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REMOTE SENSING TECHNIQUES TO RECOGNIZE ROAD SURFACE CONDITIONS FOR AUTONOMOUS VEHICLES

HONGYI ZHANG, ELS



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- > Current sensors implemented on autonomous vehicles and their limitations
- > Current techniques to detect road surface conditions
 - Polarimetry
 - Backscattering amplitude
 - Image processing and machine learning
- > Discussion and conclusion



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- > **Introduction**
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Introduction

- > Detecting obstacles is a crucial issue for autonomous vehicles.
- > Current systems have potential to be improved to detect changes in weather and road surface conditions.

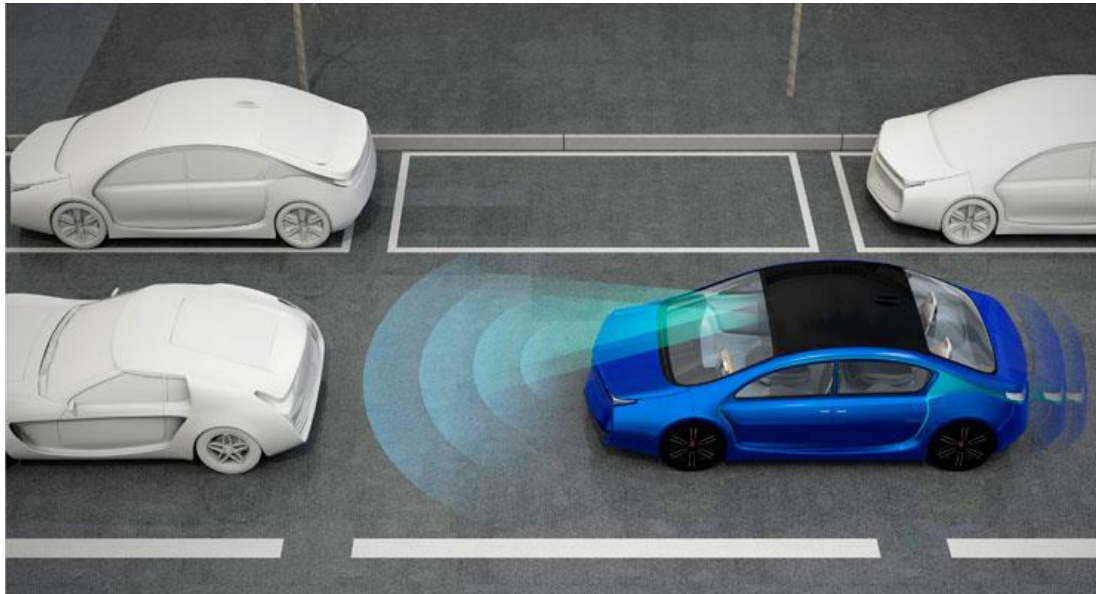


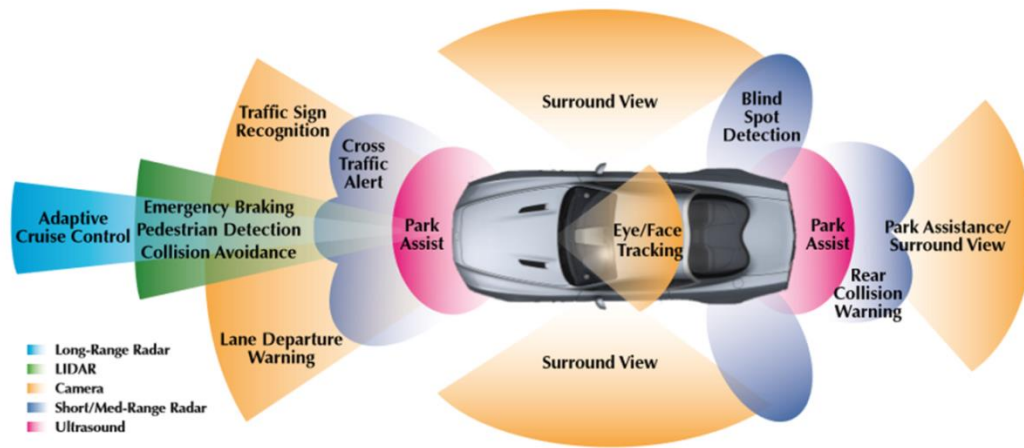
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Current sensors implemented on autonomous vehicles and their limitations

