# COST EMF - MED (Action BM1309):
# European network for innovative uses of EMFs in biomedical applications

STSM Report:

Advanced SAR Assessment of Medical Devices & Therapies Applying Surrogate Modelling

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**Abstract:**

Radio-frequency (RF) dosimetry is important for the validation of electromagnetic exposure systems and the compliance testing of wireless devices, not only for mobile communication devices, but also for RF devices used in biomedical appliances and clinical treatment (e.g., hyperthermia). To reduce the duration of a dosimetric measurement as compared to standardized procedures for evaluating RF induced absorptions by medical devices and therapies, we applied a surrogate model to optimally predict the next accessible evaluation location based on previously measured absorption values. The study showed that the adaptive sampling of surrogate modeling is able to speed up SAR assessments by up to a factor of 2 as compared to a standardized scan on a rectilinear grid.

## A. Purpose of the STSM

The objective of this STSM is to reduce the assessment time in dosimetric measurement systems as compared to standardized measurement procedures for evaluating radio-frequency (RF) induced absorptions, expressed in terms of the specific absorption rate (SAR), by medical devices and therapies by applying

## B. Work Description

During the STSM Visit, I applied and evaluated surrogate models on the measured and simulated SAR database of hyperthermia applicators and wireless medical devices of IT'IS / ETH Zurich. However, to perform a thorough investigation of the performance of the surrogate modelling for SAR assessment, the set of SAR distributions from hyperthermia applicators and wireless medical devices were extended with SAR measurement data from wireless communication devices. As such, a total of more than 500 SAR distributions were made available by the host institute ETH Zurich / IT'IS of which 100 measurement and simulated SAR distributions were used to evaluate the surrogate modeling approach for fast SAR assessment.

To evaluate the performance of the selected surrogate models in terms of measurement duration with respect to the scans based on a rectilinear grid as specified by current SAR measurement standards, it was mandatory to estimate the timings of the dosimetric measurement system (in this study a DASY6 measurement system available at the host institute) for measurements on a rectilinear grid (standardized scan) as well as for the irregular grid (from the surrogate modeling approach). Timing models were derived for the movement of the probe, the SAR measurement in a single point, post-processing of the surrogate model. These timing models were applied on the SAR database for two selected surrogate models. As first surrogate model, we selected the default model available in the Surrogate Modeling (SUMO) toolbox (developed by the surrogate modelling lab of Ghent university, http://www.sumo.intec.ugent.be/SUMO). The default surrogate model of the SUMO toolbox uses a hybrid sequential design comprising of 70 % LOLA-voronoi and 30 % error" [1]: This a combination of "Local Linear Approximation" (LOLA) for selecting samples in non-linear regions, i.e., the slopes in the SAR distribution, Voronoi tessellation to sample in under sampled regions, and Error aiming at sampling in locations where the model error is estimated to be the largest. Based on the characteristics of the SAR distribution and the measures of interest (good estimation of peak SAR location), we selected a surrogate model that combined 50% LOLA with 50 % of a maximum finding scheme (50 % maximum sample). This model focuses sampling more on regions with maximum SAR values. LOLA focuses, as mentioned previously, on non-linear regions (i.e., regions with strong SAR slopes) whereas the maximum finding focuses sampling on regions with maximum SAR values.

## C. Results

As an example, *Figure 1* shows the sample selection on the standardized rectilinear grid and the irregular grid selected by the surrogate model after 50 samples.

