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Effect of Geometrical Anisotropy on Road Surface Radar Cross Sections

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Abstract

A new modification to a method to determine the normalised radar cross section of road surfaces is proposed, so that the radar cross section of anisotropic pavement materials can also be considered. This method is applied to two types of brick pavements with different bond patterns under two different azimuth angles, both in wet and dry conditions. It is demonstrated that the radar cross section of anisotropic road surfaces can vary significantly as function on the azimuthal observation angle, and that it is dependent on the bond pattern of the pavement.

1 Introduction

In recent years, it has become increasingly more common for 77 GHz automotive radar systems to be installed in cars compared to the older 24 GHz systems [1]. As the wavelengths of the higher-frequency sensing waves emitted by these new radar systems are shorter, a higher proportion of the transmitted power is scattered back from road surfaces towards the receiver. This can lead to more intense clutter as measured by the radar system and therefore impact its performance. To properly account for this, adequate radar cross section (RCS) models are needed to analyse the effects of road surface scattering on the radar system in the 77 GHz frequency band.

In [2], a method is presented to determine the road surface radar cross section from radar measurement data, and subsequently radar cross section measurement results obtained using this procedure for two asphalt surface types were shown in [3].

The method proposed in [2] is limited to isotropic surfaces, meaning that for these surfaces the RCS does not depend on the observation direction. However, not all paving materials have isotropic geometrical properties, most notably pavements made out of bricks or stone blocks. This type of road surface is commonly found in historic city centres and is becoming increasingly popular for low speed roads as it is an effective traffic calming method, thus reducing driving speed and therefore increasing safety [4].

To account for anisotropic surfaces, this paper proposes a modification to the method presented in [2]. This modification comprises the relaxation of one of the underlying required conditions for the RCS determination procedure to be successfully applicable, and it is found that anisotropy can significantly affect the RCS of road surfaces.

The rest of the paper is organised as follows. Section 2 discusses the modelling of normalised scattering matrix, and thus by extension the normalised radar cross section (NRCS), of anisotropic surfaces. Section 3 presents measurements and results of two types of brick road surfaces. Section 4 discusses some practical implications of anisotropic road surfaces, and the paper is concluded in Section 5.

2 Modelling of Normalised Scattering Matrices for Anisotropic Road Surfaces

In [2], a method for modelling normalised RCS of isotropic surfaces was introduced. This method is based on representing a surface as a grid of uncorrelated scattering elements, where each element is characterised by a normalised scattering matrix and an area corresponding to the size of the grid cell of the aforementioned scattering element. The four elements of the normalised scattering matrix are distributed following a stochastic process that depends on the surface type/condition and the incident angle. By determining the properties of this stochastic process, a model of a road surface can be formulated.

To find these statistical properties, data from radar surface measurements can be utilised [2]. The results of this approach for four different road surface types are presented in [3]. However, to successfully find the properties of the stochastic process corresponding to a surface-under-test, two assumptions are made. The purpose of these assumptions is to make sure that the normalised scattering matrices of the elements within a single range bin are identically distributed. These assumptions are [2]:

- All scattering elements within a measured range bin experience the same *elevation* angle of the incident and scattered waves.
- The measured surface is isotropic, so that the distribution of its normalised scattering parameters does not depend on the *azimuth* of the incident and scattered waves.

However, in this work, the second assumption is relaxed so that also the statistical properties underlying the normalised scattering parameters of anisotropic road surfaces can be found. This can be done by substituting the second assumption with the new assumption below:

- All scattering elements within a measured range bin experience the same *azimuth* angle of the incident and scattered waves.

