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Metaheuristic (Ant Colony Optimization) Algorithm-Based Optimization of an Equilateral Triangle Shaped Patch Antenna for Medical Purposes

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Abstract: This paper presents the design, simulation, optimization, fabrication and testing of an equilateral shaped antenna for medical applications, Ant colony optimization (ACO) Algorithm was chosen for antenna optimization. The antenna considered here was fed by a 1.59mm diameter coaxial cable, the location of feeding and the side length of star shaped antenna was varied by Ant colony optimization Algorithm (ACO). Finding a set of settings that would enhance the antenna's performance was the optimization's goal. We have made use of MATLAB software to implement ACO Algorithm. The Ansys HFSS software was used to design antenna. Ansys HFSS software allows MATLAB to be interfaced with it for optimization purpose. The parameters considered were return loss (reflection coefficient S_{11}) and the Voltage Standing Wave Ratio (VSWR). The ACO yielded a design with return loss (S_{11}) of -25.55 and VSWR of 1.11 at 2.48 GHz. The entire antenna dimensions were approximately (5cm x 5cm). The substrate used was FR4 (flame retardant) epoxy. The fabricated antenna was tested in Anechoic chamber using network analyzer. There was strong good agreement between the measurements from the antenna's fabrication and simulation, for the operational frequency of 2.48 GHz and desirable performance in return loss, and VSWR (Voltage Standing Wave Ratio) parameters. the fabricated antenna along with Arduino uno microcontroller was used to transmit and receive physiological information like temperature and heart rate for a health care application

***Keywords:** VSWR, Return loss, Ant colony optimization (ACO) Algorithm, High frequency structure simulator (HFSS), Advanced design system (ADS), Matrix laboratory (MATLAB)*

1. Introduction

The healthcare industry is a thriving area for technological innovation. Critical human bodily functions which previously required hospital check-ups can now be done by the lay person using an affordable electronic device. For example, until a few years ago a person travelled to the hospital to obtain vital readings like O2 level, pulse, sugar and mineral levels, etc with the outset of pulse sensors, temperature sensors, etc. people can now monitor these readings in real-time using a device of their own [1]. A Wireless device may wirelessly collect and transmit such personal data. For transmission antenna is the major component of wireless device which has to be designed efficiently. This paper considers equilateral triangle shaped antenna which operates at 2. 48GHz.To design the Antenna we have made use of Ansys HFSS software. After designing the antenna, there was a need to optimize it in order to improve its efficiency. Ant colony optimization (ACO) algorithm was chosen for antenna optimization [2]. The antenna considered here was fed by a 1.59mm diameter coaxial cable; the feed location was varied by Ant colony optimization (ACO) algorithm. The antenna had one more parameter that was varied by the Ant colony optimization (ACO) that parameter included, length of sides of equilateral triangle shape. MATLAB software was used to implement the ACO Algorithm. Ansys HFSS software allows MATLAB software to be interfaced with it for optimization purpose [3]

The RLC equivalent circuit of equilateral triangle shaped antenna was constructed using Advanced Design System software [4]. Which provided results resembling the simulation results from HFSS software. Then the antenna was fabricated using Gerber file, and then this fabricated antenna was tested in anechoic chamber using Network analyzer. Then this antenna was used in medical application for transmitting temperature and heart rate using Arduino uno microcontroller and NRF24L01 transmitter and receiver module [5]. Section 2 provides the details of challenges faced and approach used to design equilateral triangle shaped antenna. Section 3 provides the information regarding ACO Algorithm. Section 4 provides the flow chart of ACO Algorithm. Section 5 provides details regarding procedure for implementation of ACO Algorithm. Section 6 explains the effect of using ACO algorithm using MATLAB, then this antennas performance

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is analysed in Section 7,then its RLC equivalent circuit is constructed and analysed in Section 8 .Once its result is satisfactory the antenna is fabricated and tested in Anechoic chamber using network analyzer which is explained in Section 9.Then this Fabricated antenna is used for Medical application for transmission and reception of temperature and heart rate of a patient which is explained in Section 10.