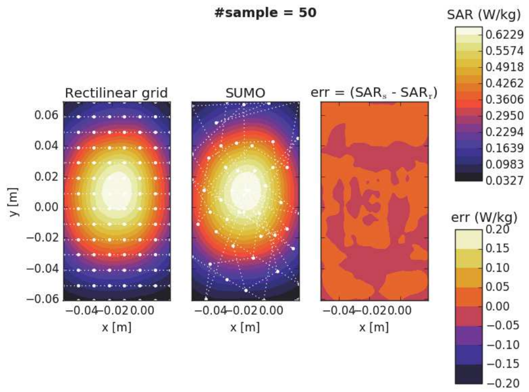
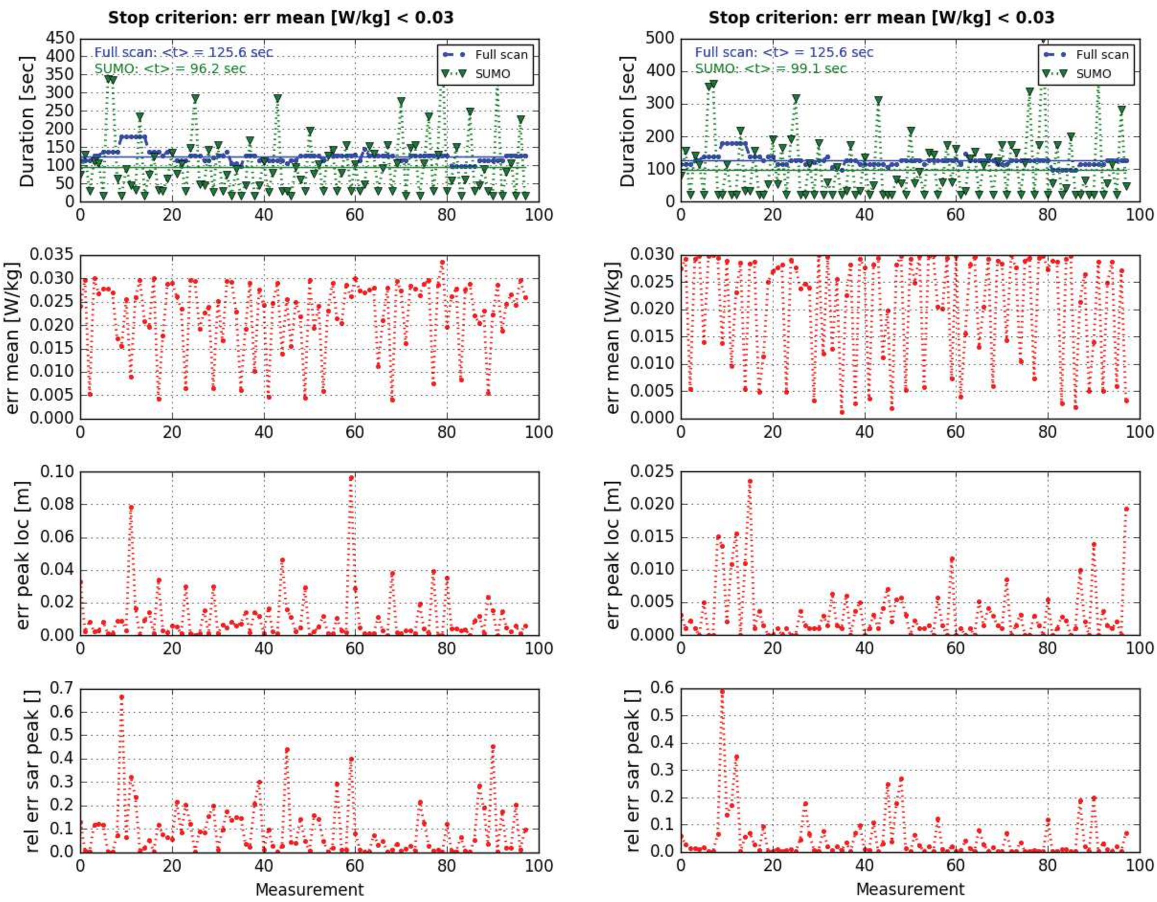



*Figure 1: Example of the SAR assessment on a rectilinear grid (left) and irregular grid selected by the surrogate model after 50 samples.*

We evaluated the time performance of the two selected surrogate models with respect to a standardized full area scan evaluated in terms of: (1) absolute mean error on the SAR distribution (see Figure 2), (2) the absolute error on the peak location (only primary peaks considered; see Figure 3) and (3) the relative error on the peak SAR value (see Figure 4). The selected limits were 0.03 W/kg, 0.005 m and 0.05 (= 5%) for the absolute mean error on the SAR distribution, the error on the peak location and the relative error on the peak SAR value, respectively. The figures show the results for about 100 measurement files. The top figures show the timings. The bottom three figures with the red curves show the errors. The blue and green curves in the top figure show the duration to comply with the limit of the selected error for the full scan and the scan using the surrogate model, respectively. The markers denote the time needed for each of the measurements, the horizontal curves (thin solid line) show the average time needed for all the measurement files. The average timings are also listed in the top left corner of the figure. To evaluate the timings the surrogate model was run for every measurement file until at least 200 samples were selected.

