Evaluation of the Impact of the Angle of Incidence Discretization in Surrogate Models of Periodic Cells in Reflectarray Antenna Analysis

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***Abstract*—Different strategies for the discretization of the angles of incidence and its influence on reflectarray analysis based on surrogate models with support vector regression (SVR) are studied. One SVR per pair of angles of incidence is considered, and it is shown that while the copolar pattern is robust against the discretization of the angle of incidence, the crosspolar pattern presents a higher sensitivity with regard to the baseline scenario.**

***Index Terms*—Machine learning, support vector regression (SVR), surrogate model, angle of incidence, reflectarray analysis**

I. Introduction

The use of surrogate models for reflectarray analysis is very interesting for the subsequent acceleration of the design and optimization procedures [1]. However, many works in the literature consider the angles of incidence as input variables to the surrogate model [2]–[5], thus increasing the dimensionality of the model, which in turn increases the training time and the number of samples needed for the training. An alternative strategy is to discretize the angle of incidence and obtain one model per pair of angle of incidence (θ, φ) [1]. However, there are no studies in the literature on how this discretization affects the accuracy in the prediction of the radiation pattern.

This work presents a study on the influence of the discretization of the angle of incidence on the reflectarray radiation pattern when employing surrogate models based on support vector regression (SVR). A method of moments based on local periodicity (MoM-LP) [6] is employed as reference to generate the samples to train the SVR models and compute the error for the radiation pattern.

II. Discretization of the Angles of Incidence

Given a single-offset reflectarray configuration where the feed is placed at coordinates $\vec{r}_f = (x_f, y_f, z_f)$ with regard to the center of the reflectarray antenna and any k-th reflectarray element with centroid coordinates $\vec{c}_k = (x_k, y_k, 0)$, each reflectarray element will have an angle of incidence that depends on those coordinates, i.e., $\theta_k(\vec{r}_f, \vec{c}_k)$ and $\varphi_k(\vec{r}_f, \vec{c}_k)$. In general, the response of the unit cell will depend on those angles [7] and they need to be taken into account in the reflectarray analysis.

Some previous works employed discretizations of θ and φ that provided a high degree of accuracy in the prediction of the radiation pattern with regard to the MoM-LP tool. For instance, in [1] a total of 152 pairs were considered, while in [8] only 52 were used. In the former case, a non-uniform discretization of θ was employed, with a step in φ of $\Delta\varphi = 10°$. In the latter, θ was discretized uniformly with a step of $\Delta\theta = 10°$ and φ with $\Delta\varphi = 20°$. Here, a systematic study will be carried out with the discretizations shown in Table I for a uniform discretization of θ and φ. A total of six discretizations are considered, with steps in θ of 5° and 10°, and steps in φ of 10°, 20° or 30°.

Table I
Data regarding the discretization of the angles of incidence for the 2D SVR. Discretizations are uniform in θ and φ.

#	**$\Delta\theta$ (°)**	**$\Delta\varphi$ (°)**	**(θ, φ) pairs**
1	5	10	190
2	5	20	98
3	5	30	68
4	10	10	102
5	10	20	52
6	10	30	34

For the testing, a large contoured-beam reflectarray for space applications will be used. It is rectangular and comprised of 7 052 elements in a regular grid of 86 × 82 elements. The periodicity is 12 mm × 12 mm and the feed is placed at coordinates $\vec{r}_f = (-358, 0, 1070)$ mm. The same unit cell described in [1] is employed, and it is analysed by the MoM-LP detailed in [6]. In addition, the SVR models are obtained following the guidelines of [9], considering the four reflection coefficients and ten SVR models per angle of incidence.

The radiation pattern is computed with an FFT in a grid of 512×512 points, giving a total of 185 269 points in the visible region. Then, the relative error is obtained as:

$$\mathrm{RE}_{\mathrm{FF}} = 100 \cdot \frac{\|E_{\text{MoM-LP}} - E_{\text{SVM}}\|}{\|E_{\text{MoM-LP}}\|}\ (\%), \tag{1}$$

where E is either the copolar or crosspolar component of the radiation pattern.