2. Equilateral Triangle Shaped Antenna Structure Design Using Ansys HFSS Software

This section provides an explanation of antenna design. The four main components of patch antenna are the antenna patch, antenna ground plane, substrate and the coaxial feed [6]. For the antenna patch we have considered equilateral triangle shape with all sides of length L. The antenna patch antenna ground plane are perfect conducting copper plates. The dielectric substrate material used is FR4-epoxy with a relative permittivity given by $\varepsilon_r = 4.4$, having a thickness of h = 1.6 mm. The parameters that determine the dimensions for rectangular patch are: (i) the operating frequency, (ii) the height of substrate and (iii) the dielectric constant. The length and breadth of the antenna patch is determined using these 7 equations [7]. The Wavelength of open space or free space (λ_0) .The free space wavelength λ_0 is given by

$$\lambda_0 = \frac{c}{f} \quad (1)$$

Equation (1), where speed of light is c, f is resonant frequency, yields width (W) for the radiating patch.

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r+1}}$$
(2)

The equation (2) , where f is the resonating frequency, ε_r is the relative permittivity, C is light speed in free space, yields the required length (L) of our radiating patch

$$L = L_{eff} - 2\Delta L$$
(3)

Where L_{eff} is the patch's effective length and ΔL is the extension length

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.30\ )(\frac{W}{h}+0.2640)}{(\epsilon_{reff} - 0.2580)(\frac{W}{h}+0.80)}$$
(4)

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}}$$
(5)

the relative dielectric constant, which is ϵ_{reff}

$$\epsilon_{reff} = \frac{\epsilon_r+01}{2} + \frac{\epsilon_r-01}{2}\left[1+12\frac{h}{W}\right]^{\frac{-1}{2}}$$
(6)

Where h gives dielectric material height used as substrate and ε_r is the substrate material's relative permittivity. We can therefore determine the width and breadth of a rectangular active patch, if we are aware of ε_r , h, and the resonating frequency (f). Equations (7) and (8) determines the width (Ws) and length (Ls) of the dielectric substrate once we have dimensions of an active patch

$$W_s = W + 6h$$
(7)

$$L_s = L + 6h$$
(8)

The above calculations are optimized for an equilateral triangle patch of equal length L having a square ground plane of length L_g. Feeding was done using coaxial cable [8]

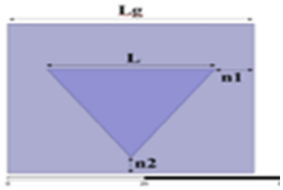

Fig 1. Equilateral triangle shaped antenna Top View

In Figure 1 the n1 indicates distance form right end of the outer square boundary to the base of optimized equilateral triangle shape and similarly n2 indicates its distance from bottom end of the outer square boundary to the tip of optimized equilateral triangle shape [9-10] . The Table I given below tabulates the properties of fundamental basic initial equilateral triangle shaped antenna for ACO optimization

Table 1. Equilateral Triangle Shaped Antenna Dimension

Parameters	L	Lg	n1	n2	H
Dimension in mm	20.5	75	4.2	7.25	1.6

Initial feed position for coaxial cable was zero. Using Ant colony optimization (ACO) Algorithm it is possible to create the efficient equilateral triangle shape structure with appropriate feed position.

3. Ant Colony Optimization Algorithm

ACO algorithms are included in the metaheuristics class the combination of two Greek terms yields the term metaheuristic [11]. The word "to find" (heuriskein) is the root of the suffix "Meta," which denotes something "beyond, in an upper level." Ants are gregarious insects. Living in colonies, their behaviour is dictated by the need to ensure the survival of the colony rather than individual members. Ants' ability to calculate the shortest routes between food sources and their nests, while also considering the location of ample food supplies, is the behaviour that served as the model for ACO. Ants initially conduct haphazard explorations of all region surrounding their nest in quest of food. Ants leave behind a chemical pheromone trail along their path when they are moving. Ants possess pheromone scent. They typically select routes with high concentrations of pheromones while making decisions

