Assessment of a localized deterministic spatial interpolation method in generating an indoor radiofrequency radiation map

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Abstract. Picocell antennas are used to improve wireless communication coverage inside an area. More picocell antennas are being used to cover small areas, thus, increasing the radiofrequency radiation (RFR) levels in an indoor environment. One method in estimating the radiofrequency radiation is by using spatial interpolation techniques. This study assessed the robustness of a localized deterministic spatial interpolation method compared to its global interpolation counterpart used in generating a radiofrequency radiation map. This was investigated to speed up the data analysis by taking a smaller number of samples. An omnidirectional picocell antenna located in an office lobby area was chosen. The NARDA Selective Radiation Meter SRM-3000™ with tri-axis antenna was used to check the central frequency and average power density emitted by the antenna. A radiofrequency map was generated using a small sample size in a grid pattern. The local Shepard interpolation method with a radius of influence of 100 cm and a power factor of 1 gives a result with a mean absolute difference lower than the global interpolation method. Thus, error contribution in RFR map generation can be minimized by considering a smaller region of samples in the interpolation.

1. Introduction

An antenna is a means for radiating or receiving radio waves for wireless communication application. The current distribution on the antenna is responsible for its emission of radiofrequency radiation (RFR) [1]. Antennas are classified based on their power output and range wherein a picocell antenna plugs coverage holes for an indoor environment. Unlike other types of antennas, picocell antennas use internal antennas so as to minimize environmental impacts and installation cost. Due to its compact size, more picocell antennas are used to cover an indoor setting [2]. Thus, it increases RFR level around the area, increasing the risk of RFR biological effects.

Although there is no consistent evidence on health effects from RFR, short-term exposure to radiofrequency (RF) fields at levels above the limits set by exposure guidelines can cause thermal and non-thermal injury. Thermal effects refer to the heat produced due to absorption of electromagnetic radiation. It increases body temperature that greatly affects body parts that does not have temperature regulation mechanism such as the cornea of the eye. On the other hand, non-thermal effects are attributed to the electromagnetic effects induced inside the biological cells that may cause more harmful effects. It includes burning to tingling sensation in the skin, dizziness, and lack of concentration [3].

Analyzing RFR spatial maps is one way to assess RFR levels in an area. However, the process on generating spatial maps is time-consuming. This study assessed the robustness of a localized
deterministic spatial interpolation method compared to its global interpolation counterpart used in generating RFR map. This was investigated to speed up the data analysis by taking a smaller number of samples.

2. General Public Exposure Limits

The International Commission on Non-ionizing Radiation Protection (ICNIRP) established guidelines for identifying the limit of electromagnetic (EM) field exposure to humans in order to avoid the adverse health effects it can cause. This reference level is also used by the Philippines Department of Health in their RFR surveys. The general public is defined as the people of all ages with different health conditions and most of the time unaware of the possible risk of being exposed to EM radiation [4]. Table 1 shows the reference levels for general public set by ICNIRP.

| Frequency Range      | E-field strength (V/m) | H-field (A/m) | B-field (μT) | Equivalent plane wave power density $S_{eq}$ (W/m²) |
|----------------------|------------------------|---------------|--------------|-----------------------------------------------|
| 400-2000 MHz         | 1.375f^{1/2}          | 0.0037f^{1/2} | 0.0046f^{1/2} | f/200                                          |
| 2-300 GHz            | 61                     | 0.16          | 0.20         | 10                                             |

* f - the specific frequency investigated; E – Electric field; H – Magnetic field strength; B – Magnetic field; $S_{eq}$ – Equivalent plane wave power density

3. Deterministic Spatial Interpolation

A two dimensional multivariate deterministic spatial interpolation method was investigated in this study. Shepard interpolation method, a neighbourhood spatial interpolation, was used due to its capability to work with limited number of samples. It uses a known set of scattered points wherein unknown points were produced as shown in Equation 1.

$$ f(x, y) = \sum_{j=0}^{N} W_j(x, y) f_j = \frac{\sum_{j=0}^{N} \frac{1}{d_j^\alpha} f_j}{\sum_{i=0}^{N} \frac{1}{d_i^\alpha}} \quad (1) $$

where $j =$ counter for specific point, $i =$ counter for calculating total inverse distance, $f_j =$ jth sampling point of magnitude, $d_i$ & $d_j =$ Euclidean distance between interpolated and sampling point, $\alpha =$ tuning/power factor

Weighted average is being assigned to unknown points using values available at known points. The interpolating function in equation 1 uses all $N + 1$ interpolation points $(x_j, y_j, f_j)$ where $j = 0, \ldots, N$ in calculating new functional values, thus it is a global method. However, it demands a high amount of computations.

Interpolating locally is considered in this study because they have the capability to robustly work with limited number of samples, making RFR survey faster. To investigate the OSM interpolation further, it was modified by making the interpolation a local method. This technique considers the direction, the number and set of neighbouring data points, and the slope of the interpolation function [5]. It was done by defining a radius of influence (R) as shown in equation 2. Thus, only the samples within R are used in the interpolation process.

$$ W_j(x, y) = \begin{cases} \frac{1}{d_j^\alpha} & \text{for} \quad 0 < d_j < R \\ \frac{\sum_{i=0}^{N} \frac{1}{d_i^\alpha}}{\sum_{i=0}^{N}} & \text{for} \quad d_j \geq R \end{cases} \quad (2) $$
4. Methodology

4.1. Antenna Selection
An omnidirectional picocell antenna was chosen inside the Philippine General Hospital (PGH). The layout of the location was noted prior to the data gathering. The antenna is located in a wide hallway and is free from any obstruction (i.e. table, chair). Thus, a square grid measurement can be easily implemented.

