BMBAD BJESR Mühendislik Bilimleri ve Araştırmaları Dergisi
Journal of Engineering Sciences and Researches

Determining the Electromagnetic Power Density of GSM Base Stations by Using Lagrange Interpolation Approach

GSM Baz İstasyonlarının Elektromanyetik Güç Yoğunluğu'nun Lagrange İnterpolasyon Yaklaşımı Kullanılarak Belirlenmesi

[1]Uğur SORGUCU

[1]Nevşehir Hacı Bektaş Veli Üniversitesi, Mühendislik Mimarlık Fakültesi Elektrik Elektronik Mühendisliği Bölümü NEVŞEHİR, Türkiye

[1]sorgucu@nevsehir.edu.tr

Araştırma Makalesi/Research Article

ARTICLE INFO

Article history

Received : 7 March 2023
Accepted : 5 May 2023

Keywords:

Lagrange interpolation, Electromagnetic Power, 900MHz, GSM, Base Station

ABSTRACT

Mobile communication systems are playing an important role in human life, and the importance of this role depends on the increase in the number of people. Reports show that the number of base stations is increasing in parallel to the use of mobile communication systems and population growth. Determining the base station strength is very important, especially in crowded cities. Because of the possible medical effects of base stations, people have the right to know how much is affected. Therefore, the radiation level of 120 base stations has been measured at 20, 40 and 60 meters from base stations at a frequency of 900 MHz. In this study, the Lagrange interpolation method is applied to estimate the strength of electromagnetic level for random intermediate distances and, above 0.99 correlation was achieved for each distance.

MAKALE BİLGİSİ

Makale Tarihleri

Gönderim : 7 Mart 2023
Kabul : 5 Mayıs 2023

Anahtar Kelimeler:

Lagrange Enterpolasyon, Elektromanyetik Güç, 900MHz, GSM, Baz İstasyonu

ÖZET

Gezgin haberleşme sistemleri insan hayatında önemli bir rol oynamakta ve bu rolün önemi insan sayısındaki artışla ortantılı olmaktadır. Raporlar, gezgin haberleşme sistemlerinin kullanımına ve nüfus artışına paralel olarak baz istasyonu sayılarının da arttığını göstermektedir. Baz istasyonu gücünün belirlenmesi özellikle kalabalık şehirler için çok önemlidir. Baz istasyonlarının olası tıbbi etkilerinden dolayı insanların baz istasyonlarından ne kadar etkilendiğini bilme hakları vardır. Bu nedenle 120 baz istasyonunun radyasyon seviyesi baz istasyonlarından 20, 40 ve 60 metre mesafelerde 900 MHz frekansında ölçülmüştür. Bu çalışmada, rastgele ara mesafeler için elektromanyetik seviyenin gücünü tahmin etmek için lagrange interpolasyon yöntemi uygulanmış ve her mesafe için 0,99'un üzerinde korelasyon elde edilmiştir.

ORCID ID: [1]0000-0001-9227-1526

1. INTRODUCTION

In the 21st century, in addition to the issues of environmental pollution and noise pollution where we live, "electromagnetic pollution" has been added [1-3]. In recent years, the rapid increase in the popularity of mobile phones has forced the planning and establishment of many new base transceiver stations each year. Although the public does not want it, the installation of base transceiver antennas on the roofs of houses, on the sides of buildings, and in the gardens of schools and hospitals causes discussions and complaints [4,5]. For instance, the study conducted in [4] investigates the exposure levels to electromagnetic radiation (EMR) from mobile phone base station tower settings in residential areas and provides recommendations for reducing the exposure levels. In another study [5], some research done by different institutions and organizations is reported and summarized. The authors stated that the motivation point of their study was public concern about base stations. Therefore, it is necessary to determine the strength of the electromagnetic field in the vicinity of a base station and to inform the public about the potential effects of electromagnetic fields and protection methods. In addition, the relevant authorities need to set up centers where complaints about the base station can be easily submitted and resolved [6, 7]. However, information technologies need electromagnetic waves to spread in space.

Electromagnetic radiation (EMR) is a form of energy that behaves like a wave as it travels through space. Sources of electromagnetic radiation can be divided into two types according to their ionizing properties. The first kind of radiation is called ionizing radiation, such as X-rays, T-rays, etc. This form of radiation converts atoms into charged ions. The other type is called non-ionizing radiation; when the radiated substance absorbs energy, its atoms do not change state [8, 9]. In this study, GSM900 communication systems, namely non-ionizing EMR, are investigated by the authors

Although the GSM900 communication system is older than Digital Cellular Systems 1800MHz (DCS1800) or third Generation (3G), it is still used in many countries effectively. Two frequency bands have been assigned to GSM 900 mobile systems, 890-915 MHz for the uplink (mobile to base station) and 935-960 MHz for the downlink (base station to mobile). The downlink of a given channel is 45 MHz higher than the uplink due to its duplex operation [10]. The number of base stations has increased in parallel to the development of communication technology, and it has become a threat to human health. There are numerous studies which are mentioned the hazardous effects of electromagnetic pollution [11-13].

