Development of a New Personal Magnetic Field Exposure Estimation Method for Use in Epidemiological EMF Surveys among Children under 17 Years of Age

Kwang-Ho Yang†, Mun-No Ju*, Sung-Ho Myung*, Koo-Yong Shin**, Gi-Hyun Hwang*** and June-Ho Park§

Abstract – A number of scientific researches are currently being conducted on the potential health hazards of power frequency electric and magnetic field (EMF). There exists a non-objective and psychological belief that they are harmful, although no scientific and objective proof of such exists. This possible health risk from ELF magnetic field (MF) exposure, especially for children under 17 years of age, is currently one of Korea’s most highly contested social issues. Therefore, to assess the magnetic field exposure levels of those children in their general living environments, the personal MF exposure levels of 436 subjects were measured for about 6 years using government funding. Using the measured database, estimation formulas were developed to predict personal MF exposure levels. These formulas can serve as valuable tools in estimating 24-hour personal MF exposure levels without directly measuring the exposure. Three types of estimation formulas were developed by applying evolutionary computation methods such as genetic algorithm (GA) and genetic programming (GP). After tuning the database, the final three formulas with the smallest estimation error were selected, where the target estimation error was approximately 0.03 μT. The seven parameters of each of these three formulas are gender (G), age (A), house type (H), house size (HS), distance between the subject’s residence and a power line (RD), power line voltage class (KV), and the usage conditions of electric appliances (RULE).

Keywords: EMF, Personal magnetic field exposure, Estimation, Prediction, Formula and Evolutionary computations

1. Introduction

There is an increasing concern regarding the potential health risk caused by exposure to power frequency EMF [1]. The concerns over the possible biological effects of power lines and other power sources began in 1979, when Wertheimer and Leeper reported that children living in the vicinity of high-voltage transmission lines have a higher risk of developing leukemia. Although a number of researches have been conducted on this subject, the biological effects of EMF remain a heated technological and medical controversy [2-12]. An indirect method to estimate the MF exposure level of the children, who were less than 17 years of age, was developed in this study. Exposure estimation formulas provide an epidemiological survey method for studying the biological effects of EMF. The 436 study participants, ranging from infants to junior high school students, were divided into three age brackets (three categories by age), and evolutionary computations are used as an optimization method in database tuning.

2. Participant and Database

The personal MF exposure data were obtained from the study participants, who resided near transmission and distribution lines with voltages of up to 345 kV. These participants were categorized according to the radial distance of their residences from a power line, and according to their age groups. The subjects included 84 preschool and younger children, including infants (1-7 years old), 289 elementary school children (8-13 years old), and 63 junior high school students (14-16 years old). The 436 study participants are as shown in Table 1. As shown in Fig. 1, according to the subjects’ age and other living conditions, MF meter (Model EMDEX-Lite, Entech, USA) was asked to be put in their bag or carried at the waist and the placed near their head at bedtime. Each participant was required to indicate his/her consent prior to
the self-survey, after which he/she received a magnetic field meter, a questionnaire, and compensation. They were then informed of the survey procedure and of matters that demanded special attention. The questionnaire includes the purpose of the survey, personal information regarding the participants, precautions to be taken for the measurement, a form for private-event recording, a written consent, and basic information regarding electromagnetic fields.

3. Evolutionary Computations as Optimization Method

3.1 Evolutionary computations

Evolutionary computations (ECs) received significant attention in the last decade, although ECs were introduced in the late 1950s.

Fig. 1. To wear a magnetic field meter to junior high school student and preschool children

Table 1. Type of participant and status of the survey

<table>
<thead>
<tr>
<th>The type of participant</th>
<th>Less than 50m from power lines</th>
<th>More than 50m from power lines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>22.9 kV</td>
<td>154 kV</td>
</tr>
<tr>
<td>Infants &amp; preschool children</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Elementary school children</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Junior high school student</td>
<td>16</td>
<td>15</td>
</tr>
</tbody>
</table>

