a standard configuration fog lamp. These wavelengths are slightly different than those proposed in the PRISM technique, but the absorption properties arise from the same phenomenology. The main difference between the two applications is that the Darmstadt/Stuttgart group did not employ polarization.

The Darmstadt/Stuttgart group separately employed LED reflectance at wavelengths near the transition of visible-NIR (about 800 *nm*) by recognizing that backscatter intensities between ice, water and dry surfaces differ; moreover, they recognized that backscatter intensities vary as a function of water depth. When both these measurements are combined with a high-resolution laser texture sensor, "wetness" and "ice" number, and an estimate of the friction coefficient are derived.

Again, these results do not utilize polarimetric return to eliminate the low grazing angle interference from the sun. This omission is shown below to degrade the utility of their technique except during the middle portion of the day, when the angle of incident sunlight is within 53° of the solar zenith. The use of active devices in determining friction coefficient, namely the LED and laser texture sensors, may not translate to the longer ranges required for infrastructure-based devices. This will depend on the complexity of the optics necessary to project the correct beam size and resolution to the ground surface. For example, the laser texture sensor employed by the Darmstadt/Stuttgart researchers met a 0.1 *mm* spatial resolution requirement; this would not be cost effective in a roadside implementation.

4.0 PRISM: Principles and Theory

We shall describe the underlying principles and theory behind two primary aspects of the PRISM technique: absorption differences between ice and water, and the use of polarization as a further discriminant, especially at lower grazing angles of incidence.

4.1 Absorption Spectra

It is well known that molecular emission and absorption energies are dependent on quantum transitions between electron excitation levels and that resulting photon energies are related to specific frequencies. These relationships were first expressed by Planck in 1900, then extended by Einstein and others into what is now termed Quantum Theory.

These principles also apply, of course, to water absorption in optical regimes, where absorption energies are dependent on temperature and state (liquid, solid, vapor). Emission/absorption studies have yielded a large body of spectroscopic literature characterizing the liquid H_2O state [5,6,7,8,9]. Also, a considerably smaller, though interesting, body of work has focused on solid state (i.e., ice) H_2O spectra [10,11]. These studies were primarily intended for meteorological and oceanographic purposes, as the application of aircraft- and satellite-borne remote sensors required knowledge of optical constants to interpret measured terrestrial phenomena and to remove atmospheric effects from data. Other applications have included botany, where optical spectra of plant foliage have proven useful in studying hydration effects [12].

Additional research in this area has focused on characterizing the differences between ice and water infrared absorption spectra. Although this research has not been reported in the literature, it was used to describe ice contamination effects on spectrally resolved images collected by high altitude sensors. This was then developed into a reliable and repeatable diagnostic procedure for high altitude remote sensors, as the absorption strength of cryocontamination was shown to be related to the degree of instrument vacuum loss.

Later, this research was extended into a proprietary application (unrelated to highway ice detection) capitalizing on the ability to discriminate between ice and water in the NIR, chiefly because of the ready availability of cheaper, uncooled sensors in this regime (e.g., InGaAs, PtSc, or if even shorter wavelengths can be found to work, Si detection substrates). Multispectral ratioing algorithms using adjacent absorption and guard bands were developed and validated through reflectometry experiments to discern the presence of ice or water on aluminum surfaces. However, commercial liability issues preempted further work on this promising technique.

Plots of absorption vs. wavelength for ice (Figure 1) and water (Figure 2) are extracted from this work to illustrate the marked differences between the two spectra. The SB1 label corresponds to the 1.20 - 1.30 μm guard band, and SB2 corresponds to 1.45 - 1.55 μm absorption band. Figure 1 shows the strong absorption within SB2 limits for ice, whereas Figure 2 shows virtually no SB2 absorption for water; and SB1, while showing some spectral content, is still relatively flat for both cases. This indicates that the SB2/SB1 quotient is a potentially powerful discriminator between ice and water spectra. Figure 3 shows these SB2/SB1 ratios for a large test matrix comprised of various thicknesses of ice, water and de-icing products. The figure verifies that an application of a multispectral ratioing rule such as SB2/SB1 indeed verifies that ice and water can be readily discerned in the NIR.