Krause and colleagues researched the effect of electromagnetic pollution on human memory capacity. In their study, a 217 Hz modulated, 576 microseconds pulsed, and 902 MHz signal were used, and a small performance increase was observed in the memory works. Under the influence of EMF during the resting state, the electroencephalogram (EEG) has not shown any changes. However, as memory operations are carried out, a significant change is observed in brain responses [8].

The effect of GSM 900, DCS 1800, and UMTS, which use RF signals, on the ability to comprehend is investigated, and this study is conducted in the TNO physics and electronics laboratory in the Netherlands. Subjects were divided into two groups, and they were kept under an electromagnetic field (EMF) for a certain period, then specific tests and questionnaires were applied. As a result of these tests, the reaction rate of interaction was observed for the GSM 900, the memory, and when doing more than one job for interaction effects, it was observed for the GSM 1800, and disturbing effects were found for the UMTS in most of the subjects [15].

Chia and colleagues' epidemic study, 808 Singaporean people, who use cell phones, compared with a group of people who do not use cell phones. At the end of the research, it is concluded that the occurrence of headaches in mobile phone users is more often than in the control group. As a second result of the study, it is reported that the occurrence of headaches in mobile phone users who use the hands-free feature decreased by 20% [16].

One of the other study areas is related with the blood-brain barrier (BBB) and RF field. BBB is the name of the membrane that creates a barrier between brain tissues and blood circulation. The main task of BBB is to block the viruses from accessing the central nervous system and brain. Changes in the permeability or leakage of the BBB may cause diseases. In most of the studies about BBB, it is indicated that there is no relationship between RF fields and BBB [17, 18]. However, there can be found many studies in the literature that shows RF fields affect BBB proteins [19, 20].

As can be seen from the literature summary above, there is a very serious relationship between electromagnetic fields and the human body. There are numerous studies in the literature to investigate this relationship. In most of these studies, electromagnetic fields have been accepted as harmful. In other studies, it has been reported that electromagnetic fields can only be harmful in the long term. However, the result that emerged in almost all of these studies is that the intensity of the electromagnetic field and the distance exposed are very important. In this context, it is very important to determine the electromagnetic field intensity in a distance-dependent manner.

In this study, the power density of 120 base stations has been measured at 20, 40, and 60 meters distances from base stations at the frequency of 900 MHz. Even though, limit values are determined by international organizations such as IEEE, ICNIPR, and the FCC, the information technology institute published a report to customize the installation of base stations. Even if this report was created based on the ICNIRP values, a maximum of 10V / m has been determined as a limit value for each base station [21, 22]

While the measurements were being made, 120 different base stations were measured from 20-40-60 meters away at 120 different locations. However, when the measurements were made, it was noticed that some people's living spaces were at intermediate distances, such as 25 or 35 meters. For this reason, in this study randomly determined intermediate distances (25, 30, 35, 45, 50, and 55 meters) have been calculated by using Lagrange interpolation.

As is known, base stations are established to expand the coverage area and meet the needs of the growing number of users. Antennas are placed on poles, towers, rooftops, and existing structures where there are no structures high enough to interrupt or prevent their broadcast. It is expected that each tower that is established in urban areas to cover an area of at least 20-30 kilometres [23, 24]. [25] contains information about the base stations that will broadcast on the carrier frequency of around 2GHz. Accordingly, micro and macro base station antenna heights are 10m and 25 m, respectively. Each channel of base stations can have 40–50 watts of output power and 20 dB of antenna gain to provide this coverage. At base stations, output power rises with the number of telephone conversations. The electric field is maximum at 30-250 m distances. Although the effects of the electromagnetic field are reduced depending on distance, no one can commit that the long-term effects of long-distance base stations are not as important as those of close-distance base stations. Since, there is no scientific evidence about the long-term effects of base stations at different distances. The strength of base stations is so important in each distance [26].

120 base stations are investigated in this study. All measurements have been carried out for three different distances from base stations. Since it is practically impossible to present all measurement results in this paper, some of the measurements are shown in Table 1. Base stations are numbered from 1 to 120, and the power density of each base station is measured at 20, 40, and 60 meters distances. All measurements are carried out with a directional antenna. A frequency-locked spectrum analyzer was used. The brand of the device is Spectran HF6080. All details about the device used during this study can be accessed from [27].