ECs are search algorithms based on the mechanics of genetics and natural selection. They combine the survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm. ECs efficiently exploit historical information to speculate on new search points with improved performance. In other words, ECs are search methods combining elements of directed and stochastic search, which can strike a remarkable balance between the exploration and the exploitation of global and local search capabilities. The GA and GP application procedures in the development of personal MF exposure estimation formulas were described as follows. Developed by John Holland in the early 1970s, GA offers the best solution for the environment by searching the solution space with a probability method and a hierarchical exchange of information between the individuals. GA does not use real parameters but uses chromosomes composed of string-coded genotypes. It simulates the crossover and mutation of natural systems, which gives it a global searching capability. GP follows the trend of the GA paradigm but uses trees of Fig. 2 to represent genotypes as they provide a flexible representation for creating and manipulating programs. GP starts with an initial population of randomly generated computer programs (S-expressions, (1)) composed of functions (F) and terminals (T) appropriate to the problem domain. The functions may be standard arithmetic operations (+, −, ×, %, etc.), standard mathematical functions (sin, cos, exp, log, etc.), or logical functions, as shown in (2). The terminals are typically either variable terms (representing the inputs or state variables of a system) or constant terms, such as those shown in (1). Each individual computer program in the population is measured in terms of how well it performs in the particular problem environment. This measure is called “fitness measure” in (3).

\[
S = T = [G, A, H, HS, RD, KV, RULE] \\
F = \{+,-,\times,%, \log, R\} \\
Fitness = \frac{1}{1 + \sum_{i=1}^{q} |\text{error}|} 
\]

where \(q\) is the number of individuals, and \(R\) means ephemeral random constant.

In the GP operator, the genetic operation of crossover is used to create a new offspring population of individual computer programs from the current population of programs as shown in Fig. 2. The mutation operation begins by randomly selecting a point within the S-expression, as shown in Fig. 3. This mutation point can be a function point or a terminal point of the S-expression. The mutation operation then removes the currently selected point and no matter what exists below the selected point. The next step is to insert a randomly generated sub-S-expression at that point. After the operations of reproduction, crossover, and mutation are performed on the current population, the offspring population of the new generation replaces the old generation. Each individual in the new population of computer programs is measured for fitness, and the process is repeated over many generations [13-21]. Fig. 4 represents the convergence properties of the objective function by generation. In Fig. 4, as the number of generation increases, the objective function decreases, which shows the search for the optimal solution as the number of generations increases based on the optimization method.
3.2 Formula development specification

The EC optimization method was applied to the measured database so that personal MF exposure estimation formulas could be developed. During such development, the following key techniques were employed:

(1) Types and characteristics of the parameters
The six main parameters are gender (G), age (A), house type (H), house size (HS), radial distance (RD), and power line voltage (KV). A supplemental parameter called “RULE” is added to increase the estimation accuracy. RULE represents the length and pattern of the use of electric appliances like PCs and electric heat mats (Table 2). On the other hand, variables with negligible effects, such as sleep, school, commute to and from school, and TV watching, were not included in the rules.

(2) Radial distance
To determine the distance between the subject’s residence and a power line, radial distance (RD), which is considered the real distance, was used instead of lateral distance (LD), as in Fig. 5. A digital laser distance meter was used to measure the radial distance in each case.

(3) Power line voltage
Transmission and distribution line voltage was used as a parameter in this research instead of load current. Although the load current dictates the MF level of a power line directly, voltage was chosen because the load current fluctuates tremendously during the day and according to the season. Moreover, it was found in this research that there is a significant similarity between an increase in transmission line voltage and an increase in the average MF as shown in Table 3.

(4) Main parameter code table
Table 4 outlines the main parameter codes and input values during database (DB) tuning.

(5) Applications of ECs
Table 5 describes the DB tuning parameters of each method based on ECs. (4) illustrates the general objective function of the genetic algorithm (GA).

<table>
<thead>
<tr>
<th>Time Span</th>
<th>Rules (RULE)</th>
</tr>
</thead>
</table>
| 24 hr.    | • Sleeping on an electric heat mat with an EMF shield: +0.02 μT/hr.  
           | • Sleeping on an electric heat mat without an EMF shield: +0.29 μT/hr.  
           | • Using a PC with a CRT: +0.04 μT/hr.  
           | • PC cyber cafe: +0.04 μT/hr.  
           | • Using an electric heat mat at a high level for 3–4 hours, excluding the sleeping time: +0.2 μT  
           | • Nightly storage electricity use at home: +0.1 μT |

### Table 2. Detailed rules

- **Parent-1** = log (G+RD) x A  
  Parent-2 = log (2KV+A−G) x KV

(a) Two parental computer programs

- **Offspring-1** = log (G−KV) x RD + A  
  Offspring-2 = log (KV+A−G)

(b) Two offspring produced by crossover

**Fig. 2.** Crossover operation in genetic programming

**MFE_{BM} = log KV + log (RD+A)  
MFE_{AM} = log (G-KV) + log (RD+A) − log G**

(Before Mutation)  
(After Mutation)

**Fig. 3.** Change in S-expression after mutation

**Fig. 4.** Development of the objective function according to the number of generations of infants and preschool children
Fig. 5. Two kinds of methods to measure the distance between a power line (or steel tower) and a residence

