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Design and miniaturization of a microsystem to power biomedical implants using grey wolf optimizer-based cuckoo search algorithm

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ABSTRACT

One of the greatest techniques, inductive coupling is frequently utilized in the biomedical sector for wireless energy transfer to implants. The aim of this article is to develop and analyze the effect of inductor geometrical characteristics, distance between transmitter (TX) and receiver (RX) and also the operating frequency on the wireless power transfer system, using grey wolf optimizer-based cuckoo search (GWO-CS) algorithm. Power transfer efficiency (PTE), power provided to load, and other critical components must all be improved or maximized and miniaturaze the microsystem proposed. The invention, design, and optimization of coils square spirals in a wireless energy transfer system using a resonant inductive link are the emphasis of this paper. The GWO-CS approach is evaluated to existing methods, demonstrated by simulations and to demonstrate the effectiveness of the suggested strategy.

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1. INTRODUCTION

Wireless technology enables consumers to traverse long distances without difficulty. The world is becoming increasingly automated [1], wireless power transfer will play an essential role in automating today's electrical and electronic devices. In a variety of situations, an implanted electronic device cannot use batteries as its primary source of power [2]–[5]. Instead, electricity must be given through an inductive link generated by mutually linked coils, which must be transferred wirelessly over the skin.

When designing a wireless energy transfer system through inductive link to transfer energy to implantable biomedical devices, the distance between the two part of the system and the coil size are the most significant features to consider [6], [7]. There are various reasons that limit the implanted coil such as: their weight, shape, size and feasibility of use [8]. As a result, the internal (implanted) coil should be as tiny as feasible, with the fewest number of rounds and minimal energy loss to avoid heating biological tissues [9]. Power transfer efficiency (PTE) and power delivered to the load (PDL), were the cornerstones of previous wireless power transfer (WPT) systems. To achieve optimal power transfer efficiency, it's critical to fine-tune the parameters that are dependent on these components. Many studies have been carried out in order to help progress these crucial keys. RamRakhyani *et al.* [10] offered a WPT based on the type of resonance, use four coils rather than just two inductive links for example. At a d=20 mm, the PTE reached 82%, while at a d=32 mm, it was 72%. On the other hand, the inclusion of many coils expanded the surface area of the biomedical implant, albeit the spacing distance remained small. A system with many coils was shown and contrasted with ones with two, three, and four coils by Kiani and Ghovanloo in [11]. He claims that the four-coil approach yields superior PTE outcomes, such as 66.7% for a 200 mm distance. On the other hand, The use of many coils makes issues like parasites and implant size distribution worse. However, as seen in [12], where the authors were able to increase PTE and PDL to 76% and 115 mW, respectively, employing a multicoil inductively coupled array can assist achieve improved PTE and PDL.

As a result, a variety of solutions to this problem have been proposed. Between those solutions, metaheuristic algorithms are discovered. As in [13], the two transceiver coils, had their geometric properties improved using a genetic technique (GA). The authors use a GA technique to undertake their theoretical investigation. At d=120 mm, the energy transfer efficiency and output power have improved to 84.18% and 109 mW, respectively, despite the fact that the implanted coil size remains fairly big. As a result, a larger surface area is needed. However, the transmission distance is relatively close.

The remainder of the work is organized as: The WPT and the inductive coupling transfer technique are introduced in section 1. also analogous works that served as inspiration for the creation of the suggested approach, and the modelization and theoretical background for inductive coupling are offered in section 2. The suggested grey wolf optimizer-cuckoo search (GWO-CS) approach is described in section 3 section 4 compares the results to those of various other methods and section 5 wraps up the study.

2. WPT CIRCUIT DESIGN AND MATHEMATICAL MODEL DERIVATION

2.1. Inductive link modeling

Wireless power transmission techniques are divided into two categories: near field and far field. One of the most effective strategies in the biomedical field is inductive magnetic coupling. It operates at really short distances (in the near field), often a few centimeters, but has excellent performances. Our proposed system consists mainly of two coils L1 outside and L2 implanted in the patient's body, with their parasitic resistances respectively R1 and R2. Also the resonance frequencies of the two system components must be synchronized [14], [15]. To make primary and secondary resonant circuits, two capacitors C1 and C2 are used in the primary and secondary circuits respectively [13], [16]. Figure 1 depicts a two-coil inductive link in simplified form.