Table 1. Power Density of Some Measurements (μW/m^2).

Base Station Number	**Distance from Base Stations (meter)**		
	20m	**40m**	**60m**
1	15.46 μW/m^2	7.11	0.95
2	0.15 μW/m^2	0.02	0.05
3	191.31 μW/m^2	157.73	179.32
4	827.75 μW/m^2	306.52	557.82
5	24.97 μW/m^2	31.24	113.24
6	111.39 μW/m^2	200.23	32.05
7	16.13 μW/m^2	18.62	21.85
8	256.21 μW/m^2	150.33	122.89
9	22.13 μW/m^2	58.20	27.27
10	39.72 μW/m^2	40.59	18.11

1.1. Lagrange Interpolation

Interpolation is one of the easiest approaches to solving problems where an approximating function is required and an unknown original function agrees perfectly with the interpolation function at the given measurement points [28]. Practical applications of interpolation consist of two phases. In the first phase, values are determined from a function or from measurements done for a finite set of independent variables. In the second step, some intermediate arguments are determined by using the values of the function or measurements [29]

Interpolation is a process of estimating an intermediate value of a (dependent) parameter that is a function of a second (independent, $f(x_i)$) parameter when values of the dependent parameter correspond to several distinct values of the independent parameter [30]. The most commonly used interpolation methods are Lagrange interpolation (that is not mandatory the difference between values are equal), and Newton Interpolation (that is mandatory the difference between values is equal) methods. Lagrange interpolation which utilizes points obtained from n+1; is based on obtaining the *n*-th order of the polynomial equation. *n*-th polynomial equation which is related to each defined as the following equations. In this study, y_i points show the distance from base stations and x_i points show the electromagnetic power density at points. In equation 1, general form of the 2nd degree Lagrange interpolation equation is presented.

$$f(x) = y = b_1(x-x_2)(x-x_3) + b_2(x-x_1)(x-x_3) + b_3(x-x_1)(x-x_2) \tag{1}$$

If the 2nd degree Lagrange interpolation equation given in equation 1 is arranged separately for the points x_1, x_2 and x_3, the equations 2, 3 and 4 are obtained.

$$f(x_1) = y_1 = b_1(x_1-x_2)(x_1-x_3) + b_2(x_1-x_1)(x_1-x_3) + b_3(x_1-x_1)(x-x_2) \tag{2}$$

$$f(x_2) = y_2 = b_1(x_2-x_2)(x_2-x_3) + b_2(x_2-x_1)(x_2-x_3) + b_3(x_2-x_1)(x_2-x_2) \tag{3}$$

$$f(x_3) = y_3 = b_1(x_3 - x_2)(x_3 - x_3) + b_2(x_3 - x_1)(x_3 - x_3) + b_3(x_3 - x_1)(x_3 - x_2) \tag{4}$$

The coefficients, b_1, b_2 and b_3 can be found by utilizing $f(x_1)$, $f(x_2)$ and $f(x_3)$ which are in equations 2, 3 and 4, respectively. The coefficients obtained accordingly are presented below.

$$b_1 = \frac{y_1}{(x_1 - x_2)(x_1 - x_3)} \tag{5}$$

$$b_2 = \frac{y_2}{(x_2 - x_1)(x_2 - x_3)} \tag{6}$$

$$b_3 = \frac{y_3}{(x_3 - x_2)(x_3 - x_1)} \tag{7}$$

If the calculated b_1, b_2 and b_3 values are replaced in equation 1, the 2nd degree Lagrange interpolation polynomial is obtained as follows.

$$f(x) = \frac{(x - x_2)(x - x_3)}{(x_1 - x_2)(x_1 - x_3)} y_1 + \frac{(x - x_1)(x - x_3)}{(x_2 - x_1)(x_2 - x_3)} y_2 + \frac{(x - x_1)(x - x_2)}{(x_3 - x_1)(x_3 - x_2)} y_3 \tag{8}$$

In equation 8, the actual measured values of 20, 40 and 60 are used, respectively, instead of the points x_1, x_2 and x_3. Afterwards, the electromagnetic power density value of the relevant base station is written Instead of y_1, y_2 and y_3. Thus, the electromagnetic power density value for the distance to be determined is found. However, the compatibility between the interpolation value found as a result of the calculations and the actual measured value should be analyzed. Otherwise, it cannot be understood how reliable the interpolation result is. For this reason, error analysis was carried out to determine the error in the relevant distance.

