Bundesamt
für Strahlenschutz

Spotlight on EMF Research

Spotlight on “A Gaussian process based approach for validation of multi-variable measurement systems: Application to SAR measurement systems” by Bujard et al. in IEEE Access (2024)

Category [radiofrequency, dosimetry/exposure]

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Competence Centre for Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

Before introducing a wireless device such as a mobile phone on the European market, the manufacturer has to demonstrate that a specific peak spatial- and time-averaged specific absorption rate (SAR) is below 2 W/kg if the device is operated close to the head or trunk. To demonstrate compliance, SAR measurement systems are used, whose sensors measure the electric field induced in a phantom (model of a human body or parts of it) filled with a tissue-simulating liquid. Such systems have themselves to be validated before being used by wireless device manufacturers or any other entity. In order to validate such systems, they have to be tested under a sufficient amount of well-defined conditions where the generated SAR levels can be compared to known values. In the standards [2] and [3], validation procedures are defined by the international standardisation bodies IEC and IEEE. In the last decade, new developments in SAR measurement system technologies as well as the need to harmonise two standards ([2, 3]) resulted in an untractably large amount of test configurations in order to comprehensively validate SAR measurement systems. The aim of the paper to be discussed [1] is to introduce a stochastic validation method to handle this problem.

2 Results and conclusions from the perspective of Bujard et al.

Contemporary SAR measurement systems are able to perform measurements in a huge variety of situations, including different frequencies, antenna and modulation types, device positions, device rotation angles, and more. Any combination of these parameters determines a point in the configuration space of the measurement system, which is a high-dimensional space. Theoretically, to validate the system, it should be tested at each point of the configuration space, i.e., test measurements have to be performed and compared to known target values. In practice, this is not feasible in a realistic amount of time. The authors propose a method based on so-called spatial regression, or kriging, known from geostatistics [4], to predict the behaviour of the measurement system at an arbitrary configuration space point, using only a feasible subset of actual measurements.

The method is based on the following steps. First, a sufficiently large number of test measurement points is spread randomly but well-spaced over the configuration space. This is achieved using Latin Hypercube Sampling, a way of random sampling with avoidance of spatial clustering of points. The number of points depends on the type of measurement system and is determined empirically by the authors, e.g., 400 for array systems. It is assumed that the measurement error is a Gaussian random process having constant mean (independent of the configuration space point) and covariance only depending on the distance of configuration space points. Based on these measurements, in a second step, a linear function is created, with its parameters determined to ensure that the function is the best linear unbiased estimator [4]. This linear function allows estimating what the system would measure at any other point in configuration space within a computable confidence interval. Third, as it is not clear if the resulting model is reliable, e.g., due to an insufficient amount of points or errors in numerical fitting, it has to be tested. The correct mathematical model would deliver a prediction at an arbitrary point in configuration space, and measurements would be normally distributed around it. Thus, the authors propose to perform a certain amount of further measurements at points not contained in the original test set (used to create the model). If these measurement results are normally distributed (within a well-defined precision) around the values predicted by the model created in the first step, it is declared as trustable. Testing normality is done using the well-established Shapiro-Wilk test in statistics. Fourth, using the tested kriging model established in the previous steps, i.e., for the measurement error, the authors suggest an algorithm to scan the configuration space in order to find subsets where the kriging model predicts values which have a high probability to cross the maximal permissible error (MPE, defined in [3]) between the prediction and the known target value. In other words, these are subsets of the configuration space which are “critical” in the sense that the measurement system is likely to fail the validation in this region. As a final step, a number of test measurements is to be performed by the test laboratory in the critical set to check whether the system performs well also in the critical subsets.

The method is first applied to an analytic example where the measurement stochastic process is known *a priori*. Critical subsets of the configuration space are found to be those where the initial Latin Hypercube

Sampling is scarce, as well as towards the boundaries of the configuration space. The authors then apply the method to two measurement systems. The first is a scanning system using a robotic arm to probe the induced fields in the phantom. The second is an array system, where an array of sensors is located at fixed positions in the phantom. In the first case, no critical regions were found, whereas in the second case, 44 additional tests had to performed to ensure a good performance of the system also in the critical subsets. The authors conclude that the proposed method works efficiently in validation practice, as the number of tests is tractable for standard test laboratories.

3 Comments by the BfS

To our knowledge, the method proposed by the authors is the first application of the kriging method in a validation protocol and thus in the context of standardisation. Validation methods have a high relevance for radiation protection, since any compliance test of wireless devices needs to rely on validated SAR measurement systems. The method is presented in a mathematically precise way and uses well-established tools. Its stochastic nature avoids the possibility of calibrating measurement systems particularly well at preselected measurement points while other areas of the parameter space are neglected, as the Latin Hypercube Sample is rolled out randomly when the model for the measurement error (see section 2) is created. The authors demonstrate that the algorithms provided to confirm the kriging model as well as the search for critical subsets work well for the examples, however a mathematical proof of convergence of the applied algorithms is not included in the publication.

A possible practical problem is posed by the accumulation of critical subsets at boundary regions of the configuration space, leading to many measurements in extreme situations with low practical relevance. Further benefits of the provided method are its device-neutrality, in the sense that no *a priori* knowledge about the type of measurement system is needed. Still, the size of the initial sample set could depend on the tested measurement system. Tests can be done independent of a specific test laboratory, and an easily accessible software tool is provided [5].

This newly proposed approach is methodologically interesting and sound and has the potential to be applicable for standardizing SAR measurement system validation, i.e., contribute to the harmonization of [2] and [3]. A standardised validation procedure is of high importance for reliable radiation protection.

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