Table 3. Comparison of the increase in line voltage with the increase in the average magnetic field

<table>
<thead>
<tr>
<th>Transmission Line</th>
<th>Line Voltage</th>
<th>Average Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>345 kV</td>
<td>154 kV</td>
<td>2.2 times</td>
</tr>
<tr>
<td></td>
<td>2.0 times</td>
<td>28.2 mG, 81 places</td>
</tr>
<tr>
<td>154 kV</td>
<td>66 kV</td>
<td>2.3 times</td>
</tr>
<tr>
<td></td>
<td>1.6 times</td>
<td>14.0 mG, 122 places</td>
</tr>
<tr>
<td>66 kV</td>
<td>22.9 kV</td>
<td>2.9 times</td>
</tr>
<tr>
<td></td>
<td>3.1 times</td>
<td>8.7 mG, 5 places</td>
</tr>
</tbody>
</table>

Distribution Line

<table>
<thead>
<tr>
<th>Line Voltage</th>
<th>Average Magnetic Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.9 kV</td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>2.8 mG, 305 places</td>
</tr>
</tbody>
</table>

Table 4. Codes and inputs of main parameters

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>House Type</th>
<th>House Size</th>
<th>Radial Distance</th>
<th>Power Line Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>1–16</td>
<td>Apt(10), Etc (20)</td>
<td>the square of meter</td>
<td>0–30m (10)</td>
<td>Line Voltage</td>
</tr>
<tr>
<td>Female</td>
<td>(20)</td>
<td></td>
<td></td>
<td>31–50m (20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51m or more (30)</td>
<td></td>
</tr>
</tbody>
</table>

\[
MF_{\text{Exposure}} = k_1 \log(G) + k_2 \log(A) + k_3 \log(H) + k_4 \log(HS) + k_5 \log(RD) + k_6 \log(KV) + \text{Rule}
\] (4)

Table 5. Tuning parameters of genetic optimizations

<table>
<thead>
<tr>
<th>EC's</th>
<th>Generations</th>
<th>Population Size</th>
<th>Crossover Probability</th>
<th>Mutation Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>2,000</td>
<td>100</td>
<td>0.95</td>
<td>0.05</td>
</tr>
<tr>
<td>GP</td>
<td>200,000</td>
<td>1,000</td>
<td>0.8</td>
<td>0.08</td>
</tr>
</tbody>
</table>

4. Results of the Developed Formulas

4.1 Development conditions

The conditional criteria for and the functional evaluation characteristics of the development of an MF exposure estimation formula are as follows:

1. Six parameters: G, A, H, HS, RD, and KV
2. Supplementary rules (RULE) applied to reduce the estimation errors
3. Target error value: The target value of the tuning, verification, and mean absolute estimation errors are below approximately 0.03 μT.

(4) KV means actual overhead power line voltage. However, in this survey, there was no subject related to underground cables. Actually, it is not easy subjects to recognize whether underground cable exists nearby them or not. Therefore, underground cables have not been considered as a magnetic field source. And also, the exposure by the power line might have been included in the exposure dose during the time when the students stayed in school. Moreover, the exposure by the transmission and distribution lines around the house was included in the exposure dose at home, where the subjects spend most of their time. Thus, the power line as one of high MF sources was considered for developing the estimation formulas.

5. The database was first tuned with GA and GP. And then, the formulas with the smallest estimation errors or the ones that incorporated the most parameters were chosen for each case.

6. When a formula produced a negative value due to a peculiar problem between the parameters under normal conditions, a penalty was issued to the string (chromosome) fitness during DB tuning.

7. Parameter signs: HS, RD, and KV must carry the −, −, and + signs, respectively.

8. RD: RD has three kinds of categories; less than 30 m, 31–50 m, and more than 50 m. The RD was determined based on the bedrooms in which the subjects were living.

9. HS: For apartments, square meter was used. For houses and villas, the square meter of the floor where the participants lived was used.

10. If there are multiple parameters in a formula, the formula was not accepted. This is so because the properties of each parameter are not reflected in the estimation formula.

