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# LiDAR design for Road Condition Measurement ahead of a moving vehicle


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***Abstract*—In this paper we present the design and the first results of a prototype road condition sensor based on diffuse reflectance spectroscopy in the near infrared using semiconductor lasers. The objective of the sensor is to alert drivers or autonomous driving assistance systems of a road condition, such the presence of water or mud or ice, that will reduce the surface grip a few meters ahead the vehicle.**



***Keywords—road condition sensor; NIR spectroscopy; remote road grip assessment***


## I. INTRODUCTION

The development of advance driving assistance systems (ADAS) for drivers and for autonomous vehicles is of paramount importance to improve road safety and to reduce the number of accidents and fatalities. These systems rely on sensors that are able to monitor the surrounding environment, such laser based 3D sensors (LiDARs) and image-based sensors. The development of such sensors has allowed the implementation of pedestrian and obstacle detection systems, line departure warning systems, park assistance systems and others. Also autonomous navigation vehicles have been demonstrated in mild weather scenarios.

Fully-autonomous system that expects the vehicle's performance to equal that of a human driver in every driving scenario (including extreme environments like dirt roads), and current ADAS such ASR (Anti-Slip Regulation) system require for a more precise drive control based on road conditions. The road condition highly affects the road surface grip, for example surface grip will be highly reduced with respect dry pavement if a puddle of water or black ice are present on the surface of the road, so the assessment of the road condition ahead of the vehicle will lead to the development of advance drive control systems based on road conditions not yet driven on.

Technologies to measure the road condition have been developed through various approaches, such as using radar [1], vision based technologies [2] and diffuse reflection in the near infrared [3][4]. However, there are still many challenges to overcome in order to perform the measurements fast enough to allow driving at regular speed and to advance the road condition a few meters ahead the vehicle, also robustness against weather conditions, such us rain or snow, and robustness against road illumination conditions are necessary.

In this paper we present the first implementation and preliminary results of a laser based sensor for the assessment of the road condition ahead of a moving vehicle. The operating principle of the sensor is diffuse reflectance spectroscopy in the near infrared.

## II. MEASURING PRINCIPLE AND SENSOR IMPLEMENTATION

The proposed technique for remote sensing of water, ice and other substances on the pavement surface is based on diffuse reflectance spectroscopic techniques combining the use of semiconductor light sources and lock-in detection techniques. When a beam of light hits a surface of a material, part of the light is reflected back. This reflection is a mixture of specular reflection (with the same angle than the incident beam) and diffuse reflection, with out-coming beams in all directions. Diffuse reflection is due to transmitted light into the material that change direction of propagation (scatters) due to the presence of particles inside the material, which then eventually comes out of the same surface at an arbitrary direction of propagation. The amount of light that is back reflected depends on the optical properties of the material that are not constant but depend on the wavelength of the illumination beam. As an example, water presents absorption peaks at wavelengths 1500 nm and 2000 nm approximately, while ice also present those absorption peaks but slightly shifted in wavelength and slightly different amplitude (Fig.1).

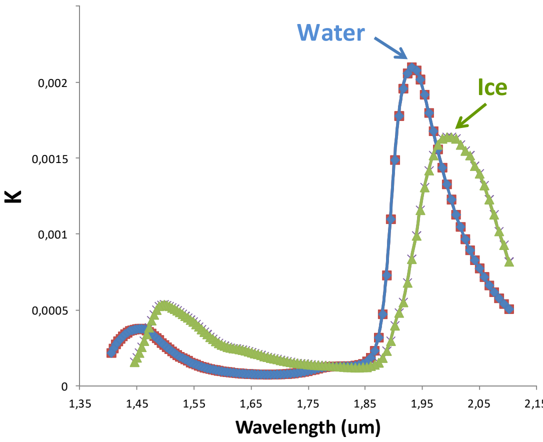


Fig. 1. Imaginary part of the refraction index of water and ice as a function of wavelength (data for the figure have been extracted from [5])

As the reflection spectrum is a characteristic of the material it is possible to identify the presence of a specific substance by analyzing its reflection spectra. Typical spectroscopic systems use wide-spectrum light sources (as a xenon lamp) and, with the aid of diffraction gratings or filters the spectral decomposition is made. Vision based systems may use ambient light but, as the sensor must operate also at night or poor illumination condition they also need a wide-spectrum light source. Instead, and to avoid lighting to other road users, we propose to use semiconductor light sources to illuminate the road surface.