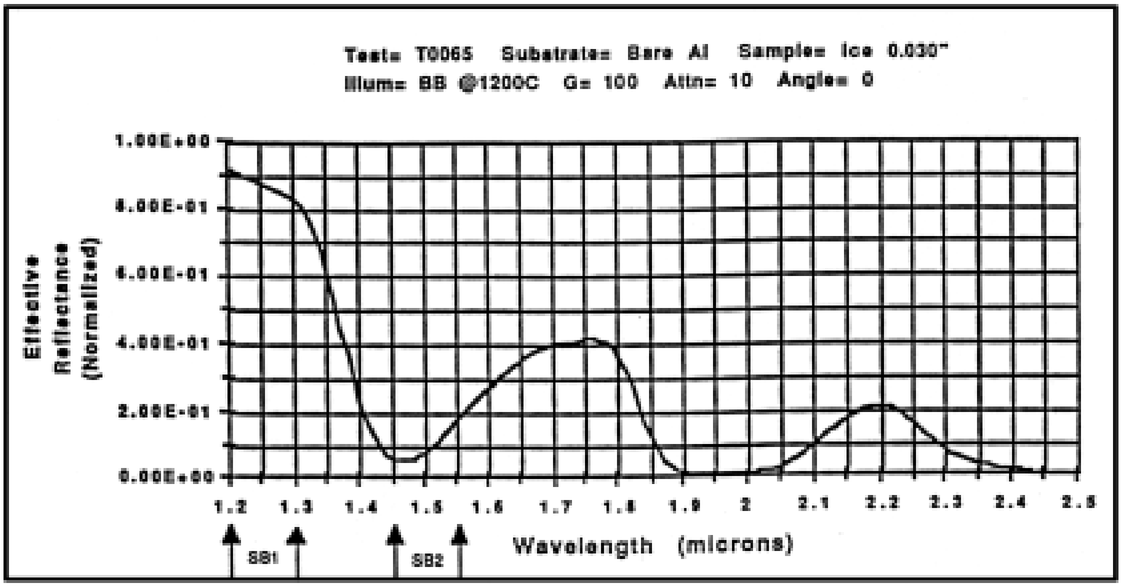

Figure 1. Ice Absorption Spectrum in the NIR.

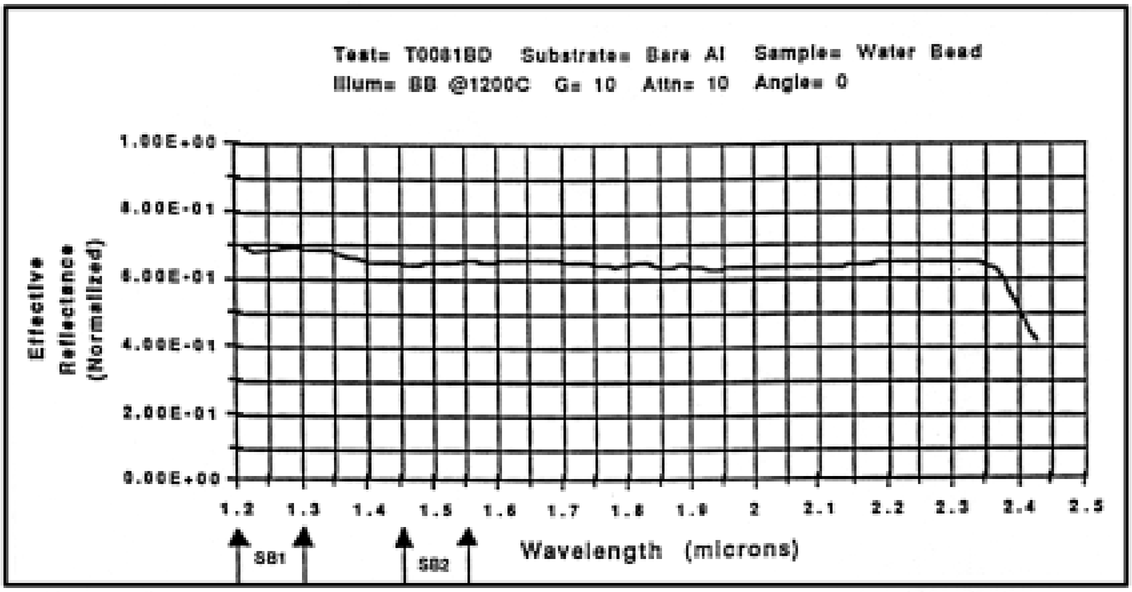

Figure 2. Water Absorption Spectrum in the NIR.

