Sequential RF-EMF Exposure Modeling and Hotspot Localization

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SUMMARY

We present a new methodology to create heat maps that accurately pinpoint the outdoor locations with elevated exposure to radio-frequency (RF) electromagnetic fields (EMF) in an extensive urban region. It comprises an iterative measurement and modeling scheme based on kriging interpolation, and allows local authorities and epidemiologists to efficiently assess the location and spectral composition of RF-EMF exposure hotspots, while at the same time developing a global picture of the exposure in the area.

INTRODUCTION

Public concerns about the possible health effects of exposure to radio-frequency electromagnetic fields (RF-EMF) are increasing. However, the general public is not at all familiar with the typical levels of RF-EMF radiation they are exposed to in their everyday environment. A visual way of filling this important public information gap is the use of a heat map, an easily comprehensible graphical representation of the magnitude of the RF-EMF exposure over a certain area. In this study, we propose a novel, efficient methodology to construct heat maps that accurately pinpoint the outdoor regions that show an elevated RF-EMF exposure (i.e., hotspots) in an extensive urban area. Our method allows for local authorities and epidemiologists to rapidly assess the location and spectral composition of these hotspots, while at the same time developing a global picture of the RF-EMF exposure in the area. Moreover, no prior knowledge about the presence of RF radiation sources (e.g., base station parameters) is required, an important advantage over non-measurement-based models.

MATERIALS AND METHODS

The area under study comprises the city center of Ghent, Belgium, and has an approximate size of 1 km^2. Being urban, the area contains a variety of RF transmitters (e.g., (digital) radio, emergency service communication networks, and mobile telephony).

The model input measurements are performed iteratively, in lots of 100 at a time, and a broadband probe is used as measurement device, because of its speed and portability. Our exposure model, K, is constructed via kriging interpolation of the measurement data, and sequentially updated after each lot (the model stages are denoted as K_0 to K_n, with n the number of the last iteration). The choice of measurement locations is based on two criteria: (a) the probability of being in a region with elevated RF-EMF exposure (defined in our study as having an electric-field strength higher than 0.7 V/m), which is assessed via the kriging model's intrinsic error estimation (called kriging variance); and (b) a distance criterion that ensures sampling in uncharted areas, in search of other hotspots. Finally, in order to identify the relevant signals contributing to the exposure, narrowband measurements are performed in the discovered hotspots using a spectrum analyzer.

RESULTS

In total, six lots of 100 input measurements (resulting in models K_0 to K_5), and 50 validation measurements were performed. The results are summarized in Table 1. The model input measurement values varied between 0.04 and 3.10 V/m, with a total average electric-field strength of 0.70 V/m. The fact that, while the median electric-field strength stays relatively stable with each successive lot, the average electric-field strength, as well as the 95th percentile steadily increase is a clear indication of the well functioning of our procedure. The validation measurements, on their turn, varied between 0.16 and 1.18 V/m with an average electric-field strength of 0.49 V/m.

The heat map constructed from the final model, K_5, is shown in Figure 1. Five RF signals were found to contribute to the exposure in the identified hotspots: FM (Frequency Modulation) radio, at 100 MHz; T-DAB (Terrestrial Digital Audio Broadcasting) at 224 MHz; GSM (Global System for Mobile Communications) downlink at 900 MHz (GSM900), and at 1800 MHz (GSM1800); and UMTS (Universal Mobile Telecommunications System), at 2100 MHz. Of the five contributing sources, only GSM900 was always present, and it was always the dominant source (representing between 45 and 100% of the total exposure).

K_5 was validated with 50 additional validation measurements, performed at locations at least 100 m apart, at least 10 m from any model input measurement location. The mean relative error between model and validation measurements is just 2 dB, with more than 75% of the relative errors below 3 dB. The correlation is also very good, with Pearson and Spearman correlation coefficients of 0.73 and 0.72, respectively, a non-weighted Cohen’s kappa, κ, of 0.41, and a sensitivity and specificity of 0.60 and 0.96, respectively.

CONCLUSIONS

An accurate outdoors RF-EMF exposure heat map was constructed from iteratively performed measurements. It characterizes and outlines the hotspot regions, and supplies an accurate, graphical representation of the exposure, which can be easily understood by laymen. Furthermore, the constructed model can serve as input, optimization, or validation to more sophisticated epidemiological RF-EMF exposure models. Extension of our procedure to indoor exposure, including personal and indoor devices (e.g., cordless phones), will be the subject of future research.