1.2. Error Analysis

The interpolation models developed in this study were assessed according to three different statistical criteria. These are statistical parameters such as Root Mean Squared Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percent Error (MAPE). The Root Mean Square Error (RMSE) is used to calculate the error rate between the measured values and the model predictions, and as the RMSE value approaches zero, it means that the predictive ability of the model is increasing. The RMSE is calculated as follows [31, 32].

$$RMSE = \sqrt{\left(\sum_{i=1}^{n} \frac{(f(x) - f(x)_{approximation})^2}{(n)} \right)} \tag{9}$$

Here, f(x) and f(x) represent measurement values and interpolation estimates, respectively. n represents the number of measurements.

To determine the absolute error between measurements and interpolation estimates, the Mean Absolute Error (MAE) is used. As the MAE value approaches zero, the predictive ability of the model increases. MAE can be calculated using the following equation [33].

$$MAE = \frac{1}{n} \sum_{i=1}^{n} f(x)_{approximation} - f(x) \tag{10}$$

Another method used to determine the estimation success of the interpolation approach is the mean absolute percent error (MAPE), which is another expression of the mean absolute error (MAE). MAPE is measure of accuracy in a fitted time series value in statistic. MAPE is found by the following equation.

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{f(x)_{approximation} - f(x)}{f(x)} \tag{11}$$

Table 2 was created by using the error functions expressed in Equation 9-10-11. The fact that the MAE, MAPE and RMSE values are quite small indicates that the interpolation method can be used to determine the electromagnetic power density.

Although Table 2 is clear enough, author would like to present the correlation between measured values and Lagrange interpolation values on Figure 1. It can easily be noticed that, Lagrange values are in very good

Table 2. Lagrange Interpolation Success.

Distance From Base Stations	MAE	MAPE	RMSE
25 m	3.664	0.084	0.658
30 m	3.215	0.087	0.577
35 m	2.694	0.101	0.484
45 m	2.538	0.117	0.456
50 m	2.106	0.077	0.378
55m.	2.885	0.088	0.518

agreement with actual values.

In Figure 1, measured power densities from different distances and interpolation results can be seen at the same time. Figure 1-a shows measurement results from a distance of 25 meters as well as interpolation results from distances of 20, 40, and 60 meters. It can be observed in Figures 1-b, 1-c, 1-d, 1-e, and 1-f that measurement results which are carried out at 30, 35, 45, 50, and 55 meters, show a great agreement with the interpolation results. To express the relationship between measurement results and interpolation estimates, a correlation coefficient is used. For each distance, over 99 percent success is shown.

Lagrange interpolation is a powerful technique that is commonly used in various fields of engineering and science. In the context of electromagnetic field estimation, it is a successful method for determining the electromagnetic power density. Accurately estimating this parameter is crucial for ensuring the safety of individuals working in environments with high levels of electromagnetic radiation. However, estimating the electromagnetic power density can be a challenging task, especially in complex environments. From this point of view, the high accuracy results obtained in Figure 1 make this study more valuable.

Another advantage of using Lagrange interpolation for electromagnetic power density determination is its ability to handle non-uniformly spaced data points, which can be seen in Figure 1. As can be seen in Figure 1, estimates have been made for many different distances. These estimates can also be evaluated individually. In this case, successful results are also observed in the case of a non-uniform distribution. This is important because in real-world applications, the data points may not be uniformly distributed, and other interpolation methods may not be suitable, just like in this study.

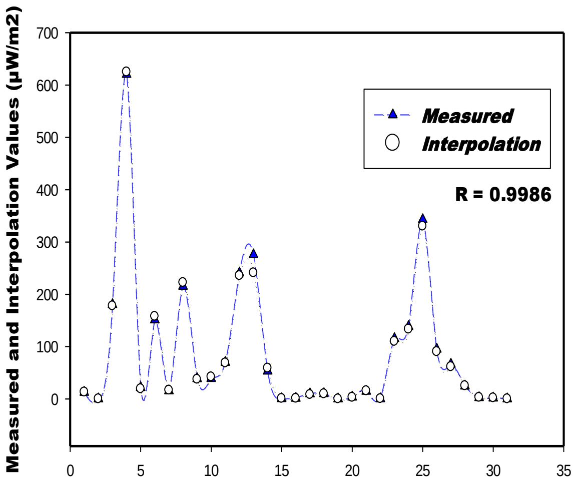
2. RESULT AND DISCUSSION

In this study, electromagnetic power density is determined by Lagrange interpolation technique. In literature, different types of interpolation are used to determine the power density [34-36] Since the measurement of power is usually done at discrete points in space. To obtain a continuous estimate of the power density at any point in the space, interpolation is necessary and useful. Also, interpolation is a mathematical technique that estimates the value of a function between two known values. In the context of electromagnetic field measurements, interpolation can be used to estimate the power density at a location between two measurement points, which has been tried for different locations before [36].