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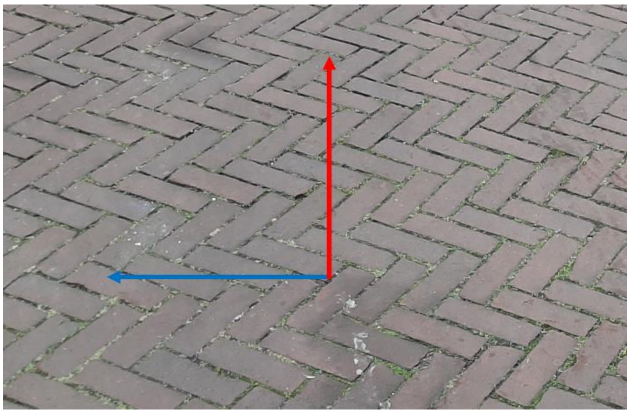

Figure 1 Red brick road surface. The red arrow indicates regular driving direction (||), while the blue arrow indicates the perpendicular direction (⊥).

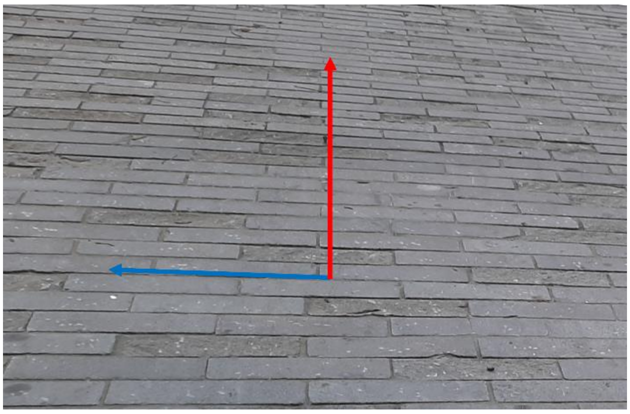

Figure 2 Grey brick road surface. The red arrow indicates regular driving direction (||), while the blue arrow indicates the perpendicular direction (⊥).

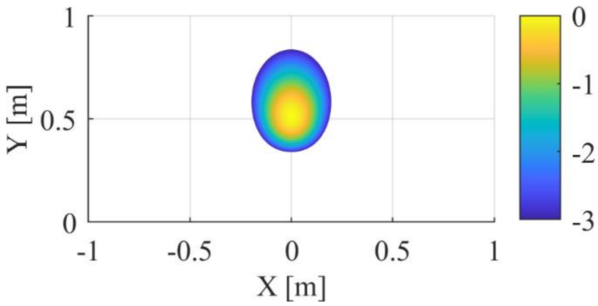

Figure 3 Footprint of the antenna beam of the measurement setup in VV-polarised mode in dB.

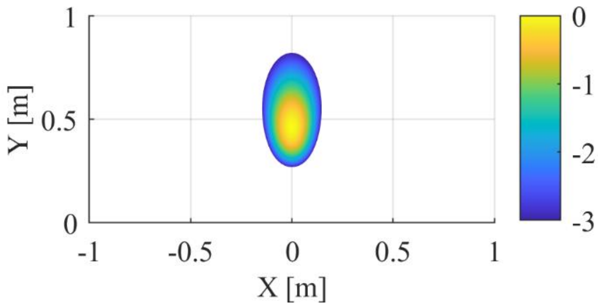

Figure 4 Footprint of the antenna beam of the measurement setup in HH-polarised mode in dB.

As long as such assumptions are true, then within a measured range bin, the equality of the statistical process underlying the scattering matrix is preserved, also for anisotropic surfaces.

This new assumption is valid in a number of situations. For example, if measurements are performed with a radar with high angular resolution, then the variation of azimuthal angle within a range-angle bin is limited, thus the second assumption holds, as long as this angle is smaller than the azimuthal variation of the scattering parameters. Alternatively, if measurements are done with an antenna with a narrow beam in the azimuthal direction, then the majority of backscattered power from a surface-under-test will be from surface area within that beam. As the beamwidth is small in this case, this means that the majority of backscattered power results from a narrow surface area which approximately shares the same azimuthal angle. Therefore, backscattering contributions from surface areas outside of the beam can be neglected, and thus the properties of the scattering process can be successfully computed.