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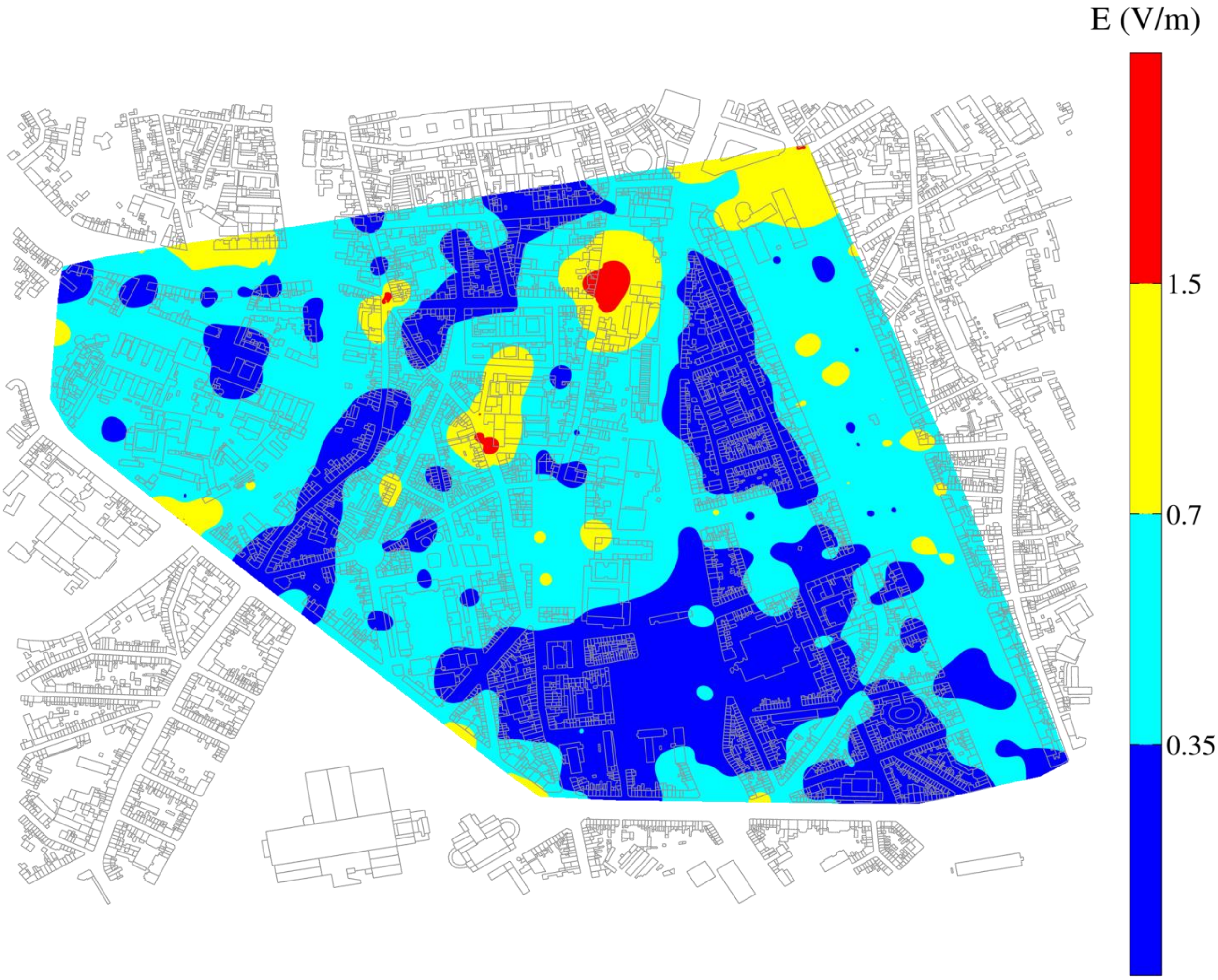

Figure 1

	# measurements	E_{min} - E_{max} (V/m)	E_{avg} (V/m)	E_{median} (V/m)	E_{p95} (V/m)	STD (V/m)
Lot 0	100	0.25 - 1.60	0.56	0.48	0.96	0.23
Lot 1	100	0.15 - 2.83	0.64	0.50	1.46	0.44
Lot 2	100	0.10 - 2.77	0.63	0.46	1.66	0.50
Lot 3	100	0.12 - 2.52	0.76	0.45	1.96	0.61
Lot 4	100	0.04 - 3.06	0.75	0.49	2.07	0.63
Lot 5	100	0.12 - 3.10	0.85	0.56	2.29	0.68
Total	600	0.04 - 3.10	0.70	0.49	1.90	0.54

E_{min} – E_{max} is the minimum – maximum interval, E_{avg} is the average value, E_{median} is the median value, E_{95} is the 95th percentile of the distribution, and ***STD*** its standard deviation.

Table 1