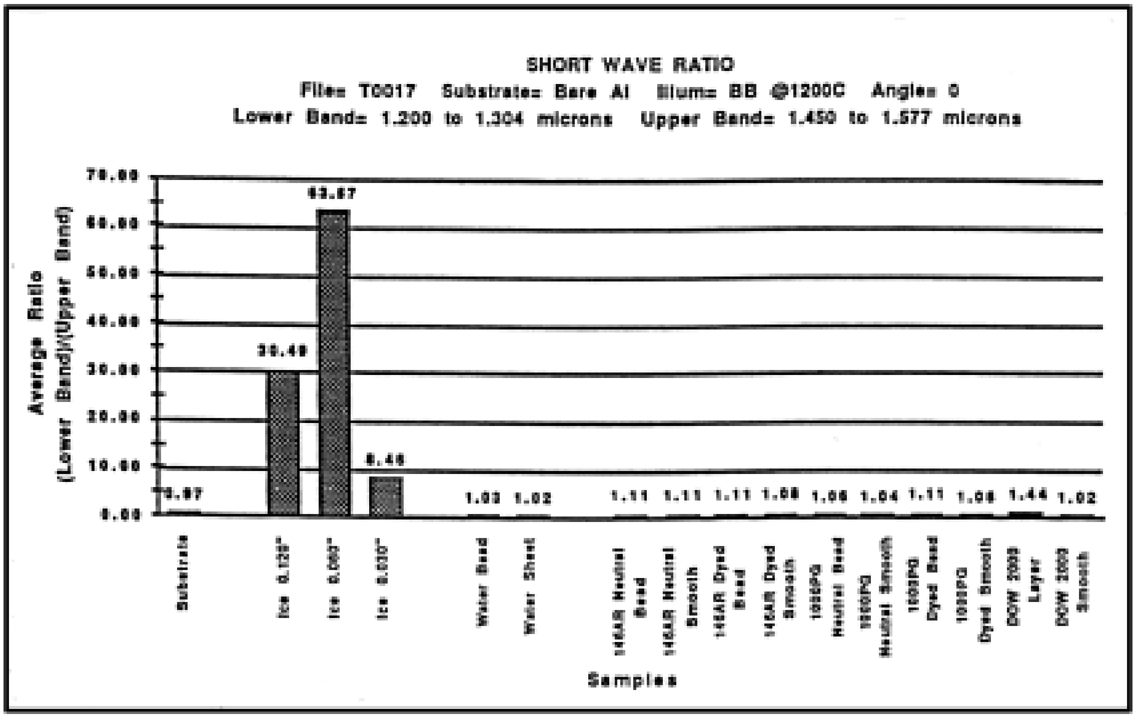

Figure 3. SB2/SB1 Ratios of Ice, Water, Aluminum and Various Solutions.

Hence, it is apparent that distinct quantities can be associated with water absorption, ice absorption, and for dry road surfaces. This allows discrimination between these types of road surface in the NIR spectral regime.

4.2 Use of Polarization

Two questions, which are best answered by experiments, are posed:

1. Does the just-described discriminant work on rough surfaces such as asphalt?
2. Can a technique be devised to counter the potentially dominant effect of highly reflective solar incidence?

Question 1 can be best answered by experimentally determining the feasibility of differentiating ice spectra from dry or wet pavement spectra in the NIR regime on a typical road surface and in the "real" world, i.e., asphalt with varying background solar incidence angles.

The second question is more difficult to experimentally answer since low grazing angle solar incidence is primarily evidenced as a specular surface reflection, much of which is not transmitted to the underlying ice or water medium. Because the differential measure of absorption is the central thesis in discriminating ice from water, the reflected sun could dominate any measurement and compromise the effectiveness of this technique.

To experimentally test the proposed technique, a polarizing plate or retarder will be inserted into the optical train during data collection, and horizontally polarized incident radiation is expected to separate most of the low grazing angle insolation from lamp irradiation. This makes intuitive sense because this is how polarized sunglasses work.