An ant that discovers a food supply quickly assesses the amount and quality of the food before bringing some of it back to the nest. The amount and calibre of food an ant eats may determine how much pheromone it deposits on the ground on its return journey. Other ants can find the food source by following the pheromone trails. It has been demonstrated in [12] that ants may determine the optimum routes between their colony and food sources by communication with others via pheromone trails known as stigmergy

4. ACO Metaheuristic

The Artificial pheromone trails (APTs) facilitate the indirect communication of a colony of artificial ants, which forms the basis of ACO.An ant is a basic computational entity that generates a solution probabilistically by repeatedly adding solution components to partial solutions while accounting for 1) Prior knowledge of heuristic information on the issue instance being solved, such that the desirability function or problem-specific greedy heuristic 2) Artificial pheromone trails that adapt dynamically in real time to the overall search experience of the ants. Exploratory-exploitive methodology is used by ACO. It is clear that as the search goes on, deposited pheromone takes precedence over ants' selectivity, decreasing the algorithm's unpredictability [13]. As a result, ACO is an exploitative algorithm which searches for optimum solutions near viable. Ones by utilising previously acquired data. Nevertheless, ACO is also an exploratory algorithm that tests a broad variety of solutions in the solution space because the ant's motions are stochastic A flow chart explaining the structure of ACO algorithm is shown in Figure 2

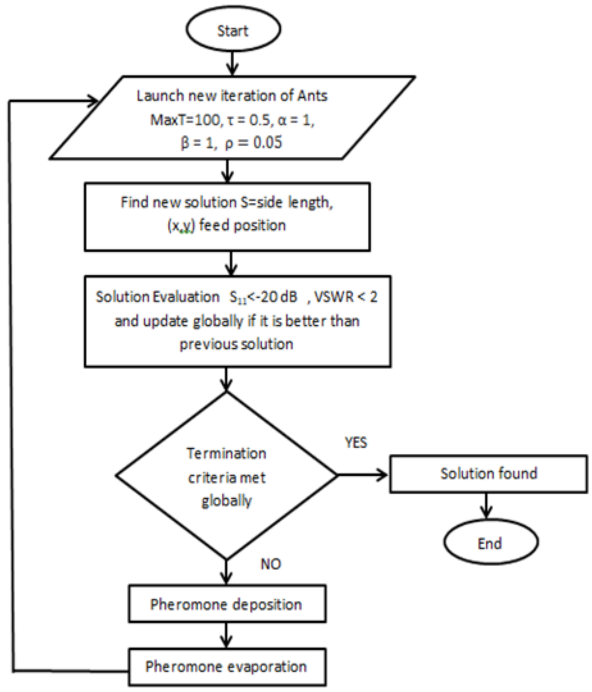

Fig 2. Flow chart of ACO Algorithm implemented for equilateral triangle patch antenna optimization

The main difficulty in creating an ACO-based optimisation strategy varies depending on the situation at hand and is the only connection between the optimisation algorithms and the real-world issue. This optimisation approach uses the basic fitness function as shown in Equation (9) to converge to the best solution for an equilateral triangle shaped antenna

$$f_{fitness} = \begin{cases} \left[\frac{(f_r - f_{goal})}{f_{goal}}\right], \ if\ f_r \neq f_{goal} \\ \frac{10}{S^2{}_{11}}\ ,\ if\ f_r = f_{goal} \end{cases} \quad (9)$$

5. Ant colony optimization algorithm procedure

The method for designing equilateral triangle shaped patch antenna using the Stepwise Ant Colony Optimization Algorithm can be summed up as follows

1: Initialize ACO Parameters

Population size (k) =20; Artificial Ants count

MaxT=100; Maximum iteration count

τ = 0.5; Pheromone initial value

α = 1; Pheromone exponential weight

β = 1; Pheromone heuristic weight

ρ = 0.05; Pheromone evaporation rate

2: ANT solution construction

Current iteration = 1 to MaxT

3: Position each ant at the starting node

Here Kth Ant move from node i to j with probability

(transition probability)

$$P_{ij}^{K} = \frac{\left(\tau_{ij}^{\alpha}\right)\ \left(\eta_{ij}^{\beta}\right)}{\sum_{Z\epsilon\ allowed\ i}\left(\tau_{ij}^{\alpha}\right)\ \left(\eta_{ij}^{\beta}\right)}$$