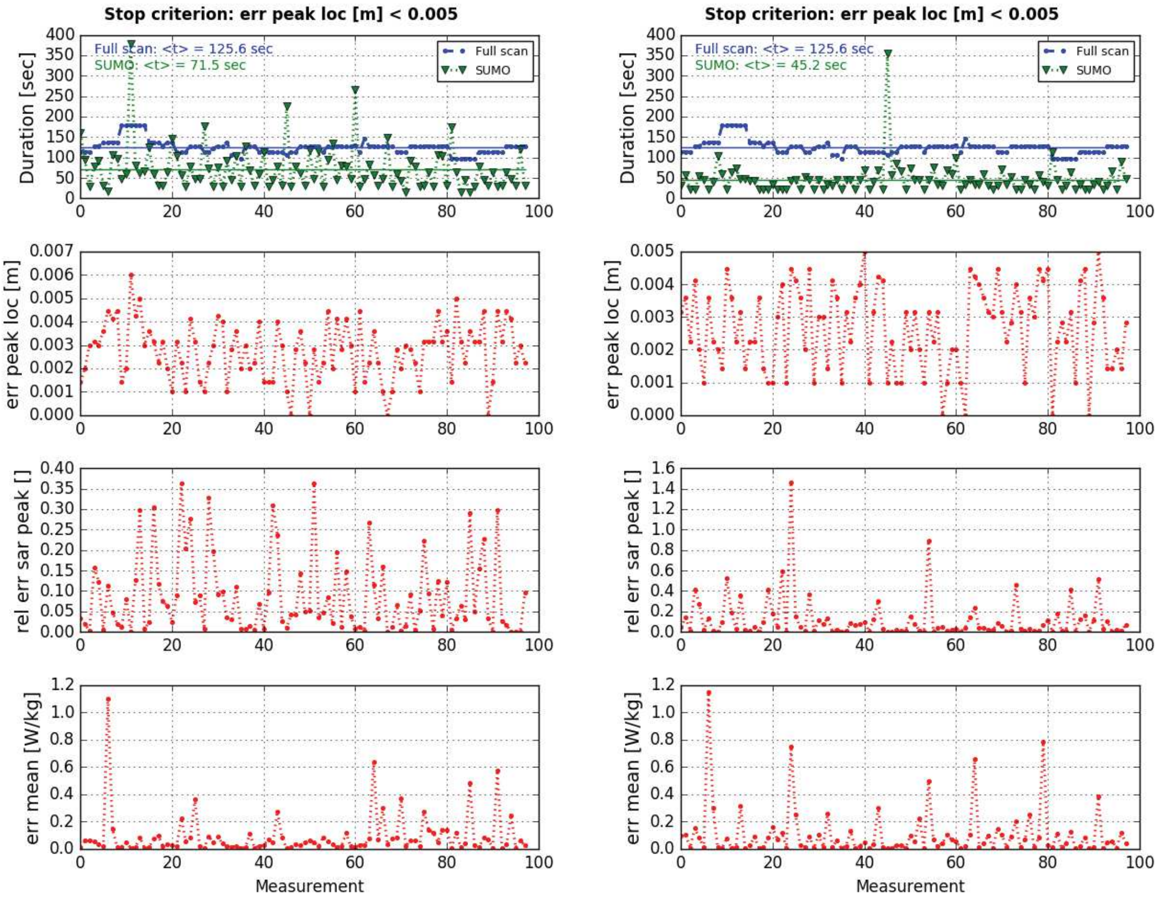
[1] Karel Crombecq, Dirk Gorissen, Dirk Deschrijver, and Tom Dhaene. 2011. A Novel Hybrid Sequential Design Strategy for Global Surrogate Modeling of Computer Experiments. *SIAM J. SCI. COMPUT*. Vol. 33, No. 4, pp. 1948–1974.