This extent of the problem and the potential degree that it can be solved by using polarizing optics can be shown by applying Snell's law ($n_1 \sin\psi_i = n_2 \sin\psi_t$) in combination with the Fresnel equation describing *p*-polarization reflective properties ($E(p,r) = [\tan \psi_i - \psi_t)/\tan(\psi_i + \psi_t)]E(p,i)$).[2] The quantity E represents the electric-field amplitude, and ψ_i and ψ_t depict the respective angles of incidence and refraction as

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[2] The question arises on whether irregular features on otherwise smooth, planar ice surfaces would contribute significant clutter. Circumstantially, this is not expected; polarized sunglasses work well in diminishing glare in the shorter-wavelength (and therefore more susceptible to clutter) visible band, from even relatively rough surfaces. For a high concentration of internal irregularities, multiple scattering would render individual scatter source contributions to be incoherent or random, as each reflection results in a 90-deg phase shift in polarization. In either case, the signal-to-noise ratio of the polarized return will likely be adequate for discrimination, unless the sensor field of view (FOV) is too small and can perhaps subtend an irregularity-dominant area. To compensate for that, the FOV can be made wider, or perhaps the discrimination processing algorithm should take into account time for a vehicle-based system (which would effectively provide a pushbroom longitudinal scan), or a spatial scan for a roadside-based system. However, an unequivocal answer would be best borne from test results.

measured from the surface normal. The *i, r* and *t* notations refer to the incident, reflected and transmitted (refracted) waves, while *p* and *s* identify the polarization directions parallel (or vertical to road surfaces) and perpendicular (or horizontal to road surfaces) to the plane of incidence, respectively. The plane of incidence is defined by the surface normal and the direction of *E* propagation. (Other Fresnel equations describe *p*-polarization transmittance, *s*-polarization refraction and *s*-polarization transmittance. A concise and informative review of these physical optics concepts can be found in Fincham and Freeman, 1980 [13].)

Substituting values for the relative refractive index at the air/water and air/ice boundary ($n_1/n_2 = 0.75$) in Snell's law yields a refracted angle ψ_t of 37^o and a reflected angle ψ_i of 53^o. Using these angles in the Fresnel equation for *p*-polarized reflectivity reduces the Fresnel coefficient to zero. This implies that there is no reflected illumination along the *p*-polarized plane of incidence, which means there is no vertically polarized light reflected at $\psi_i = 53^o$. At $\psi_i < 53^o$, the Fresnel coefficient is less than zero, indicating that vertically polarized light is internally reflected.

Therefore, with the ice detection application on essentially horizontal road surfaces, a horizontal polarizer will eliminate most specular insolation components, which enter the detector aperture at $\psi_i(\text{sun}) < 53^o$. Likewise, for polarization effects to *not* figure into the artificial source/ice detector geometries, $\psi_i(\text{lamp}) > 53^o$. The resulting source/ice line-of-sight is relatively vertical, but this configuration is already expected since it would yield by far the strongest signal with a relatively monostatic (or same-location) source/detector arrangement.

5.0 Conclusions and Recommendations

The review of alternative techniques – ranging from passive, in-pavement technologies, through various remote sensing techniques – indicates that the PRISM technique is potentially the most effective for the widest range of weather conditions and for multiple (i.e., on-vehicle and/or roadside) uses. Other techniques suffer various limitations in terms of limitations of spatial coverage, constituting an indirect measure (i.e., via road surface temperature) of the presence of ice, offering a lesser degree of coverage (i.e., applicable for times when the sun does not interfere with the returned signal), or not being applicable to infrastructure-based roadside ice sensors.

In terms of weather, the PRISM technique offers the potential for full day and night use (with night use supplemented by artificial illuminants). For nearly half the daylight time ($> 53^o$ from the normal) the sun can be expected to significantly interfere with the ability to discriminate ice from water unless the PRISM polarization technique proves to be effective. During nighttime operation with artificial illumination, the look-down angle must be relatively steep ($> 53^o$) unless again, the PRISM polarization technique proves to be effective. Hence, the PRISM technique can increase area of coverage per infrastructure-mounted device and also reduce the look-ahead distance of a forward-looking vehicle-mounted optical ice detector. It seems reasonable to investigate this new technique of considering polarization in discriminating ice from water.

In terms of offering a potential infrastructure-based sensing system for anti-icing strategy to be employed for more efficient winter operations in California, a network of PRISM sensors could be used as an ice detection component of the FHWA Strategic Highway Research Program's Road Weather Information System (RWIS).

For these reasons, an additional proof of concept experimental increment of work to investigate PRISM is still a prudent first step, to be followed by a prototype to test the device in real and icy highway situations.