3 Experimental Measurements and Results

To study the effects of anisotropy of road surfaces on their radar cross sections, measurements were performed on two types of common anisotropic road surfaces. These surfaces comprise two types of brick-paved road surfaces shown in **Figure 1** and **Figure 2**.

The first type of road was made out of a red brick laid in a 45° herringbone bond pattern, while the second type was a grey brick road laid in a running bond pattern. Both types of road surface were measured in the driving direction (indicated by the || symbol) and perpendicular to the driving direction (indicated by the ⊥ symbol), as may be encountered at an intersection. Each surface was measured 50 times with an antenna orientation angle of 60°, as per the procedure described in detail in [2].

As mentioned in Section 2, radar cross sections can successfully be determined from radar measurements if the radar system has a sufficiently narrow beam. The measurement setup used in this experimental campaign comprises of a vector network analyser (VNA) with both of its channels connected to a 15 dB dual polarised horn antenna. **Figures 2** and **3** shows the simulated -3 dB footprint of this measurement setup for the vertically and horizontally co-polarised channels. From these figures, it can be seen that for the VV-polarised mode, the -3 dB footprint fits in a cone of approximately ±30°, while in HH-polarised mode, the widest beamwidth is approximately ±25°. This essentially means that the widest range bin covers this angle, while other range bins cover a smaller angular range of the surface. For the considered type of surfaces, it was found that these maximum beamwidths were sufficient for this experiment as the two considered measurement azimuth angles are 90° apart.

Figure 5 and **Figure 6** show the NRCS results for the red brick and grey brick surfaces respectively, obtained by the

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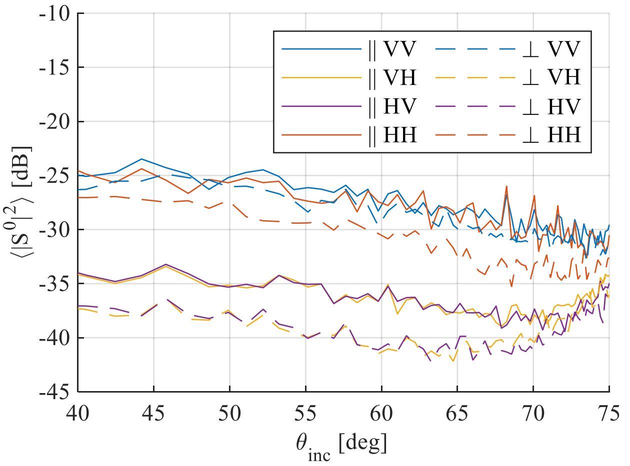

Figure 5 Normalised Radar Cross Section of the *red brick* pavement, measured in driving (||) and perpendicular directions (⊥).

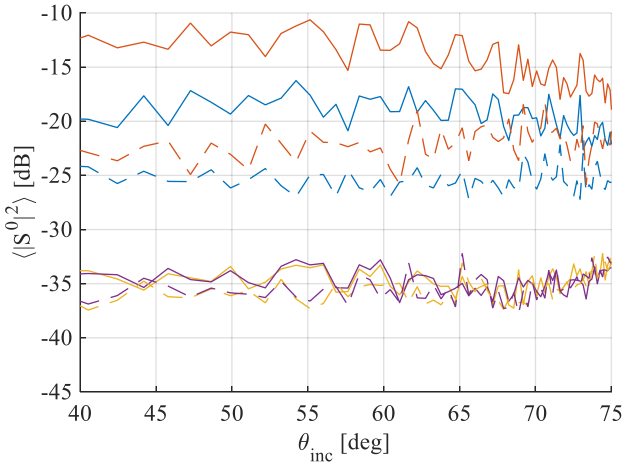

Figure 6 Normalised Radar Cross Section of the *grey brick*, measured in driving (||) and perpendicular directions (⊥).