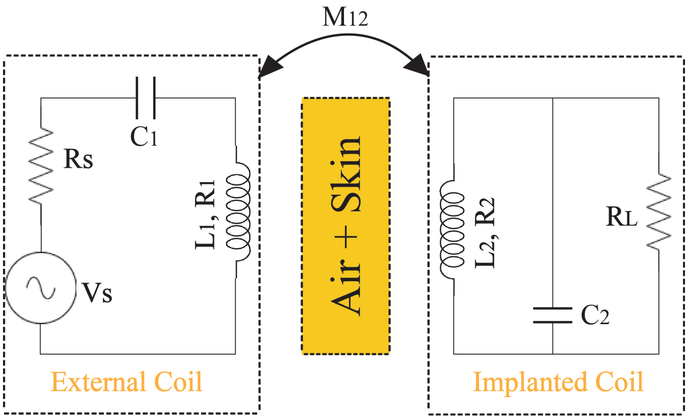

Figure 1. A diagram of inductive coupling's equivalents

2.2. Mutual and personal inductances

A type of electromagnetic induction is self-inductance. The following are the definitions of self inductance (auto-inductance) L and mutual inductance M:

$$L = \frac{1.27.\mu_0.n^2.d_{avg}}{2}.[l(\frac{2.07}{\phi}) + 0.18\phi + 0.13\phi^2] \quad (1)$$

$$M_{12} = k_{12}\sqrt{L_1 L_2} \quad (2)$$

such as;

$$\phi = \frac{(d_{out} - d_{in})}{(d_{out} + d_{in})}; d_{avg} = \frac{(d_{out} + d_{in})}{2}$$

where n represent a number of turns,l is the length of conductor, d_{out} the outer diameter, d_{in} is the inner diameter, and ϕ is a form factor. The Figure 2 illustrates the quote of dimensions on a square coil.

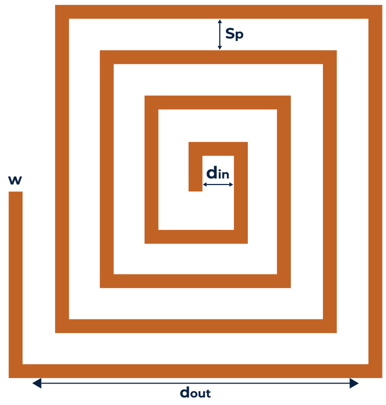

Figure 2. Dimensions of a coil with a square form

The following equations connect the geometric properties of the square coil (inner diameter, outer diameter, track spacing, track width, number of turns):

$$d_{out} = d_{in} + 2.n.w + 2.(n-1).S_p \quad (3)$$

and

$$l = 4.n.(d_{out} - (n-1).S_p - n.w) - S_p \quad (4)$$

2.3. Parasites's impact

The inductor quality factor has an impact on the link power efficiency [1]. The parasitic resistance and capacitance of the inductor are to blame. The following formula, which accounts for the skin effect, can be used to determine overall parasite resistance [17].

$$R_s = R_{dc}(\frac{t_c}{\delta(1 - \exp(\frac{-t_c}{\delta})}) \quad (5)$$

The skin metal depth is δ, and the resistance is R_{dc}, stated as:

$$R_{dc} = \rho_c \frac{l_c}{w.t_c} \quad (6)$$

where; $\delta = \sqrt{\frac{\rho_c}{\pi.\mu.f}}$ and $\mu = \mu_0.\mu_r$.
l_c: total length of conductor;
t_c: thickness of the conductor;
ρ_c: conductor resistivity;
δ: depth of skin;
μ: constant permeability;
μ_r: Relative penneability of the conductor.