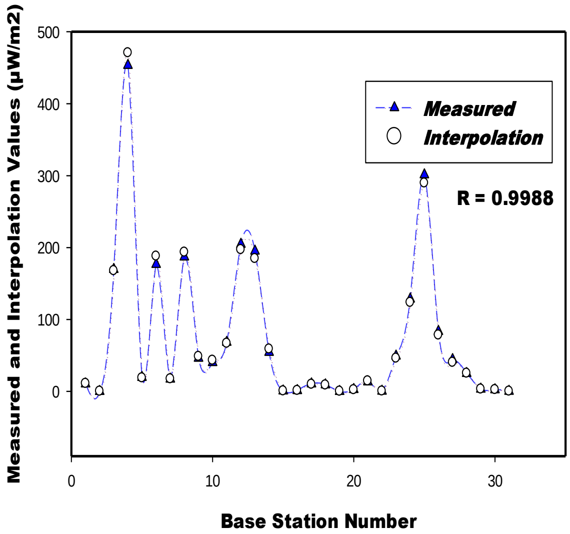
One of the main advantages of interpolation is its simplicity and ease of use. It is a straightforward technique that requires minimal computational resources, making it an attractive option for quick estimations in simpler environments. Additionally, interpolation can be used to estimate the power density at any point within a given range, regardless of whether or not data points are uniformly spaced. However, interpolation has some limitations that must be considered when comparing it with other methods. First, it assumes that the electromagnetic field varies smoothly between the known data points, which may not be the case in complex environments. In such cases, the accuracy of the interpolation may be reduced, leading to potential errors in the estimated power density. Additionally, interpolation may not be able to account for the effect of different materials or objects in the environment, which can have a significant impact on the electromagnetic field and the power density.

In contrast, other methods for estimating electromagnetic power density, such as numerical methods (e.g., FDTD, FEM) and analytical methods (e.g., MoM, UTD), can handle complex geometries and materials and are generally more accurate than interpolation. However, these methods can be computationally expensive and may require specialized expertise and software. Measurement-based methods, which involve measuring the electric and magnetic fields at various points in space and then using these measurements to estimate the power density, are also highly accurate but require specialized equipment and may not be practical in all situations. These methods are also very time-consuming and therefore generally difficult to implement in practice.

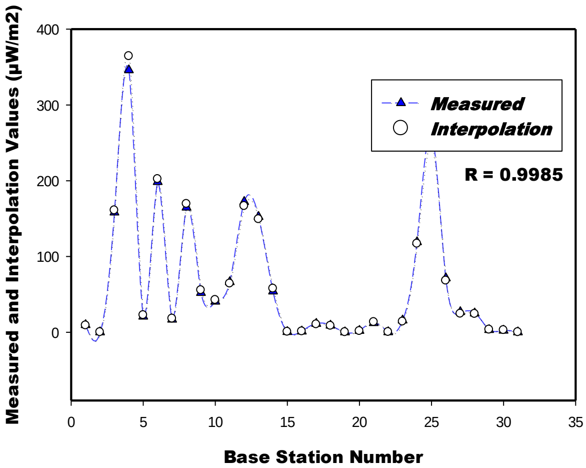
Electromagnetic power density is a key parameter for assessing potential health risks associated with exposure to electromagnetic fields [37]. It is important to have accurate estimates of power density in the areas where people live, work, and play to evaluate compliance with safety standards and to inform the public about the potential risks associated with electromagnetic fields. In this respect, this study has produced very useful results. As mentioned above, estimating the electromagnetic power density is an important aspect of understanding the potential health effects of electromagnetic radiation. For this purpose, there are several methods for estimating the electromagnetic power density, including measuring the surface power density of radio frequency or