- > 4 kinds of sensors are implemented on autonomous vehicles: **Camera, Lidar, Radar and Ultrasonic sensors.**
- > All these sensors have their **advantages** and their **limitations.**
- > Currently **road surface identification system** is not yet developed and embedded



| | Video | Lidar | Sonar | 24 GHz Radar | >77 GHz Radar |
|--------------------------------|-------|-------|-------|--------------|---------------|
| Operation in rain, fog or snow | - | - | + | ++ | ++ |
| Operation at night | -- | ++ | ++ | ++ | ++ |
| Range | ++ | + | - | + | ++ |
| Angular resolution | ++ | + | -- | -- | - |
| Range resolution | + | + | ++ | + | ++ |

++ Ideally suited + Good performance
 - Feasible -- Impossible

[1] A. Bystrov, et al., "Sensors for Automotive Remote Road Surface Classification," 2018 IEEE International Conference on Vehicular Electronics and Safety (ICVES). IEEE, 2018: 1-6.



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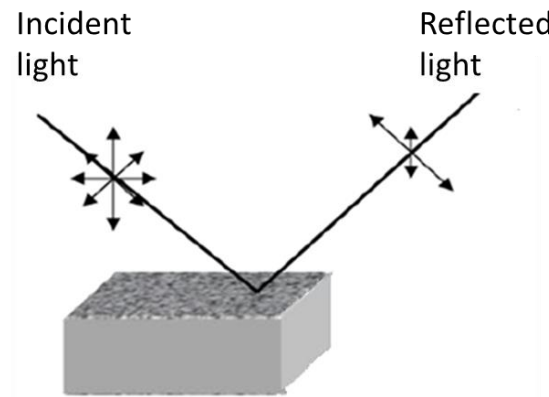
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Polarimetry

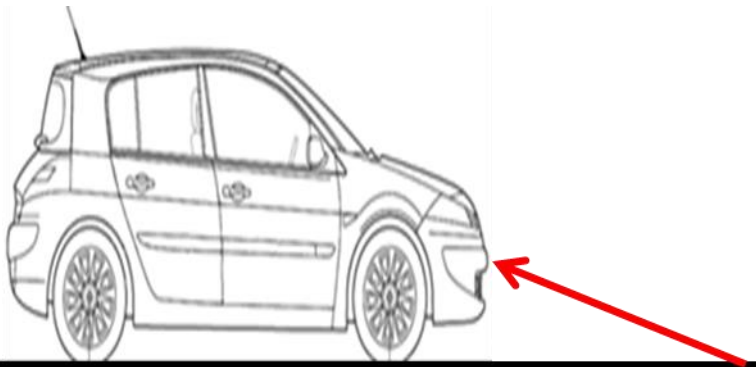
Principle

- > The **polarization state** of light is changed when light is reflected on different road surfaces.
- > **Sensors (camera / photodiode) with polarizers** or **Radar** are needed in this technique.
- > **Different wavelengths of signal (light/radar)** can be exploited.



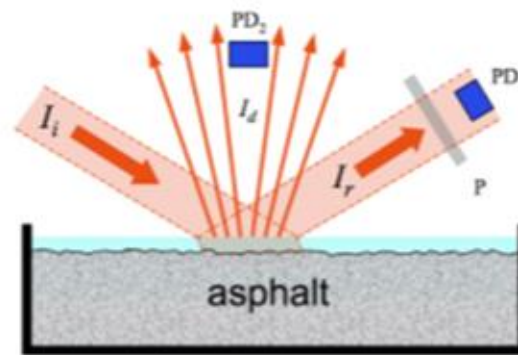
Polarimetry

Visible light



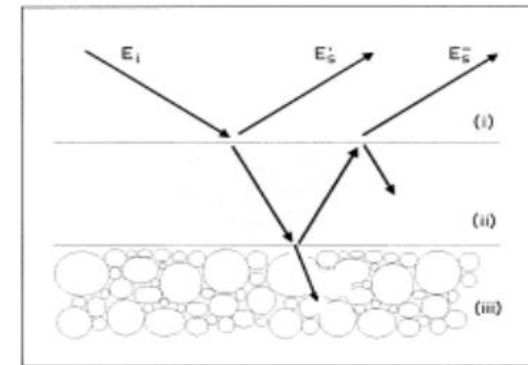
Dry and wet road surface can be distinguished [2]