6.0 Future Work

Two increments of future work are envisioned: conduct the proof of concept test originally planned for MOU 285, and if the concept is proven build a prototype.

6.1 Proof of Concept Test

This test should not be extensive and would cost approximately 1 – 2 staff months and several hundred dollars of spectrometer rental and miscellaneous positioning equipment. During the testing, data will be collected with a NIR spectrometer both with and without a horizontal polarizer inserted in the optical train. This data collection need not be done to laboratory precision but will be conducted with sufficient care to prove the ice discrimination concept within the context of a rather difficult outdoor test. Absolute (intensity) calibrations are not necessary due to the objective of a *relative* comparison between ice and water spectra; hence, prior factory absolute calibrations will suffice. Wavelength calibration will be conducted via registering fluorescence spectra of low pressure office lamps and are of sufficient fidelity for the relatively broad absorption bands expected with these phenomena.

Several thicknesses of ice samples (~1, 2, 5 *mm*) will be overlaid atop an asphalt substrate during short periods in the outdoors at RFS on clear, sunny days. The ice-asphalt combination will be set on an ice water bath cold sink of approximately 0^{o} C, and illuminated by a miniature quartz-halogen lamp for measurements to occur at incidence angles of ~5^{o}, 10^{o}, 22.5^{o} and 45^{o} from the surface normal throughout the daily solar cycle (morning, noon, afternoon). Water-asphalt combination and dry asphalt surfaces will be measured under the same geometries immediately after each of the ice-asphalt measurements.

Prototyping

If the proof of concept tests indicate that this method is technically feasible, then the next steps would be to implement the technology on a prototype. The prototype will likely be a NIR imaging sensor, fitted with a polarization retarder, and with a controllable filter wheel corresponding to three positions: open, 1.20 - 1.30 μm (i.e., the SB1 guard band), and 1.45 - 1.55 μm (i.e., the SB2 absorption band). The cost-effectiveness of NIR is increasing, and a variety of room-temperature, high-resolution NIR area cameras are on the market by vendors such as Sensors Unlimited, Inc., Electrophysics Corp, and Optical Insights, LLC, to name a few.

Once a prototype is built, it should be verified in the laboratory, then field tested alongside icy sections of California highways.

7.0 References

[1] M. Andrews, "Porsche's Contribution to Safer and More Comfortable Driving in the Future", Proc. First ITS World Congress, 1994.

[2] T. Uno, et. Al., "Road Surface Recognition Method Using Optical Spatial Filter", Proc. Int. Symp. AVEC, 089 (1994)

[3] "Temperature Measurements Reveal Accretion of Ice on Airfoils", *NASA Tech Briefs LEW-15639*.

[4] F. Holzwarth and U. Eichhorn, "Non-Contact Sensors for Road Conditions", Eurosensors VI, San Sebastian, Spain, 5 – 7 October, 1992.

[5] G. Hale and M. Querry, "Optical Constants of Water in the 200-nm to 2000-nm Wavelength Region," *Applied Optics*, Vol 12, pp. 555, 1973.

[6] "A Detailed Assignment of the Stretching Bands of Ice," *Canadian Journal of Chemistry*, Vol 55, pp. 3429 - 3441, 1977.

[7] A. Rusk and D. Williams, "Optical Constants of Water in the Near Infrared," *Journal of the Optical Society of America*, Vol 61, pp. 895 - 903, 1971.

[8] U. Fink and H. Larson, "Termperature Dependence of the Water-Ice Spectrum Between 1 and 4 Microns," *Icarus*, Vol 24, pp. 411 - 420.

[9] D. Wieliczka, et. al., "Wedge Shaped Cell for Highly Absorbent Liquids: Infrared Optical Constants of Water," *Applied Optics*, Vol 28, 1989.

[10] W. Irvine and J. Pollack, "Infrared Optical Properties of Water and Ice Spheres," *Icarus*, Vol 8, pp. 324, 1968.

[11] R. Clark, "Water, Frost and Ice: the Near-Infrared Sepctral Reflectance 0.65 - 2.5 _m," *Journal of Geophysical Research*, Vol 86, pp. 3087 - 3096, 1981.

[12] L. Ning, et. al., "Spectroscopic Imaging of Water in Living Plant Leaves," *Spectroscopy*, Vol 11, pp. 34 - 43, 1996.

[13] W. Finchan and M. Freeman. *Optics,* 9th ed. Butterworths, 1980.