Semiconductor light sources present two main advantages for building remote optical sensors. The first one is that they emit monochromatic light centered at a specific wavelength. The second advantage is that their output light intensity can be modulated at high speed using electronic circuits and thus high sensitivity detection techniques, as lock-in detection, can be used to avoid the influence of ambient illumination and increasing resolution. Our system uses standard communication semiconductor lasers, at least three laser diodes at different wavelength, which are combined to illuminate the same area of the road simultaneously. A single photodiode collect the light reflected at all wavelengths and the discrimination of the reflected light at each wavelength is realized in the electronic domain instead of in the optical domain.

The sensor prototype implementation can be seen in Fig. 2. For the design of the optical sensor head we used standard DFB pigtailed semiconductor laser diodes at 1460, 1490, 1550 nm. Those emitters are combined into a single fiber with a standard fiber optic coupler whose output fiber is connected to a fiber collimator, so the three wavelength point to the same area of the road surface. The sensor head also hosts a large numerical aperture optical system for collecting the reflected light on to a Thorlabs SM05PD5A InGAs photodetector. The receiving optics also includes a filter to reduce the influence of external light. Moreover, considering the sensor must operate under direct sun light, including sunrise and sunset, and direct light from the headlight of other vehicles, the photodiode amplification circuit includes a DC feedback compensation circuit.

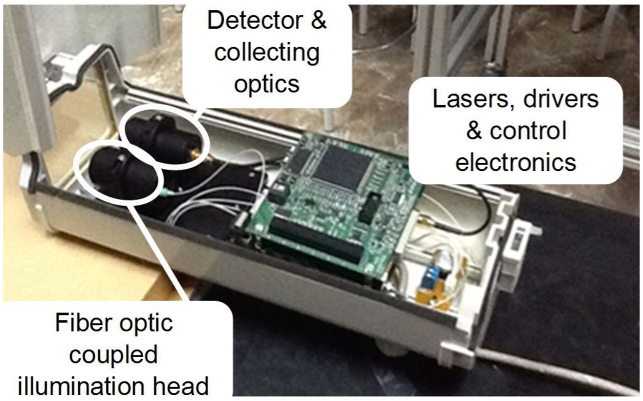


Fig. 2. Sensor prototype implementation

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Fig. 2 also shows the sensor electronics. It is composed of three electronic boards: (1) a commercial vehicular power supply DC to DC converter, (2) laser drivers for sinusoidal modulation of laser amplitude and detection electronics and (3) control electronics, which is the printed circuit board that can be seen on top.

The control electronic board perform all the data acquisition and signal processing stages using an FPGA (Altera Cyclone III EP3C40) as the core of the control electronics. It implements the modulation and demodulation circuits for each laser diode. Fig. 3 represents a simplified block diagram of the control electronic where only one modulation/demodulation channel is shown. Each channel consists on an embedded digital lock-in amplifier composed of a digital signal synthesizer (DSS) to generate the modulation signal to one laser diode, and a synchronous detection block that provides the amplitude and phase of the detected signal at a single modulation frequency associated to its laser diode.

The lock-in detection is configurable, allowing sinusoidal modulation frequencies up to 50 kHz (limited by the digital to analogue converter external to the FPGA), sampling frequencies up to 50 MHz and integration times between 420 μs and 4 s. Considering the application, we assume a maximum vehicle speed of 120 km/h, which results on a scanning time/distance of 0.03 s/m. In this situation, an integration time of 30 ms would average the road condition information along 1 meter. If higher spatial resolution is required (i.e. to detect a puddle of water) shorter integration times are needed, so it is of paramount importance the use of fast modulation/demodulation techniques. The possibility of easy configuration of the integration time is useful in case of bad weather condition, when the speed of the vehicle is reduced so larger integration times can be used to increase the sensibility of the sensor. The FPGA has an embedded NIOS II processor used for data acquisition, processing and communication with a PC via RS232.