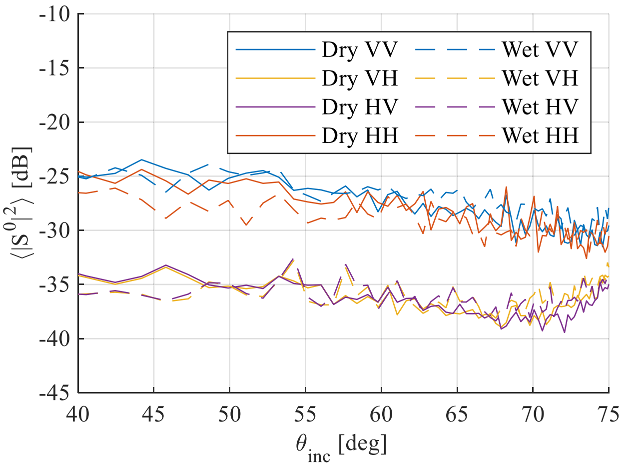

Figure 7 Normalised Radar Cross Section of the *red brick* pavement in dry and wet conditions, measured in the driving direction (||).

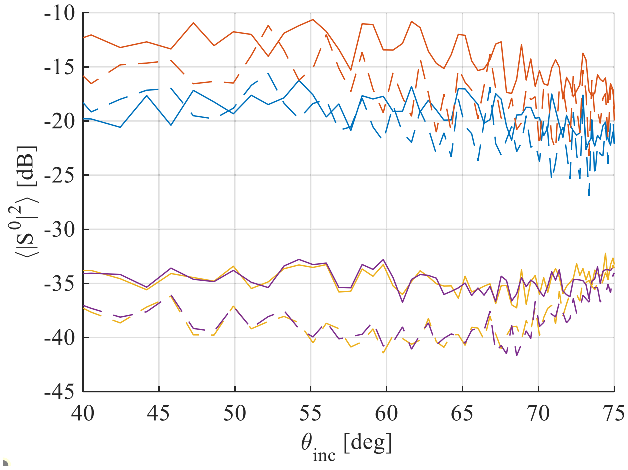

Figure 8 Normalised Radar Cross Section of the *grey brick* pavement in dry and wet conditions, measured in the driving direction (||).

post-processing procedure described in [2]. It can be seen in **Figure 5** that for the red brick surface, there is a slight decrease in the co-polar normalised radar cross sections, with the largest decrease occurring in the horizontal polarised channel. This can likely be explained by the length and orientation of the slits between the bricks with respect to the azimuth of the incident wave. In the driving direction, all slits are oriented at 45° with respect to the incident wave. When measuring in the parallel direction, the slits are still oriented at 45°, thus leading to similar NRCSs.

For the grey brick pavement, a significant difference between the HH- and VV-polarised NRCS can be seen from **Figure 6** when measured in the driving direction. This likely indicates that the slits in between the bricks play a significant role in its scattering behaviour, as slits on the long side of the bricks are mainly oriented along the horizontal direction and perpendicular to the radar, thus leading to more backscattered power for horizontally polarised waves compared to vertical polarisation.

Furthermore, the grey brick pavement, when measured in the perpendicular direction, shows a significant decrease of the co-polarised NRCSs compared to the measurements in the driving direction. This can be explained by the slits on the long side of the bricks now being oriented in the same direction as the incident sensing wave, leaving only the slits on the short side of the bricks oriented perpendicular to the incident wave. This effectively reduces the total length and number of slits perpendicular to the radar, thus reducing their contribution to the total backscattered power. Therefore, the total backscattered power is reduced and the difference between the VV- and HH-polarised NRCS decreases as the relative contribution of rough surface scattering increases.

It is also interesting to note that for the red brick pavement, the cross-polarised radar cross section decreases for measurements in the perpendicular direction compared to the driving direction, whereas it remains approximately similar for the grey pavement. It can also be seen that from an incident angle of about 70°, the cross-polarised RCS starts to increase. This is likely due to the sensitivity of the measurement setup, where the measurements from this angle onwards start to be dominated by noise. A more

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detailed discussion on this phenomenon can be found in [2].