70 % LOLA-voronoi + 30 % error (Default)

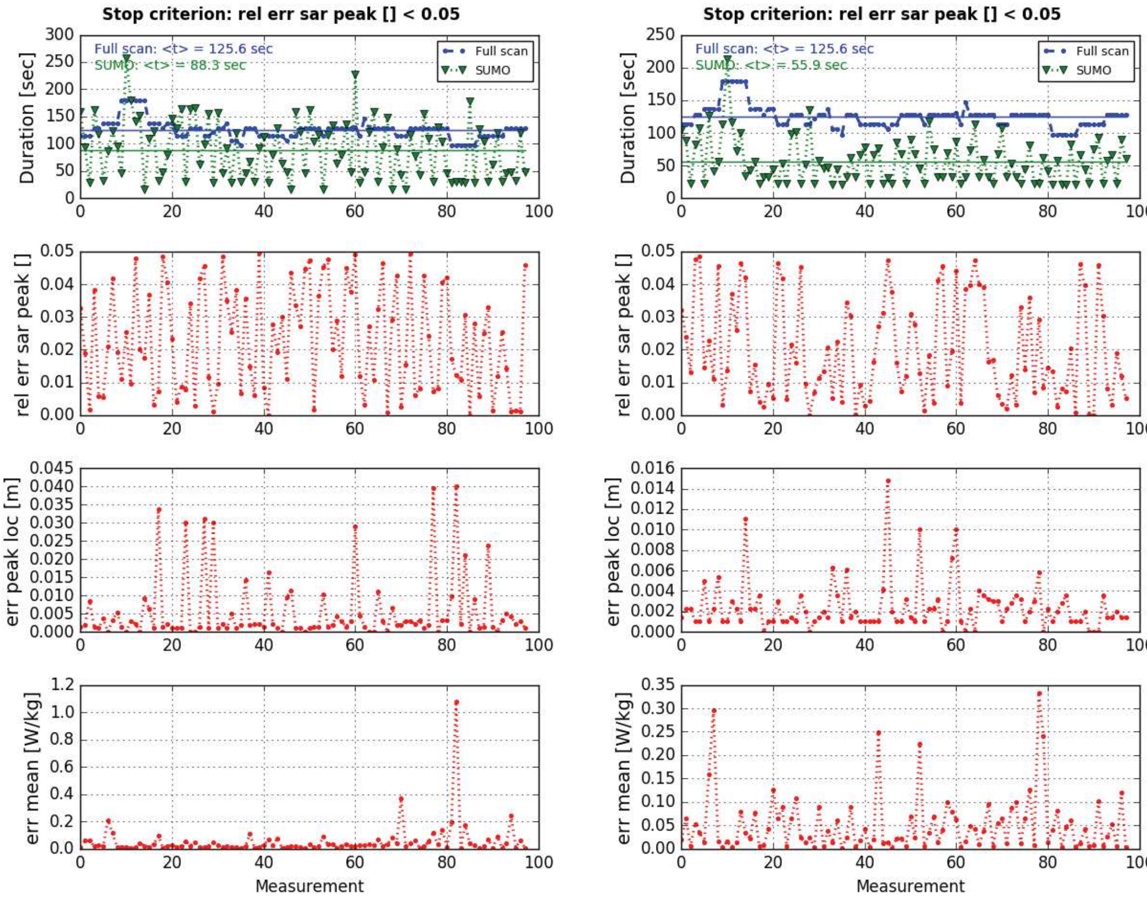
50 % LOLA + 50 % maximum sample (LOLA-max)

*Figure 2: Performance of the surrogate modeling with respect to the standardized area scan for a a limit of 0.03 W/kg on the mean absolute error on the SAR distribution.*




70 % LOLA-voronoi + 30 % error (Default) | 50 % LOLA + 50 % maximum sample (LOLA-max)

*Figure 3: Performance of the surrogate modeling with respect to the standardized area scan for a limit of 5 mm on the peak SAR location (only primary peak).*