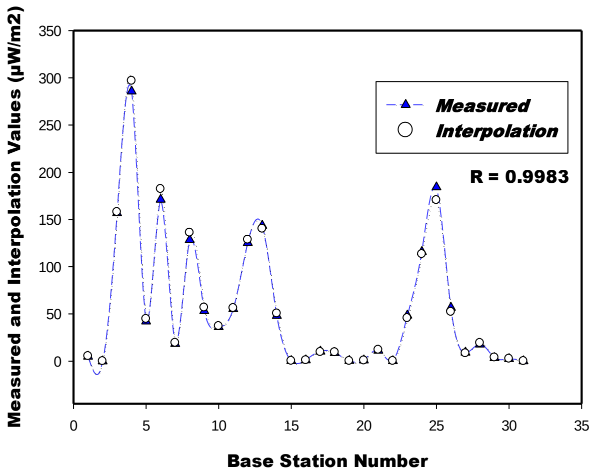
a) For 25m distance



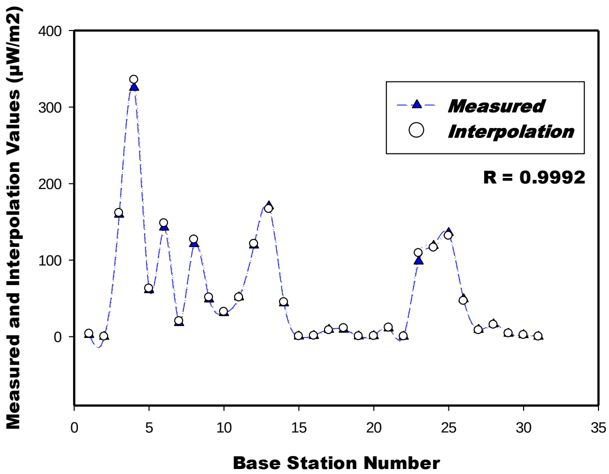
b) For 30m distance



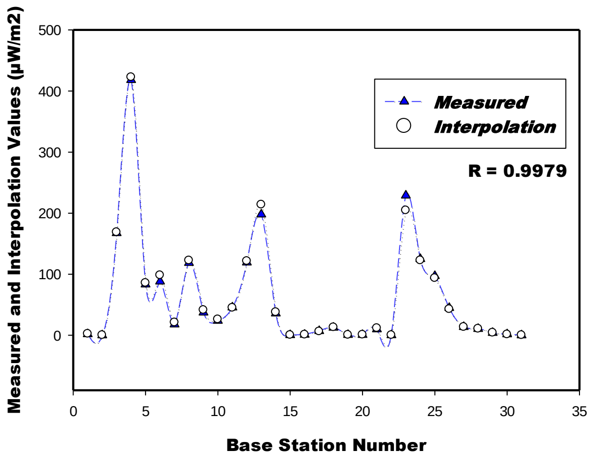
c) For 35m distance



d) For 45m distance



e) For 50m distance



f) For 55m distance

Figure 1. Correlation between measured values and Lagrange interpolation prediction.

microwave fields, using theoretical models of the mass-spring-damper system, calculating the electromagnetic energy density and flux, and predicting foul-weather electromagnetic interference from power lines [38,39]. In addition, the Lagrange interpolation method has been applied to estimate the strength of electromagnetic radiation for random intermediate distances. The results showed that the method achieved a correlation of above 0.99 for each distance. From this point of view, it can be said that these kinds of methods are important for determining the possible medical effects of electromagnetic radiation on human health, especially in crowded cities where the number of base stations is increasing in parallel to the use of mobile communication systems and population growth. Lastly, it should be noted that base station establishment depends on many parameters. Therefore, important optimization processes are performed for the establishment of the base stations. Many parameters are considered, including the terrain of the area to be installed, the crowdedness, and the number of moving people [40]. Interpolation techniques can also be used to estimate power density in such places. This is particularly important in situations where measurements are sparse or unevenly distributed. This study, which was carried out for this purpose, contributed to the literature in this sense.

3. CONCLUSION

Within the scope of this study, electromagnetic field intensity measurements were made at 120 different base stations at different distances. However, measuring every base station from every distance is not suitable for working practice. The fact that the studies carried out for this purpose were completed over a very long time has been the main motivation for this study. To overcome the difficulties experienced, a method should be determined to estimate the electromagnetic power density on a mathematical basis. So, the power density (µW/m2) of 120 base stations was measured at 20, 40, and 60-meter distances from base stations, respectively. The intermediate distances (25m., 30 m, 35 m, 45 m, 50 m, and 55 m) were measured for randomly selected 35 different base stations, and the correlation between Lagrange interpolation results and measured values are investigated for 25 m, 30 m, 35 m, 45 m, 50 m, and 55m. Above 0.99 correlation values and very small errors (MAE, MAPE, and RMSE) have been achieved for each distance. For the first time in literature, an interpolation approach has been successfully applied to determine the power density at different distances. Based on the observations in the present study, the Lagrange interpolation method can be applied to any other province for different distances from the base stations.

Statement of Conflict of Interest:

Author has declared no conflict of interest.

Author's Contributions:

All processes were carried out by the Author.

REFERENCES

[1] N. Leitgeb, J. Schröttner, M. Böhm and W. "Does, Electromagnetic pollution cause illness?", Medizinische Wochenschrift, vol. 155, no. 9-10, pp. 237-241, 2005.

[2] A. Balmori "Electromagnetic pollution from phone masts. Effects on wildlife", Pathophysiology, vol. 16, no. 2–3, pp. 191–199, 2009.