III. Results

Figure 1 shows the results for the discretizations of Table I. As it can be seen in Figure 1(a), the copolar pattern is very robust against the discretizations, with relative errors

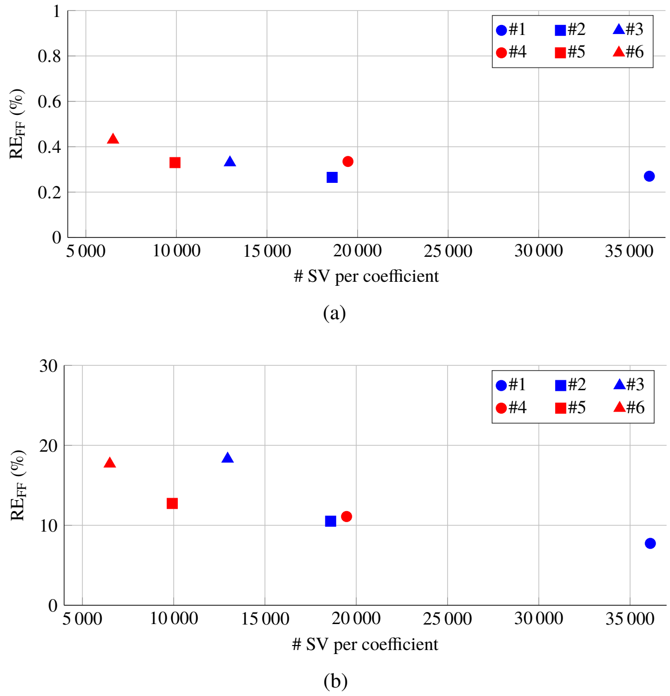

Figure 1. Relative error for the discretizations of the angles of incidence for the (a) copolar and (b) crosspolar patterns.

below 0.5%. The crosspolar pattern is more sensitive to the discretizations as shown in Figure 1(b). The discretizations for $\Delta\varphi = 30°$ present a relative error close to 20%, which decreases for smaller steps at the expense of increasing the number of pairs of angles of incidence, and thus the number of surrogate models. A good trade-off between the total number of angles of incidence and the achieved error is provided by discretization #5 which correspond to $\Delta\theta = 10°$ and $\Delta\varphi = 20°$.

Finally, Figure 2 shows the crosspolar pattern of a reflectarray with a European coverage zone [1] comparing the MoM-LP simulation and the SVR-based prediction using the discretization #5. It can be seen how the SVR accurately predicts the XP pattern around the coverage area, but there are larger discrepancies elsewhere.

IV. Conclusion

A study on the influence of the discretization of the angles of incidence in surrogate models for reflectarray analysis has been carried out. For the considered discretizations, the copolar pattern presents little variation, in contrast to the crosspolar pattern, which is very sensitive to the discretization of the angles of incidence. Finer discretizations increase the accuracy of the predicted radiation pattern, providing a smaller relative error, at the expense of increasing the total number of surrogate models. A comparison of the MoM-LP and SVR-based simulations of the crosspolar pattern shows that good accuracy may be achieved around the coverage area.

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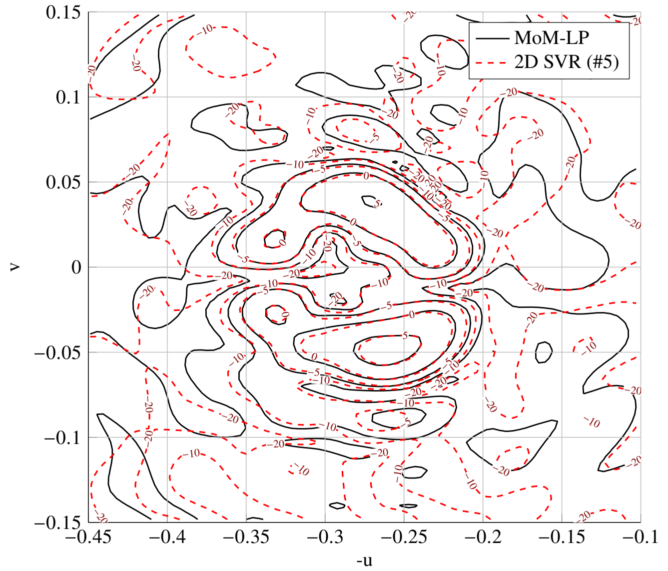

Figure 2. Comparison of the MoM-LP and the SVR-based prediction for the crosspolar pattern.

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