(10)

η_{ij}^{β} : *total pheromone deposit by Ant*

η_{ij}^{β} : *Value of path ij*

K: Ant

P: Probability of moving from node i to j

4: Each ant will select next node by applying state transition rule

5: Repeat until ant build the optimal solution then compute the fitness value

6: Update best possible solution

7: Apply offline pheromone update Pheromone updating equation is provided by

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_{k}^{m} \Delta\tau_{ij}^{k}$$

(11)

τ_{ij} : *Total Pheromone deposit by Ant*

ρ: *Pheromone evaporation rate*

$\sum_{k}^{m} \Delta\tau_{ij}^{k}$

: *Total Pheromone deposit by Kth Ant on path ij*

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{1}{t_k}, & if\ Ant\ k\ uses\ curve\ ij\ in\ its\ path \\ 0, & otherwise \end{cases}$$

t_k : *path length*

8: Display the best result: Loop will repeat until maximum number of iterations (100) after that it will display best solution (optimal solution)

6. Resultant antenna from Ant colony optimization algorithm

Figures 3 and 4 depict the final antenna with ACO optimization that was simulated using HFSS software. A substrate which uses FR4 is made used to design since it is less expensive and simpler to fabricate [14]. The substrate of FR4 will have a dielectric value of 4.3 and a height of 1.6 mm, and loss tangent of 0.02. Table I provides an antenna specifications overview. Figure 5 shows execution of ACO algorithm using MATLAB software. Figure 6 shows optimization process result in HFSS software. Figure 7 shows the result of various feed positions with different length of side of equilateral triangle shape antenna

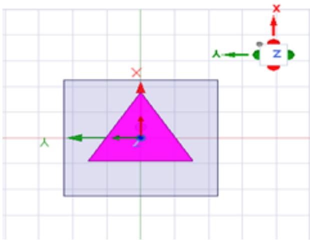

Fig 3. Top view of ACO Optimized antennas showing Patch shape

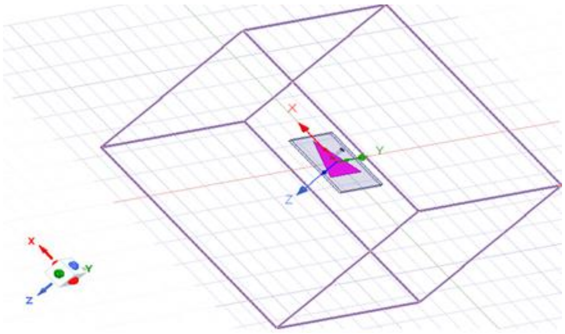

Fig 4. Bottom view of ACO Algorithm optimized antenna showing coaxial feed position

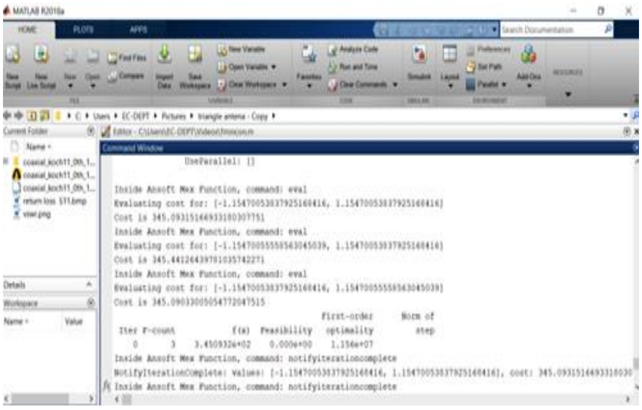

Fig 5. MATLAB to implement ACO Algorithm for optimization of antenna in Ansys HFSS software