As a result, if the parasitic capacitance of the circuit is neglected and the frequency is low [18], [19], the quality factor can be calculated by:

$$Q_i = \frac{wL_i}{R_i} \quad (7)$$

2.4. Power transfer efficiency and Power delivered to load

The real problem of many researchers is the improvement (increase, maximization) of the two important keys of wireless energy transfer systems (PTE and PDL). The simplified equations of these two factors are mentioned:

$$PTE = \frac{k_{12}^2 Q_1 Q_{2L}}{1 + k_{12}^2 Q_1 Q_{2L}} \frac{Q_{2L}}{Q_L} \tag{8}$$

such as:

$$Q_{2L} = \frac{Q_L Q_2}{Q_L + Q_2}, Q_L = \frac{R_L}{wL_2}; k_{12} = \frac{M_{12}}{\sqrt{L_1 L_2}}. \tag{9}$$

The PDL is a quantity related to the PTE as it shows on the following (10):

$$PDL = \frac{V_s^2}{R_s} PTE \tag{10}$$

where V_s is the source voltage, and R_s is the resistance to the source.

3. PROPOSED METHOD

As previously noted, metaheuristic algorithms can be used to optimize the PTE function of the scale model in order to present appropriate fits to the wireless power transmission transfer system. This research provides an adaptation of a new optimization method. based on the best geometric qualities of the WPT's essential element. The GWO-CS algorithm is described in depth in this section, and it is applied to our optimization problem [20], [21].

3.1. GWO-CS algorithm

In 2014, the grey wolf optimizer was revealed as a novel meta-heuristic method by Mirjalili *et al* [22]. Like many other algorithms (particle swarm optimization (PSO), GA,...) [23], is inspired by the natural hunting technique of grey wolves [24]. The behaviour of grey wolves and their hunting mechanism is represented in the GWO to solve optimization problems. [22, 25, 26], Grey wolve's established structure is divided into four main categories:

- Alpha wolves are the greatest answer because they lead the other wolves in chasing or surrounding the prey.
- The beta wolves are the second class, and they are the second best solution; they serve as an aid to the alphas.
- Delta wolves are also the third tier, and they offer the third best solutions.
- The fourth set of wolves is the omega wolves; during the pursuing (optimization) process, they reposition themselves and follow the alphas, betas, and delta's lead.

The omega wolves follow the alpha, beta, and delta wolves as they direct them to pursue, encircle, and then attack the prey. The mathematical model for this behavior is as [22]:

$$\vec{D} = \mid \vec{C} \cdot \vec{X}_p(t) - \vec{X}(t) \mid \tag{11}$$

$$\vec{X}(t+1) = \vec{X}_p(t+1) - \vec{A}\vec{D} \tag{12}$$

where t is the current iteration, $\vec{D}$ represents the distance vector, $\vec{A}$ and $vecC$ denote coefficient vectors, $\vec{X}_p$ indicates the prey location, and $\vec{X}$ means the grey wolf's position vector. The vectors $\vec{A}$ and $\vec{C}$ are calculated as:

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \tag{13}$$

$$\vec{C} = 2.\vec{r}_2 \tag{14}$$

where components of $\vec{a}$ are linearly decreased from 2 to 0 over the course of iterations and $\vec{r}_1$, $\vec{r}_2$ are random vectors in [0,1]. If $\mid \vec{A} \mid < 1$ is true, the wolves attack the prey, and if $\mid \vec{A} \mid > 1$ is true, the wolves avoid the prey, avoiding a local minimum. The wolves update their positions as the hunt progresses to get close to the prey that is considered the best solution; the positions of every group of wolves are adjusted as [26]:

$$\begin{cases} \vec{D}_\alpha = \mid \vec{C}_1 \cdot \vec{X}_\alpha(t) - \vec{X}(t) \mid \\ \vec{D}_\beta = \mid \vec{C}_2 \cdot \vec{X}_\beta(t) - \vec{X}(t) \mid \\ \vec{D}_\delta = \mid \vec{C}_3 \cdot \vec{X}_\delta(t) - \vec{X}(t) \mid \end{cases} \tag{15}$$

$$\begin{cases} \vec{X}_1(t) = \vec{X}_\alpha(t) - \vec{A}_1 \vec{D}_\alpha \\ \vec{X}_2(t) = \vec{X}_\beta(t) - \vec{A}_2 \vec{D}_\beta \\ \vec{X}_3(t) = \vec{X}_\delta(t) - \vec{A}_3 \vec{D}_\delta \end{cases} \tag{16}$$