IR light



By combining the diffused intensity and polarization contrast, dry wet, water and ice can be distinguished [3]

Millimeter wave (Radar)



A bistatic fully polarimetric Radar at 76GHz can be used to distinguish dry road and black ice on the road surface [4]

[2] M. Yamada, et al., "A study of the road surface condition detection technique for deployment on a vehicle," JSAE review, 2003, 24(2): 183-188.

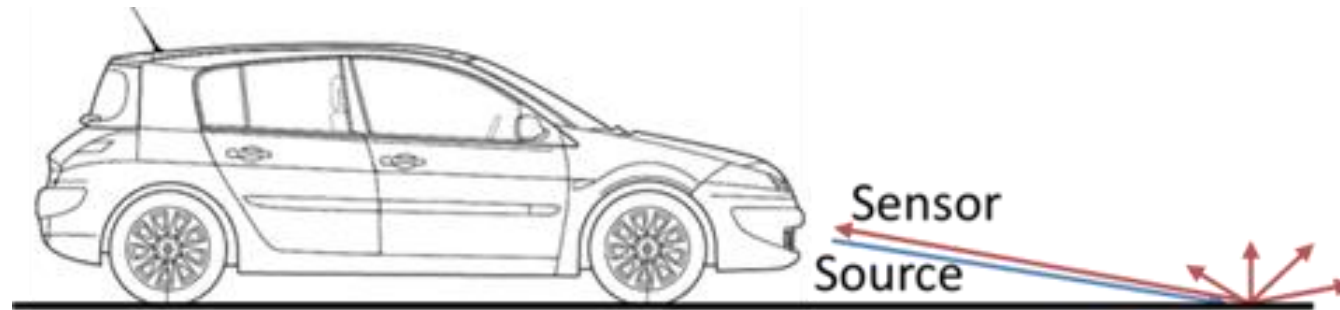
[3] L. Colace, et al., "A near-infrared optoelectronic approach to detection of road conditions," Optics and Lasers in Engineering, 2013, 51(5): 633-636.

[4] R. Finkle, "Detection of ice layers on road surfaces using a polarimetric millimetre wave sensor at 76 GHz," Electronics Letters, 1997, 33(13): 1153-1154.



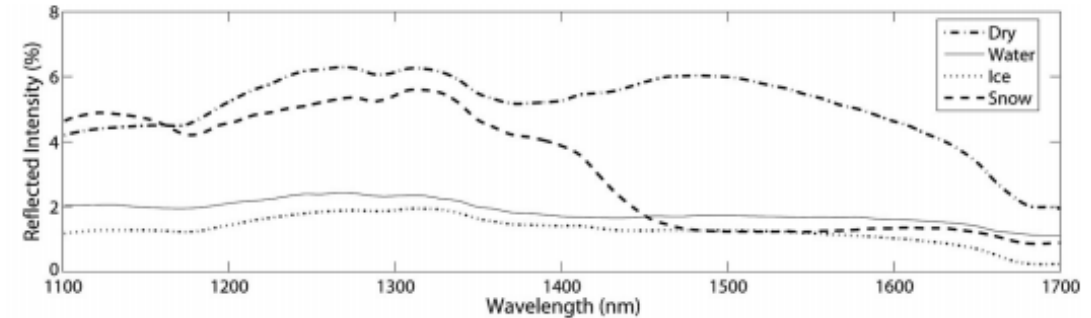
Backscattering signal

- > The principle of backscattering technique is that the amplitude of backscattered signal depends on the road conditions for certain wavelengths.
- > For this technique, a source and a sensor to receive the signal are required.