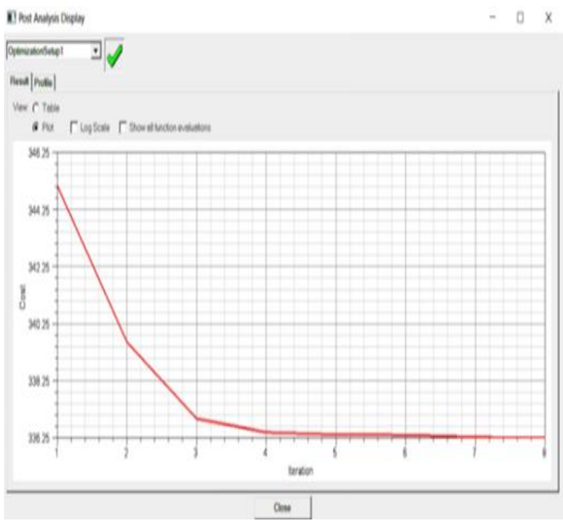

Fig 6. Ansys software showing best optimization was obtained at 7th iteration with a cost function of 336.25

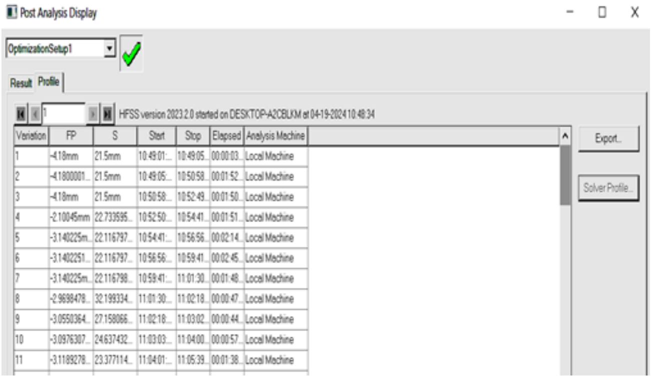

Fig 7. Ansys software showing best optimization was obtained for side S=21.5mm and (x,y) = (-4.18 , 0) feed position

7. ACO Optimized Patch antenna simulation results

The simulated return losses (S11) and VSWR for the proposed ACO optimised antennas is presented in Figure 8 and Figure 9. We can see that the return losses (S11) is -25.55dB and VSWR is 1.13 at resonating frequency of 2.48GHz .The objective of ACO was to have low VSWR and good return losses (S11) at the resonating frequency. Figure 10 to Figure 13 shows return loss for different feed position with different side length of antenna. Figure 14 shows the consolidated VSWR for all possible feed position and side length of antenna

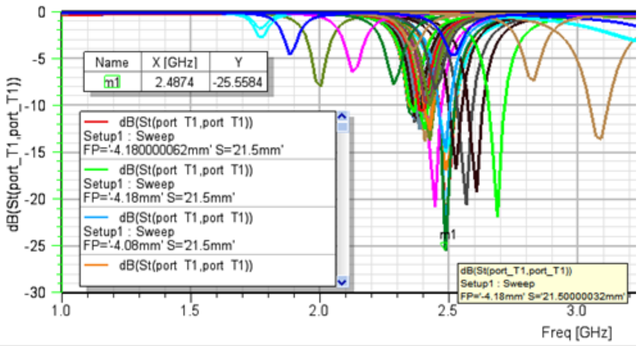

Fig 8. Consolidated Return loss of ACO optimized antenna of -25.50 dB for resonating frequency of 2.48GHz fed at (x= - 4.18,y=0,S=21.5)

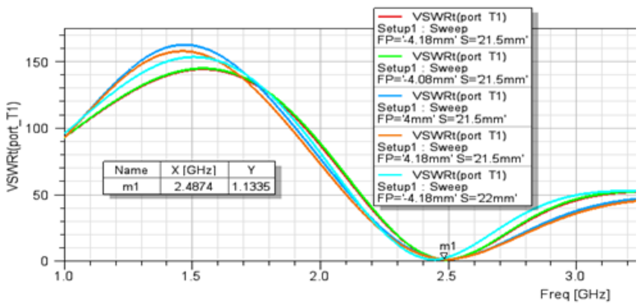

Fig 9. Consolidated VSWR of ACO optimized antenna of 1.13 for resonating frequency of 2.48GHz fed at (x= - 2.09,y=0,S=21.5)