$$\vec{X}\,(t) = \frac{\vec{X}_1\,(t) + \vec{X}_2\,(t) + \vec{X}_3\,(t)}{3} \tag{17}$$

where t indicates the current iteration, $\vec{X}\,(t)$ is the current location vector of the grey wolf , $\vec{C}_1$, $\vec{C}_2$, $\vec{C}_3$ and $\vec{A}_1$, $\vec{A}_2$, $\vec{A}_3$ are vectors generated at random. $\vec{X}_1\,(t)$, $\vec{X}_2\,(t)$, $\vec{X}_3\,(t)$ are vector locations, depending on whether the wolves exclusively follow alpha, beta, or delta. The pseudo code of GWO-CS methode is as [21]:

Algorithm 1 Cuckoo search based grey wolf optimizer

Begin
Set up the variables a, A, C and p_d
Compute the objective function for every wolf species
Choose the top, second, and third candidates for the search $\vec{X}_\alpha$, $\vec{X}_\beta$, $\vec{X}_\delta$
  While (k<max number of generations)
    For each wolf
      Update every wolf's location utilizing (16)
    EndFor
    Modify a, A and C
      Compute the fitness function for all wolves
      Update $\vec{X}_\alpha$, $\vec{X}_\beta$, $\vec{X}_\delta$
      For $\vec{X}_\alpha$, $\vec{X}_\beta$, $\vec{X}_\delta$
        Update the wolves position
        If random number$>p_d$
          shift the wolve's position at random
          calculating and modifying the fitness function
        EndIf
        k=k+1
      EndFor
  EndWhile
  return The ideal solution $\vec{X}_\alpha$
End

In our case, the PTE across two coupled coils should be maximized. Is the purpose or goal. To deliver the energy required to operate the implant. The different algorithmic parameters are shown in Table 1 together with the values that were taken into account.

Table 1. GWO-CS configuration parameters

Parameter	Value
Ceiling number of generations	1000
Dimension	12
Search agents	50
Probability of discovered eggs	1
Frequency samples N_ω	1000

4. SIMULATION RESULTS

The outcomes of our target function's proposed implementation utilizing the grey wolf optimizer-based cuckoo search algorithm are discussed in this section. Our hypothesis was tested using the MATLAB software. Similarly, we plot the optimal solution against the number of generations after selecting the algorithm's parameters to demonstrate how our approach converges to the greatest PTE value. Because the fitness function reaches the highest point 95.47% after only 20 iterations, the GWO-CS approach obviously converges to the optimal solution rapidly. This is depicted in Figure 3.

Figures 4(a) and 4(b) show how power transfer efficiency changes as a function of operating frequency and separation distance between the two WPT parts. In a comparison of our suggested approach to some other ways in the literature, the GWO-CS algorithm achieves the maximum PTE value of 95.47%, wfrequency of operation and distance while GA and the method proposed in [17], achieve 86% and 15%, respectively. In addition, there is a variance based on the distance between the transceiver coils. When compared to previous approaches, our technology consistently achieves a transmission distance of more than 14 cm. Figure 5 shows how the energy transfer distance affects the energy given to the load in quantity. The GWO-CS algorithm can transmit a substantial energy suplied to the implant compared to GA and KIANI.

