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Mass-producible near near infrared spectroscopy detector system for water, sludge and ice on the road

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Introduction

Precise knowledge of the current road conditions concerning water, sludge and ice will improve overall vehicle safety considerably. Furthermore the automobile industry is very interested, because the system will improve the performance of several systems as ABS, anti skid (ASC) and vehicle dynamics control (VDC). For adaptive cruise control (ACC) it even might turn out to be crucial.

First attempts to detect water and ice spectroscopically can be traced back for twenty years when a first patent[1] was issued containing the basic idea to measure spectroscopically the shift in vibrational energy between liquid and frozen water. At that time it was far ahead of technological possibilities and public awareness, hence for more than a decade no real attempts were made to really build such a detector.

Seven years ago during the "Prometheus" project different ways of estimating the friction potential were investigated in detail, spectroscopic measurements included.[2]

This concept also failed to solve the problem, mainly because of prohibitively high prices for infrared detectors, of a sensitivity of the device to movements of the car and because it could not detect ice under thicker layers of water. These problems are overcome in the system presented.

All overtones of the stretching vibration of the O–H bonds show a strong wavelength shift between ice and liquid water. They mainly differ in their absorption strength, which falls roughly one order of magnitude when going to the next higher harmonic. This also means the penetration depth rises reciprocally at each harmonic. Since only silicon-photodiodes have production prices that justify their use in automotive consumer products, the third harmonic (see Figure 1) was chosen for the sensor to work on. The penetration depth at this wavelength is several centimetres, which means on one hand that ice can still be detected even under a puddle of water, but on the other hand for thin layers the peak absorption is only a few per thousand. Since a layer of 0.1 mm water already reduces friction noticeably, the design goal was set to develop a spectrometer system with an SNR of > 1000 : 1 at a measurement time of 10 ms.

Another effect of the large penetration depth is the strong visibility of all features in the spectrum of the underlying asphalt. Fortunately, most common road surfaces exhibit no specific absorbtion in this spectral region, as can be seen in Figure 2. Their spectrum is governed by the scattering cross section of the surface grains. To compensate for that, two further wavelengths outside the resonant bands are used. By this the absorbance of ice and water is linearly corrected. The correction might even be used to estimate a figure for the surface roughness.

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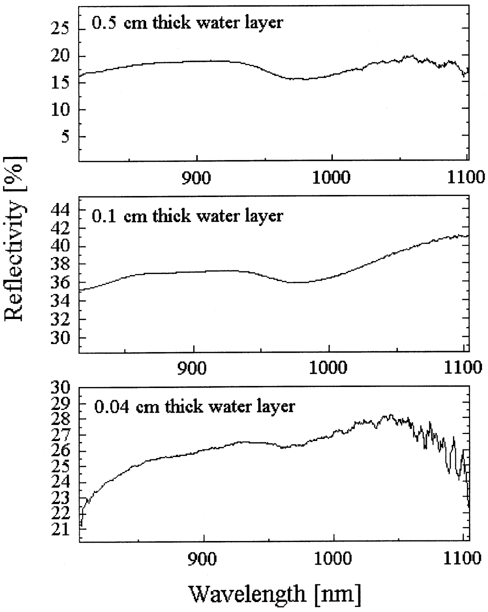

Figure 1. Spectrally resolved reflectivity of wet asphalt.

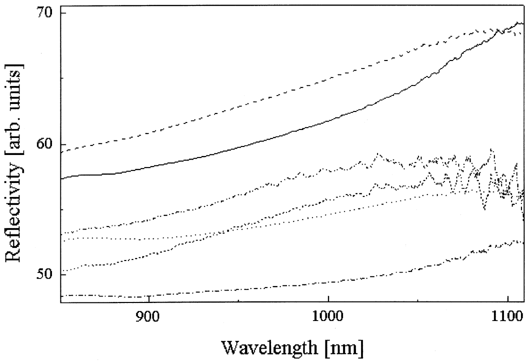

Figure 2. Spectra of different road surfaces: road mark, concrete, new asphalt, old aspalt, cobbled pavement and asphalt with oil (from top to bottom).