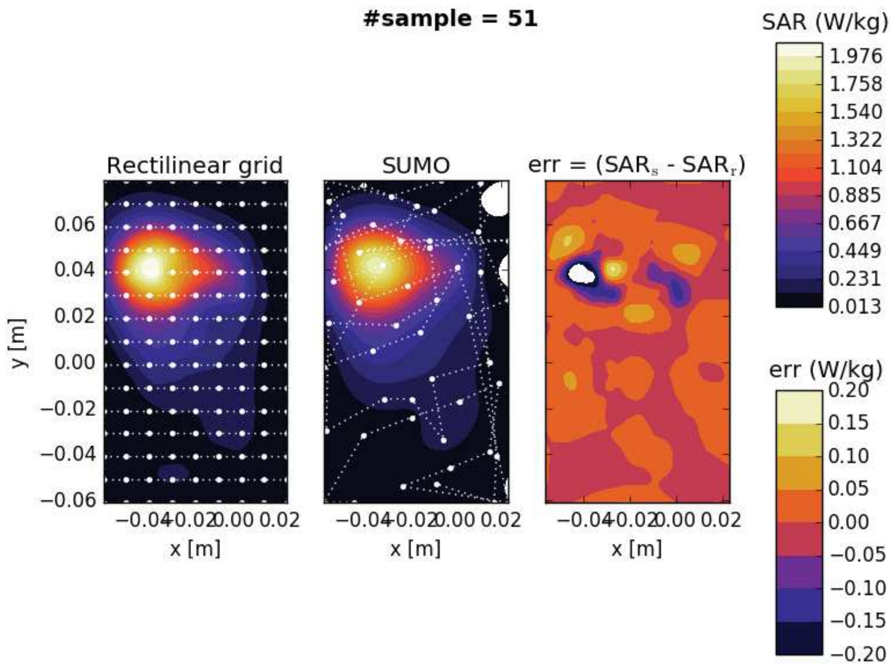



70 % LOLA-voronoi + 30 % error (Default) | 50 % LOLA + 50 % maximum sample (LOLA-max)

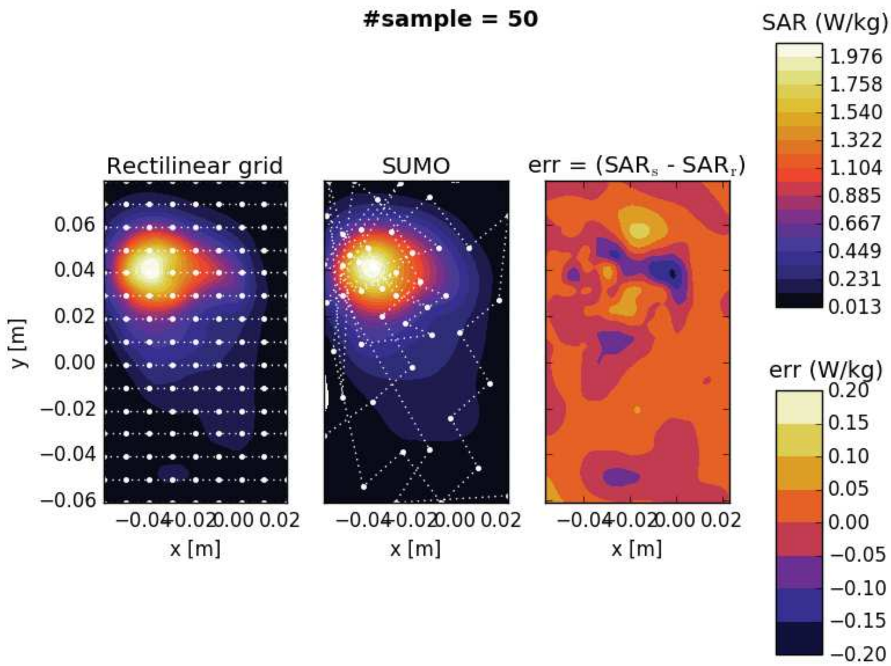
*Figure 4: Performance of the surrogate modeling with respect to the standardized area scan for a limit of 5 % on the peak SAR value (only primary peak).*

From the figures, we observe that the selected surrogate models perform on average 30 % and 55 % faster than the standardized full scan for the default and the LOLA-max surrogate model, respectively.

Figure 5 compares visually the sample selection of the two selected surrogate models for the same SAR distribution. We observe that the max-LOLA surrogate model selects more samples around the peak location then the default surrogate model.




70 % LOLA-voronoi + 30 % error
(Default)




50 % LOLA + 50 % maximum sample
(LOLA-max)

*Figure 5: Sample selection of the default (top figure) and LOLA-max (bottom figure) surrogate model after about 50 samples on the same SAR distribution.*

## D. Future collaboration with host institution

The promising results of the fast SAR assessment using surrogate model might result in a joint project with the host institute. One of the major tasks of the project will be the investigation and development of an appropriate stopping criteria for the surrogate modeling approach.

E. Expected Publications

A joint peer-reviewed publication on the surrogate modeling for fast SAR assessment is currently planned. A possible journal might be the bioelectromagnetics journal.

## F. Other Comments

None.

**Confirmation by the host institution of the successful execution of the STSM:**

We confirm that Günter Vermeeren has performed the research work as described above.

Contact Person of Host Institution

Signature

Name of researcher
Günter Vermeeren

Signature