4.2. Radiation Meter
A calibrated NARDA Selective Radiation Meter SRM-3000™ with tri-axis antenna was used. The average power density was measured in each assigned point for six minutes per grid point [4]. The height of the instrument’s antenna was set to 1.5m because it is commonly used in RFR surveys.

A pre-defined pattern of known and unknown points were created before applying the interpolation technique. The number of sample data (known) points used was 20 out of the 36 measured power densities. In figure 1, the dots represent the known data and the stars are the unknown points. Samples (dots) with significant change in magnitude compared to adjacent points were chosen because they have a huge contribution in constructing the spatial map. Examples of these are the points at the corners of the area which showed sudden peak in average power density magnitude due to RFR reflections on the corner walls. This is done to take into account border effects as done by Denkovski, D. et al [5]. Samples inside the rectangular grid were chosen alternately.

![Pre-defined pattern to test the accuracy of interpolation methods used](image)

4.3. Interpolation Method
Interpolation methods were then implemented using the grid data around the antenna. After the interpolation process, the accuracy was quantified by calculating its corresponding errors through comparison of the interpolated value to the actual gathered data. This was done by calculating the mean absolute error (MAE). Then, an RF map was generated using a smaller size of samples (20 samples). The generated RF map using fewer number of samples was then compared to the RF map using all the available 36 samples. By doing so, the robustness of the interpolation method in using a small number of samples was identified.

5. Results and Discussion
Spectrum analysis graph was generated by gathering the power densities gathered for the assigned frequency range. The frequency resolution was automatically assigned by the instrument (i.e. 0.25MHz, 0.094MHz). Both 650MHz-1250MHz and 2000MHz-2500MHz ranges did not produce any significant
power density measurement. On the other hand, 1250MHz-2000MHz frequency range resulted into two power density peaks as shown in the figure 2.

![Figure 2. Spectrum analysis graph for the antenna with the frequency range of 1250MHz – 2000MHz](image)

After identifying that the frequency with the highest power density contribution is 1878 MHz, it was set as the central frequency of the selective radiation meter. The highest and lowest values measured were 4.221 mW/m² and 0.308 mW/m², respectively [6]. Thus, all the measured averaged power densities are magnitudes below the ICNIRP reference levels.

Using the pre-defined pattern, the global and local Shepard interpolation methods were used to generate a spatial map of the radiation frequency radiation in the vicinity of the indoor antenna. The MAE was calculated by comparing the result of the interpolation to the actual measured data. The power factor (α) was set as 1 and 2 which are the usual values that were investigated by previous researches [5, 7]. For the global interpolation method, a power factor of 2 gives the lowest error while a power factor of 1 gives the lowest error for the local interpolation method.

Figure 3 shows the RF map generated using the global Shepard method. Figure 3.A shows the map generated using all the 36 measured averaged power densities while figure 3.B was generated using the pre-defined pattern with 20 known points. The difference map between figures 3.A and 3.B is shown in figure 4.

![Figure 3. RF map using global-original Shepard method (α = 2) using: A) 36 samples, B) 20 samples](image)
The MAE observed in the global method is 0.1663. In addition, points near the walls and in between the wall and open space were observed to produce high difference. This is due to the sudden change in the environment (presence or absence of walls) that significantly affected how the RFR interacts with the environment. In addition, a ring-line pattern was observed in the difference map due to the pre-defined pattern used. Thus, the global-original Shepard method is highly affected by the pattern of the known points and by the interaction of the RFR with the environment.

Figure 5 shows the RF map generated using the local Shepard method. Figure 5.A shows the map generated using all the 36 measured averaged power densities while figure 5.B was generated using the pre-defined pattern with 20 known points. The difference maps between figures 5.A and 5.B is shown in figure 6.

The difference map generated using the localized Shepard method generally shows a lower MAE compared to the global Shepard method. Most of the errors are seen near the corner of the lobby area that is due to the reflection of the RFR in that area. This reflection in the corner is also called the border effect and was suggested by previous studies to exclude these points to lower its contribution to the error [7]. Another advantage of this localized method is that the ring-like pattern decrease. Thus, the pre-defined pattern used during the data gathering does not significantly affected the RFR map generated.
The local Shepard interpolation method with a radius of influence equal to 100cm and a power factor of 1 gives a result with a MAE of 0.144. This is more accurate compared to the global interpolation method investigated with 0.166 MAE.

6. Conclusion and Recommendation
Both the global and local interpolation methods produced varying errors. This is due to the multiple reflection, diffraction, and scattering of RFR as it propagates. For the Shepard method used, the local-original Shepard method produced a more accurate result compared to its global interpolation counterpart. Thus, error contribution in RFR map generation can be minimized by considering a smaller region of samples in the interpolation.

Future research on this should focus on the proper tuning of the Shepard method to consider the interaction of radiofrequency radiation with surrounding objects. This will provide the interpolation function the ability to adjust to the specific obstacle present in the environment.

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