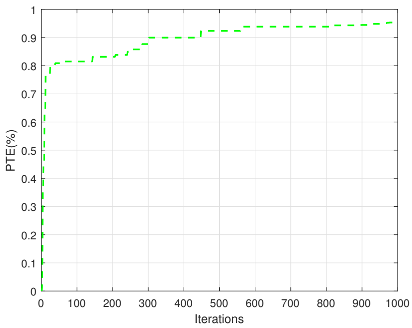

Figure 3. Power transfer effeciency versus number of iterations

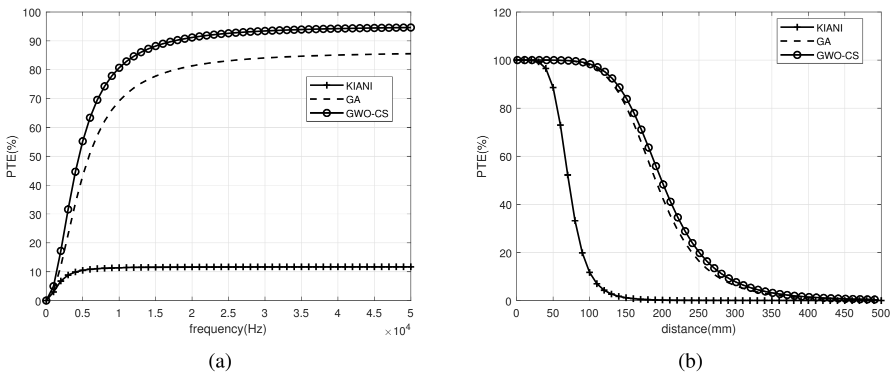

Figure 4. Objective function (PTE) versus influential parameters (a) frequency and (b) separation distance

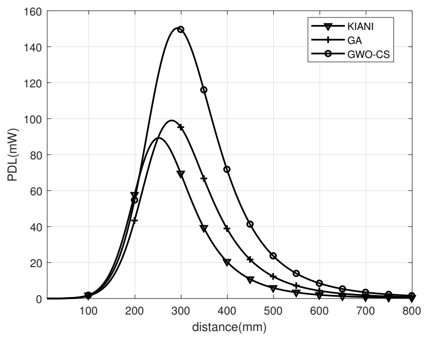

Figure 5. Power delivered to load versus separation distance

4.1. Results discussion

The Figure 4(a) illustrates the overall efficiency values for the optimized coils using cuckoo search based grey wolf optimizer, as well as KIANI and GA method efficiency results. With a frequency range of [0-18 MHz] simulated, these efficiency values are supplied as a function of frequency. In particular, GWO-CS can achieve 95.47% for 13.46 MHz. The same as always, our fundamental method is ranked highest, as in 95.47% at 14 cm. According to Figure 4(b). Additionally, it was demonstrated through simulation in Figure 5 that the cuckoo search-based grey wolf optimizer approach is capable of supplying a significant quantity of energy to the load at Vs=1V and a low source resistance (Rs). The other methods are less efficient than GA.

The GWO-CS algorithm outperformed the GA and KIANI methods in terms of power transfer efficiency and power delivered to load across large separation distances. At the level of the values of the optimal parameters, the following table compares the suggested methodology to other approaches in the literature. Table 2 shows that the ideal attributes found by our novel contribution are more reduced than those detected by existing approaches.

Table 2. Specifications results for all optimization approaches

Parameters	KIANI	GA	This work
Outer diameter of external coil (d_{out1})	36 mm	51.60 mm	53.06 mm
Outer diameter of internal coil (d_{out2})	10 mm	5.22 mm	5.20 mm
Line width of external coil (w_1)	1.15 mm	2 mm	1.9 mm
Line width of internal coil (w_2)	0.51 mm	0.05 mm	0.05 mm
Line spacing of external coil (S_{p1})	100 µm	0.6 mm	0.58 mm
Line spacing of internal coil (S_{p2})	100 µm	10.3 µm	0.026 mm
Number of turns in external coil (n_1)	10	9	10
Number of turns in internal coil (n_2)	1	2	2
Separation distance (d)	10 cm	13 cm	14 cm
Operating frequency (f_0)	13.56 MHz	13.56 MHz	13.46 MHz
Power delivered to load (PDL)	83 mW	110 mW	136 mW
Power transfer efficiency (PTE)	15%	90%	95.47%

5. CONCLUSION

We have proposed a new technique for designing and optimizing an efficient wireless power transfer system in this paper. This method belongs to the metaheuristic algorithms category. They're repetitive stochastic algorithms that work their way to a global optimum, or the target function's global extremum. In the futur work, machine learning will be used to achieve a high PTE and a big PDL value across a long transmission distance, resulting in a more downsized implant.

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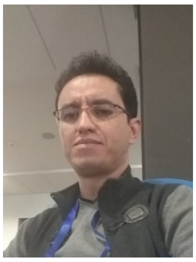

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