[3] O. Uygunol, S.S. Durduran "Gsm Baz İstasyonlarında Elektromanyetik Kirlilik Haritalarının Coğrafi Bilgi Sistemi (Cbs) Yardımıyla Oluşturulması; Konya Örneği", Tmmob Harita ve Kadastro Mühendisleri Odası 12. Türkiye Harita Bilimsel ve Teknik Kurultayı, Ankara, 2009.

[4] S. A. Meo, M. Almahmoud, Q. Alsultan, N. Alotaibi, I. Alnajashi, W. M. Hajjar "Mobile phone base station tower settings adjacent to school buildings: impact on students' cognitive health", American journal of men's health, vol. 13, no. 1, pp. 1-6, 2019.

[5] J. Nadimikeri, M. P. Kumar, G. Sreenivasulu, T. L. Prasad, B. Lakshmanna, K. Nagalaksmi, M. Madakka "Mobile phone and base stations Radiation and its effects on Human health and environment: A Review", Sustainable Technology and Entrepreneurship, vol. 2, no. 2, 2022.

[6] E. van Rongen, E.W. Roubos, L.M. Aernsbergen, G. Brussaard, J. Havenaar, F.B. Koops and A.P.M. Zwamborn "Mobile Phones and Children: Is Precaution Warranted", Bioelectromagnetics, vol. 25, no. 142-144, 2004.

[7] O. Uygunol and S.S. Durduran "Elektromanyetik Kirlilik Haritalarının Coğrafi Bilgi Sistemi (Cbs) Yardımıyla Oluşturulması", TMMOB Harita ve Kadastro Mühendisleri Odası Ankara Şubesi I. CBS Günleri Sempozyumu 19–21 Kasım 2008, Ankara.

[8] B.S. Levy, D.H. Wegman, S.L. Baron, and R.K. Sokas "Occupational And Environmental Health: Recognizing And Preventing Disease And Injury", Williams and Wilkins, Lippincott, USA, 2006.

[9] Ş.S Şeker and O. Çerezci "Çevremizdeki Radyasyon ve Korunma Yöntemleri", Boğaziçi Üniversitesi Yayınları, vol. 607, 1997.

[10] G. Gu and G. Peng "The survey of GSM wireless communication system," 2010 International Conference on Computer and Information Application, Tianjin, China, pp. 121-124, 2010

[11] N.J Cherry "Evidence that electromagnetic fields from high voltage powerlines and in buildings, are hazardous to human health, especially to young children", Lincoln University. Human Sciences Department, 2001.

[12] J. Czyz, K. Guan, Q. Zeng, T. Nikolova, A. Meister, F. Schönborn and A.M. Wobus "High Frequency Electromagnetic Fields (GSM Signals) Affect Gene Expression Levels in Tumor Suppressor p53 - Deficient Embryonic Stem Cells", Bioelectromagnetics, vol. 25, no. 4, pp. 296-307, 2004.

[13] A. McKinlay "A European Research Initiative Dosimetry", Radiotelephones and Human Health, vol. 72/3-4, pp. 313-320, 1997.

[14] C.M. Krause, l. Sillanmaki, M. Koivisto, and A. Haggqvist "Effects of Electromagnetic Field Emitted by Cellular Phones on the EEG During a Memory Task", Neuroreport, vol. 11 , no. 4, pp. 761-764, 2000.

[15] TNO Report "Effects of Global Communication System Radio-Frequency Fields on Well Being and Cognitive Functions of Human Subjects with and without Subjective Complaints", TNO Physics and Electronics Laboratory, FEL-03-C148, 2003.

[16] S.E. Chia, H.P. Chia, and J.S. Tan "Prevalence of Headache among Handheld Cellular Telephones Users in Singapore: A community Study", Environmental Health Perspectives, vol. 24, pp. 1059-1062, 2003.

[17] G. Tsurita, H. Nagawa, S. Ueno, S. Watanabe, and M. Taki "Biological and Morphological Effects on the Brain After Exposure of Rats to a 1439 MHz TDMA Field", Bioelectromagnetics, vol. 21, pp. 364-371, 2000.

[18] J.W. Finnie, P.C. Blumbergs, J. Manavis and T.D. Utteridge "Effect of Global System for Mobile Communication (GSM)-like Radiofrequency Fields on Vascular Permeability in Mouse Brain", Pathology, vol. 33, no. 3, pp. 338-340, 2001.

[19] L.G. Salford, A.E. Brun, J.L. Eberhardth, L. Malmgren, and B.R.R. Persson "Nerve Cell Damage in Mammalian Brain After Exposure to Microwave Exposure to Microwaves from GSM mobile Phones", Environmental Health Perspective, vol. 111, pp. 881-883, 2003.