Experimental set-up

The road surface is illuminated by a 50 W halogen lamp (1) (Osram) from a 30 cm distance. A BK-7 lens (4) collects the back-scattered light into an optical fibre (5) of 600 µm diameter. Those two items are mounted in a watertight housing and can be affixed to the front bumper of a test car. The fibre leads the light into the spectrometer system inside the car. Here it gets equally distributed into four channels in each of which it passes an interference band pass filter (8) and is converted into a photocurrent by solar blind photodiodes (9). These currents are converted into voltages by gated integrating

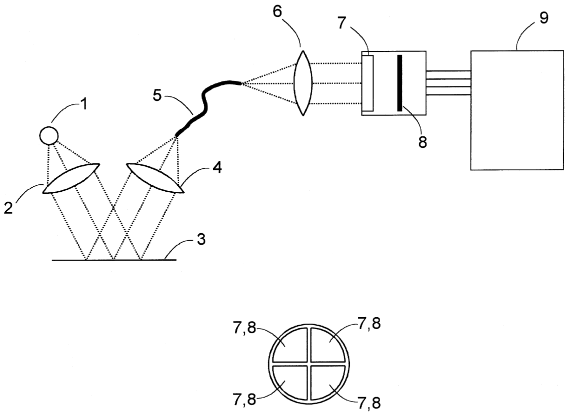

Figure 3: Principle set-up of the sensor system: (1) lamp; (2) optional condensor lens; (3) road surface; (4) collecting lens; (5) light fibre; (6) beam shaping lens; (7) optional window; (8) filters; (9) four photodiodes (one for ice, one for water, two for linear correction); (10) preamplifiers.

preamplifiers (10), again amplified and finally digitised.The final conversion of these four raw signals into layer thicknesses of ice and water is performed by software on a standard laptop computer. Figure 3 shows the principle set-up.

First test results

Several laboratory set-ups and test drives were done to prove the capacities of the prototype and to test the sufficient resolution for thin water layers. First, a laboratory test sequence was started. Therefore, defined amounts of water were measured by the system to assure the height calibration. Then the system's capacity of detecting ice and water in snow was demonstrated under laboratory conditions. Several snowflakes, each of different height, were tested. Figure 4 shows a sequence of different

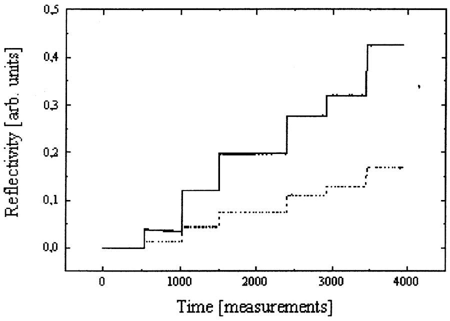

Figure 4. Laboratory test with snow. Different parts of melting snow were placed below the optical head to test the thickness of frozen and liquid water. Solid line: ice channel, dotted line: water channel.

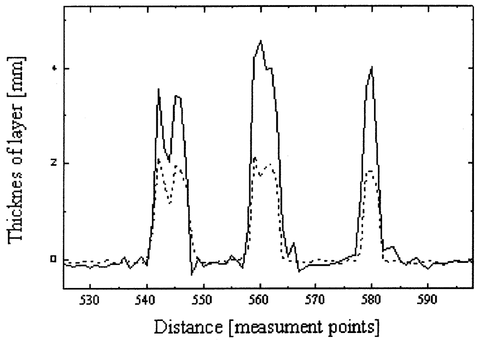

Figure 5. Test drive with system mounted on a car. Three different ice spots were passed sequentially. The *x*-axis shows arbitrary length units. Solid line: ice channel, dotted line: water channel.

flakes. Here thickness is drawn against an arbitrary time line. The rising portion of molten water in the snow is caused by the test conditions at room temperature.

Finally, a test drive with the prototype fixed to a car was arranged. The optical head was mounted in front of the bumper, while the spectroscopic part with the laptop was put on the front seat for operation. Then a stretch of road was prepared with three ice fields and the car drove along at 50 km h^{-1} while measurements were made. Figure 5 shows the measured sequence, the *x*-axis represents the length of the test course, where about 100 measurements per second were taken. Because of non-freezing external temperatures at that time, the ice was already partially thawn when measured.

Conclusion

A fibre-optic filter-spectrometer with a software algorithm can determine the height of ice and water without contact and within 10 milliseconds. The system also allows the estimation the roughness of the roadway. By this development it is possible to improve the performance of driving systems such as ABS, cruise control or anti-skid systems. Because of its simple construction and low-cost parts, the system is suitable for mass production at a reasonable price. With its inexpensive silicon detectors and interference filters that can be micromachined into an ASIC the development presents a small and compact design which can easily be integrated in today’s automotive technology. Once implemented and mass produced in this field, it can be modified for inexpensive use in other applications.

References

1. P. Decker, German Patent office DE 2712199 (1977).
2. F. Holzwarth and U. Eichhorn, *Sensors and Actuators A* **37/38,** 121 (1993).