4.2 Resulting formulas and their applicable conditions

1. Types of Formulas
   - Three types of formulas were developed in this research, as follows:
     - Formula for infants and preschool children (5)
     - Formula for elementary school children (6)
     - Formula for junior high school students (7)

2. Results of the Personal MF Exposure Estimation Formula Development and Their Applicable Conditions
   - Formula for infants and preschool children

   \[
   MF = 0.92 \left( \frac{RD(A + G + HS + KV) + H \times G}{G \times RD^2} \right) + \frac{2.26}{G} \log(RD) \log(RD) + \frac{2.55}{H} \log(KV) + \text{Rule}
   \] (5)
Applicable conditions:
A: ages between 1 and 7
KV: 22.9–345 kV

• Formula for elementary school children

\[ MF = 0.1\log(G) + 1.31\log(A) + 0.13\log(H) - 0.23\log(HS) - 5.09\log(RD) + 3.17\log(KV) \]  
\[ + \text{Rule} \]  
\[ (6) \]

Applicable conditions:
A: ages between 8 and 13
KV: 22.9–345 kV

• Formula for junior high school students

\[ MF = 0.09\log(G) + 2.02\log(A) - 0.67\log(H) - 0.005\log(HS) - 0.94\log(RD) + 0.12\log(KV) \]  
\[ + \text{Rule} \]  
\[ (7) \]

Applicable conditions:
A: ages between 14 and 16
KV: 22.9–345 kV

4.3 Estimation error

Table 6 shows the estimation errors of each formula. Most estimation errors satisfy the target error of approximately 0.03 μT. In Table 6, ‘Tuning’ means the process of finding the coefficients (k1~k6) of the estimation formulas using a GA (genetic algorithm) with the measured DB, or the process of developing the estimation formulas using the GP (genetic programming) method. ‘Verification’ is the process of confirming the usefulness of the estimation formulas by confirming the estimation errors of the formulas using the measured data that are not yet being used to develop the estimation formulas. Fig. 6 is the graphic representing DB tuning and verification trend among elementary school children. Table 7 shows several statistical values of the measured database according to occupations including student [22].

Table 6. Collection of magnetic field exposure estimation errors

<table>
<thead>
<tr>
<th>Formula type</th>
<th>Tuning error/ average measurement value</th>
<th>Verification error/ average measurement value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula for infants &amp; preschool children</td>
<td>0.027/0.184 μT</td>
<td>0.018/0.100 μT</td>
</tr>
<tr>
<td>Formula for elementary school children</td>
<td>0.029/0.168 μT</td>
<td>0.027/0.125 μT</td>
</tr>
<tr>
<td>Formula for junior high school student</td>
<td>0.030/0.184 μT</td>
<td>0.025/0.100 μT</td>
</tr>
</tbody>
</table>

4.4 Formula features applied to sample participants

Determining MF exposure is complicated, and it may even be impossible, depending on the circumstances. The formulas that were developed in this research allow the accurate estimation of personal MF exposure levels without measuring directly. Table 8 shows the results of various computation cases among the sample participants. In Table 8, k1(0~3) means the Conditions in which the electric pad is used, k2(0 or 1) means late-night electricity for residential use,
Therefore, formulas that can estimate the personal MF exposure levels of children in their general living environments were proposed in this paper. The key features and significance of these formulas are as follows:

(1) The measured data that were used to develop the estimation formulas were from the 436 study participants.

(2) Since these formulas were developed to estimate the effects of MF near power lines, people living near power lines were selected as study participants. To be specific, 47% of the participants living within 50 m from power lines were chosen.

(3) A total of three formulas were developed, including one for infants and preschool children.

(4) Gender, age, house type, house size, radial distance between the subject’s residence and a power line, line voltage, and daily living patterns (RULE) were chosen as formula parameters. It was found in this research that the voltage (KV), distance (RD), and age (A) parameters have a high correlation to the MF exposure level. In other words, the greater the size of this coefficient was, the greater its correlation with the applicable parameter was. For example, in the case of RD, it can be seen that the correlation of the MF exposure to the RD of the elementary school children was approximately 5 times as much as that of the junior high school students in (6) and (7).

(5) It is the first time to utilize evolutionary computations as an optimization method for MF exposure calculations. The above computations show that these estimation formulas have approximately 0.03 μT mean errors.

(6) The formulas that were developed in this research can serve as valuable tools in estimating the 24-hour personal MF exposure of children without direct measuring.

(7) The use of the developed formulas for estimating MF exposure levels is the first MF exposure estimation method to emerge since the wire code has been introduced in the late 1970s [2]. In addition, these formulas will provide an effective and practical means to study MF’s effects on human health, especially the epidemiological study of the correlation between magnetic fields and childhood cancer.

### 5. Conclusion

The human health risk caused by the ELF magnetic field has become one of the most controversial issues in Korean society. Especially, its possible health effect on children less than 17 years of age is a matter of primary concern. Therefore, formulas that can estimate the personal MF exposure levels of children in their general living environments were proposed in this paper. The key features and significance of these formulas are as follows:

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References


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