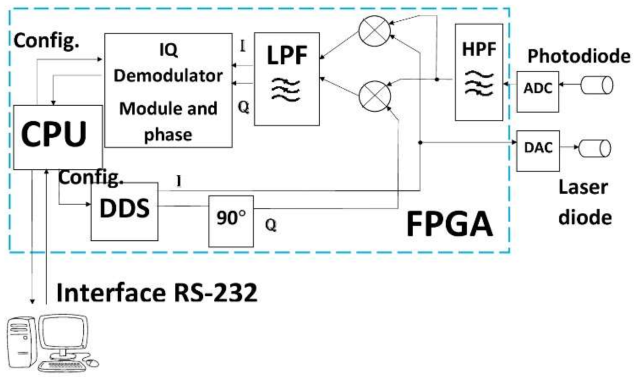


Fig 3. Sensor block diagram. For simplicity a single channel is shown, where each channel modulates a single laser diode and only one detector is used by the four implemented channels.

## III. RESULTS

First tests have been carried out in laboratory using different pieces of road asphalt. The first goal was to verify the sensor is able to detect slippery conditions due to the presence of ice and water on the surface of the pavement. For the tests the average optical power emitted by the laser diodes has been limited to 3 mW because of eye safety reasons.

Fig. 4 shows the results of a typical test that consists on freezing a layer of water over the pavement surface and to perform continuous measurements until the asphalt dries. This figure shows the amplitude of the detected light at the three wavelength which behaves as expected according the absorption coefficients at each wavelength represented in Fig.1. In this experiment water is melted and the asphalt is dry at faster speeds using a drier after 700 seconds and 1700 seconds respectively.

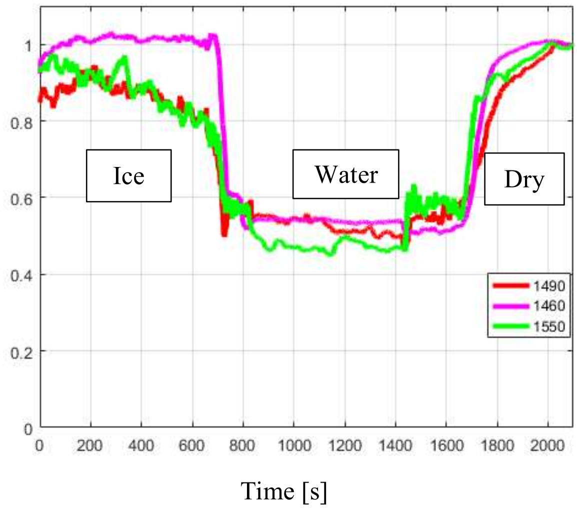


Fig. **4**. Evolution of the normalized amplitude [au] at each wavelength starting from a frozen water layer on asphalt.

After several tests using a climatic chamber and different pavement condition, as ice and water layers of different deep, and asphalt temperature, it has been verified that the sensor distinguishes at least three pavement conditions: dry, wet and icy. Figure 5 represents the ratios of the amplitudes at two wavelengths using 1490 nm as a reference, and different clusters associated to each pavement condition can be seen.

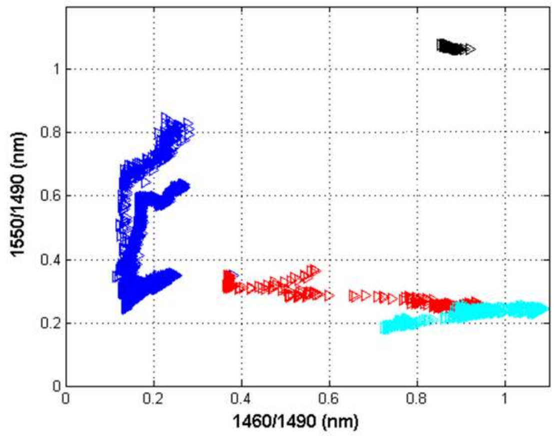


Fig. 5. Road condition classification. Black: dry. Dark blue: water. Light blue: ice. Red: melting ice/freezing water.

## IV. CONCLUSIONS

This prototype sensor has allowed us to verify that the proposed technique is able to identify the presence of a potential slippery road condition in front of a moving vehicle.

The implementation of the laser modulation/demodulation digital circuits on an FPGA has many advantages as the sensor is designed for vehicular applications. It results on a compact system with all control, processing and communication electronics into a single board. Also digital lock in demodulation design is robust to changes in operation conditions as ambient temperature and humidity.

The present prototype, if laser intensity is limited to class 3a safety, operates at a maximum distance of about one meter. Target application requires measuring distances of 20 m or higher. As average optical power of laser sources cannot be increased due to eye safety issue, future development will focus on the design of larger aperture receivers and the implementation of modulation/demodulation techniques based on pulsed operation of the lasers [6].

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