Both pavements were also measured under wet conditions along the driving direction, similar to the approach described in [3]. The results of these measurements for the red brick pavement can be found in **Figure 7**, while the results for the grey brick pavement can be found in **Figure 8**. It can be seen that in the case of the red brick pavement, the presence of water does not change the NRCS significantly for all channels. This is likely due to the good drainage the slits in this type of brick provide, and thus puddles of standing water do not form.

The NRCSs of the grey brick pavement is more influenced by the water layer compared to the red pavement. It can be seen that the HH-polarised normalised RCS reduces slightly while the VV-polarised normalised RCS remains similar to that of the pavement measured in dry conditions. Thus, in this case of the wet grey brick pavement, this can likely be explained by the water layer smoothing out the slits between the bricks, which leads to a visible reduction in the HH-polarised NRCS.

Furthermore, it can be seen that for the grey brick surface the cross-polar NRCS reduces. This can potentially also be explained by the increase in effective flatness, which results in a change in scattering behaviour towards scattering from a flat dielectric interface. This same phenomenon is also observed in scattering from wet asphalt road surfaces [3].

4 Discussion

Brick pavements are a common class of road surfaces that are usually encountered in areas where also vulnerable road users are present, or where the road is even shared with them. Therefore, it is important to have a good understanding of the behaviour of the radar cross sections of these surfaces, as increased amounts of clutter may influence radar measurement data that is to be used in safety-critical advanced driver assistance systems such as automatic braking.

Furthermore, anisotropic road surfaces also pose an interesting challenge for driver assistance systems that are concerned with the properties of the road surface. Examples of these systems are the anti-lock braking system and electronic stability control. For example, when a radar system is used for classification of road surface materials, e.g., to estimate its friction coefficient, a change of pavement direction could lead to misclassification of the surface thus potentially impacting safety system performance. This may for example occur at an intersection where different brick bond patterns have to be merged and the radar system might misclassify the road surface at the intersection as covered by a puddle of water. This can cause dangerous situation where a driver suddenly has to brake, without optimal brake performance, to avoid collision with traffic that enters the intersection unexpectedly.

Finally, anisotropy of road surfaces, when understood properly, can also be used to aid in classification of road surface materials. When a radar system with good angular resolution or a system with multiple radar channels at different azimuth angles is used for road surface classification purposes, the variation of the measured backscattering along azimuth can also be used to increase the classification accuracy.

5 Conclusions

In this paper, the NRCS of anisotropic surfaces are studied. By relaxing an assumption from the method to compute road surface NRCSs from radar data presented in [2], this approach can be generalised to allow for computation of NRCSs of anisotropic surfaces as well. Specifically, this involved replacing the condition that surfaces should be isotropic, by the condition that the surface is locally isotropic within the range-azimuth cell or antenna beam.

Subsequently, measurements of two types of brick pavements were performed. The first surface class comprised a type of red brick laid in a 45° herringbone bond pattern, while the second type consists of a type of grey brick, laid in a running bond pattern. Both surfaces were measured in driving direction and perpendicular to this direction.

It is shown that for the red brick pavement, the variation in NRCS is relatively limited between driving and perpendicular directions, while for the grey brick surface, the NRCS showed significant differences. From the computed NRCSs, it was found that this behaviour can likely be explained by the orientation of slits between the bricks, which increase the HH-polarised RCS significantly when perpendicular to the radar.

Both surface types were also measured in wet conditions in the driving direction to study the impact of the water layer in terms of reduction of the scattering contributions of the slits between bricks. Here, it was found that the water layer significantly influences the NRCS of the grey brick type, while the variation of the NRCS of the red brick pavement is relatively little.

Finally, a brief discussion on the practical implications of the variation in NRCSs of anisotropic surfaces was presented.

6 Literature

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