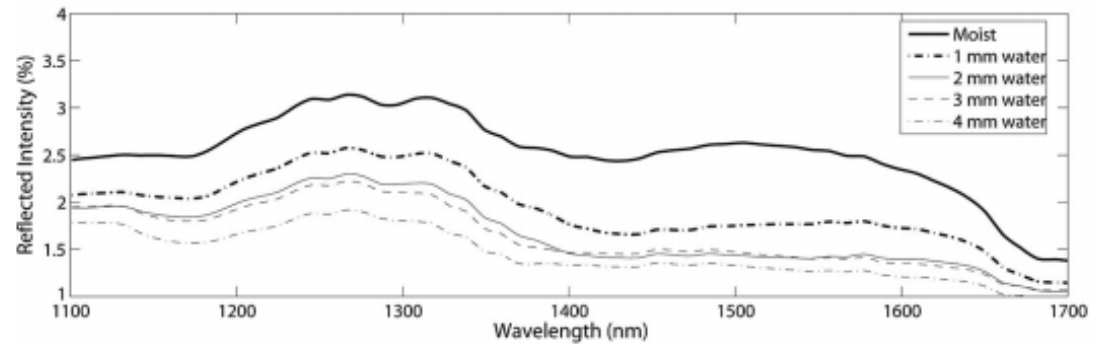


Backscattering signal - Near infrared

- > Average spectral responses of ice, snow and water on asphalt are different.
- > This is due to the absorption difference of IR light of ice and water.
- > Using 2 or 3 wavelengths in near infrared, wet, water, dry, snow and ice could be distinguished.



(a)



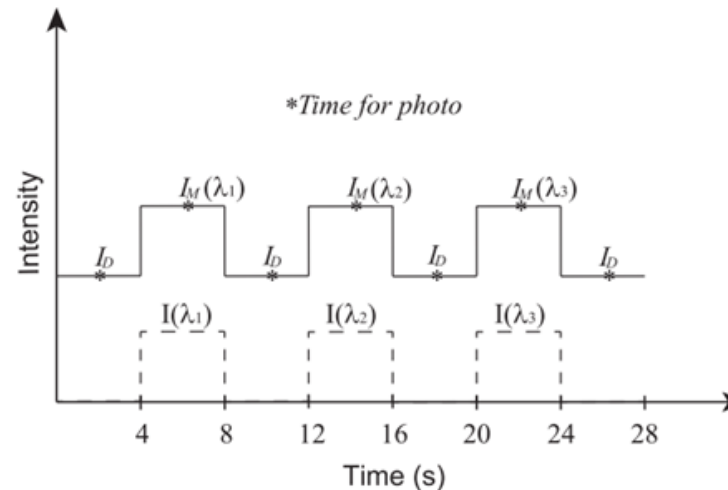
(b)

[5] J. Casselgren, et al., "Angular spectral response from covered asphalt," Applied optics, 2007, 46(20): 4277-4288.



Backscattering signal - Near infrared

- > As the spectral response of the source is investigated in this technique, **ambient light** should be taken into account.
- > **Modulated signal of the IR source** can be exploited to eliminate the influence of the ambient light.



[6] J. Casselgren, et al., "Road condition analysis using NIR illumination and compensating for surrounding light," *Optics and lasers in engineering*, 2016, 77: 175-182.

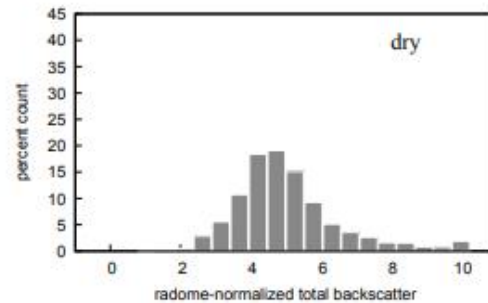


Backscattering signal - Radar

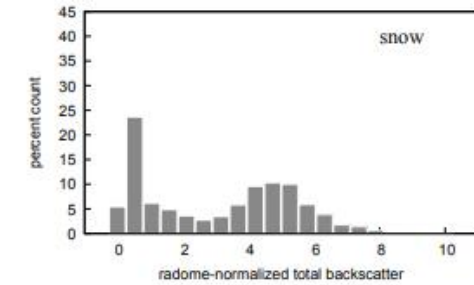
- > **Backscattering of Radar** on autonomous vehicles can distinguish the road condition by the **distribution of normalized amplitude**.