[20] A. Schirmacher, S. Winters, S. Fischer, and J. Goeke "Electromagnetic Fields (1,8 GHz) Increase the Permeability to Sucrose of the Blood-Brain Barrier in Vitro", Bioelectromagnetics, vol. 21, pp. 338-345, 2000.

[21] ICNIRP, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Phys, vol. 74, pp. 494-522, 1998.

[22] IEEE Standart for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz "Questions and Answers about Biological Effects and Potential Hazards of Radiofrequency Electromagnetic Fields", Federal Communications Commission Office of Engineering and Technology, OET Bulletin 56, Fourth Edition, August 1999.

[23] MOA. "Base Stations and Masts. Mobile Operators Association",

[24] Mobilemastinfo,URL:http://www.mobilemastinfo.com/base-stations-and-masts/ Son Erişim Tarihi: 29.05.2017

[25] A. Bibi "Baz Istasyonu Ölçümlerinin Gerçek Zamanli Ve Konum Tabanli Olarakkaydedilmesine Yönelik Bir Arayüz Geliştirilmesi" Gazi Üniversitesi Bilişim Enstitüsü, Yüksek Lisans Tezi, 72s, Ankara, 2018,

[26] F. Richter, G. Fettweis "Cellular Mobile Network Densification Utilizing Micro Base Stations," 2010 IEEE International Conference on Communications, Cape Town, South Africa, 2010, pp. 1-6.

[27] M.A. Baldauf, S. Kn¨orzer, J.A. Pontes, and W. Wiesbeck "Safety Distances Underneath Vertically Polarized Base Station Antennas", Proceedings, 18th Int. Zurich Symposium on EMC, Munich 2007.

[28] Spectran HF6080 User Manual, www.aaronia.com, Erişim Tarihi 13/04/2023.

[29] E. Waring "Problems Concerning Interpolation", Philos. Trans. R. Soc. London, vol. 69, pp. 59–67, 1779.

[30] L.M. Milne-Thomson "The Calculus of Finite Differences", Macmillan and Co., London, 1951.

[31] A.Kovacs and L. I. Kovacs "The Lagrange Interpolation Formula in Determining the Fluid's Velocity Potential through Profile Grids, Research Institute for Symboloic Computation", Bulletins for Applied Mathematics, pp. 26-29 2005.

[32] K.P. Singh, A. Basant, A. Malik, and G. Jain "Artificial neural network modeling of the river water quality-A case study", Ecological Modelling, vol. 220, no. 6, pp. 888-895, 2009.

[33] B. Eren, and V. Eyüpoğlu "Yapar Sinir Ağları ile Ni(II) İyonu Geri Kazanım Veriminin Modellenmesi", 6. International Advanced Technologies Symposium, pp. 186-190, 2011.

[34] N.S. Kaveh,, S.N. Ashrafizadeh, and F. Mohammadi "Development of an artificial neural network model for prediction of cell voltage and current efficiency in a chlor-alkali membrane cell", Chemical Engineering Research and Design, vol. 86, no. 5, pp. 461-472, 2008.

[35] L. Horowitz "The effects of spline interpolation on power spectral density", IEEE Transactions on Acoustics, Speech, and Signal Processing, vol, 22, no. 1, pp. 22-27. 1974.

[36] S. Moreau, G. Plantier, J. Valière, H. Bailliet, L Simon "Estimation of power spectral density from laser Doppler data via linear interpolation and deconvolution". Experiments in Fluids, vol. 50, pp. 179-188, 2011.

[37] U. Sorgucu, I. Develi, S.S. Durduran "The Use Of Different Interpolation Methods In Estimating Electromagnetic Power Density", Sigma, vol. 29, pp. 148-155, 2011.

[38] A. Peyman, M. Khalid, C. Calderon, D. Addison, T. Mee, M. Maslanyj, S. Mann "Assessment of exposure to electromagnetic fields from wireless computer networks (wi-fi) in schools; results of laboratory measurements". Health physics, vol. 100, no. 6, pp. 594-612, 2011.

[39] H. Shirai, R. Sato, K. Otoi "Electromagnetic wave propagation estimation by 3-D SBR method". International Conference on Electromagnetics in Advanced Applications, pp. 129–132, 2007.

[40] Y.A. Dama, S. Abd-Alhameed, R.A. Salazar-Quinonez, F. "MIMO indoor propagation prediction using 3D shoot-and-bounce ray (SBR) tracing technique for 2.4 GHz and 5 GHz", Fifth European Conference on Antennas and Propagation (EUCAP), pp. 1655–1658, 2017.

[41] I.H. Cavdar, O. Akcay "The optimization of cell sizes and base stations power level in cell planning", IEEE VTS 53rd Vehicular Technology Conference, Spring 2001. Proceedings vol. 4, pp. 2344-2348i 2001.