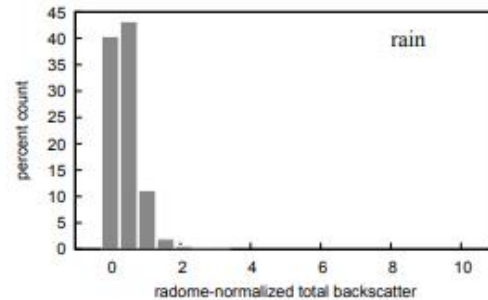
(a) dry



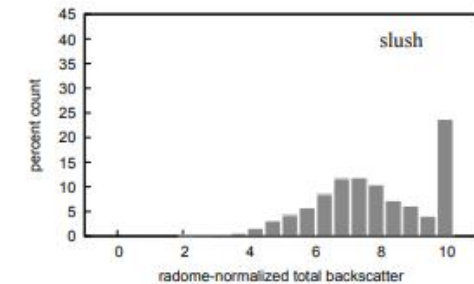
(c) snow



(b) rain



(d) slush



6. Snapshots of road conditions for moving vehicle test scenario

Fig. 7. Histogram distribution of integrated radar backscatter for various road conditions

[7] P. Asuzu, et al., "Road condition identification from millimeter-wave radar backscatter measurements," 2018 IEEE Radar Conference (RadarConf18). IEEE, 2018: 0012-0016.



Image processing and machine learning

- > In 1990s, the image processing methods to recognize the road surface condition was based on **morphological and texture analysis** [8].
- > In recent years, **machine learning** has been a promising technique to distinguish road conditions thanks to the growth of computer performance.
- > **SVM (Support vector machine)** and **Deep learning** are two mostly investigated techniques to distinguish road surface conditions and their accuracy can be up to 97% [9][10].

[8] Y. Chen, "Image analysis applied to black ice detection," *Applications of Artificial Intelligence IX. International Society for Optics and Photonics*, 1991, 1468: 551-562.

[9] J. Zhao, et al., "Road surface state recognition based on svm optimization and image segmentation processing," *Journal of Advanced Transportation*, 2017, 2017.

[10] S. Roychowdhury, et al., "Machine Learning Models for Road Surface and Friction Estimation using Front-Camera Images," *2018 International Joint Conference on Neural Networks (IJCNN). IEEE*, 2018: 1-8.



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Discussions and conclusions

> Polarimetry

- **Sensors (camera / photodiode / radar) with polarizers** are needed.
- In **visible band**, **dry and wet** can be distinguished.
- In **IR band**, **dry, wet, water and ice** can be distinguished.
- In **millimeter band**, **black ice** can be recognized from dry asphalt.
- **Specular reflection** must be fulfilled, thus this technique is difficult to be mounted on the vehicles.
- Roadside infrastructure is a more appropriate solution.



Discussions and conclusions

> Backscattering of IR signals

- **Near infrared sources and sensors** are needed based on the spectral responses of different road conditions.
- **Modulated signals** can be applied to the sources to eliminate the influence of the ambient light.
- The cost of the sensors might be a problem.

> Backscattering of millimeter signal (Radar)

- **Distribution of the backscattering signal** can be exploited to distinguish the road conditions. The accuracy needs to be improved.



Discussions and conclusions

> Image processing and machine learning

- **No supplementary sensor or source** needs to be installed on the autonomous vehicles.
- **Data from any sensors can be exploited.**
- **Data from the camera is easily influenced by illumination conditions.** At night, **the detection range and accuracy** would be weakened due to the low illumination and illumination range of headlamps compared to sunlight.



Discussions and conclusions

- > In conclusion, a system to recognize the road surface conditions will indeed increase the driving safety of autonomous vehicles.
- > Three main techniques have been identified: polarimetry, backscattering signal and image processing/machine learning.
- > In order to make the system work in daytime and nighttime and obtain an appropriate accuracy, a combination of the techniques seems to be a promising method.

THANK YOU FOR YOUR ATTENTION

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