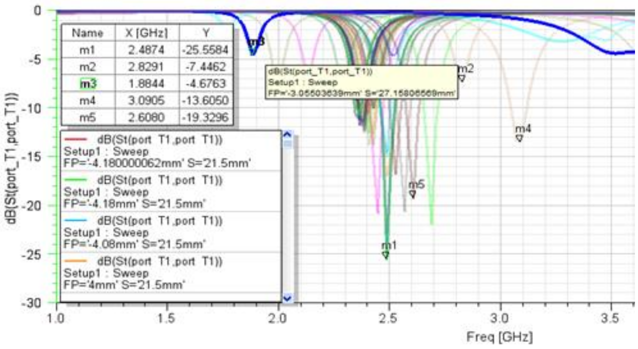

Fig 10. Consolidated Return loss of ACO optimized antenna of -7.44 dB for resonating frequency of 2.82GHz fed at (x= - 4.18,y=0,S=18.52)

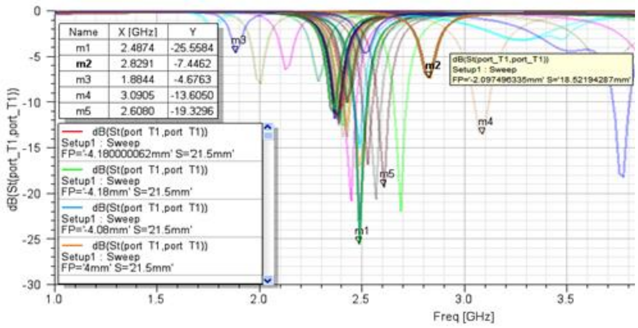

Fig 11. Consolidated Return loss of ACO optimized antenna of -4.67 dB for resonating frequency of 1.88GHz fed at (x= - 3.05,y=0,S=27.15)

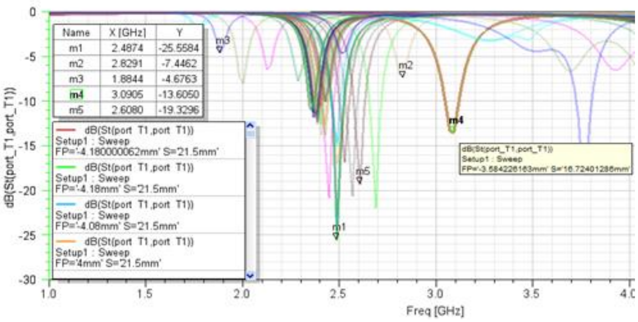

Fig 12. Consolidated Return loss of ACO optimized antenna of -13.60 dB for resonating frequency of 3.09GHz fed at (x= - 3.58,y=0,S=16.70)

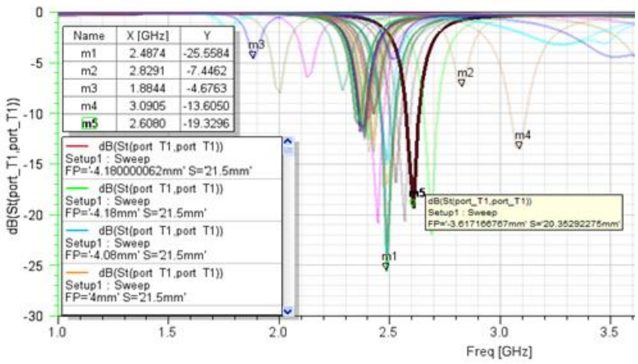

Fig 13. Consolidated Return loss of ACO optimized antenna of -19.32 dB for resonating frequency of 2.60GHz fed at (x= - 3.61,y=0,S=20.35)

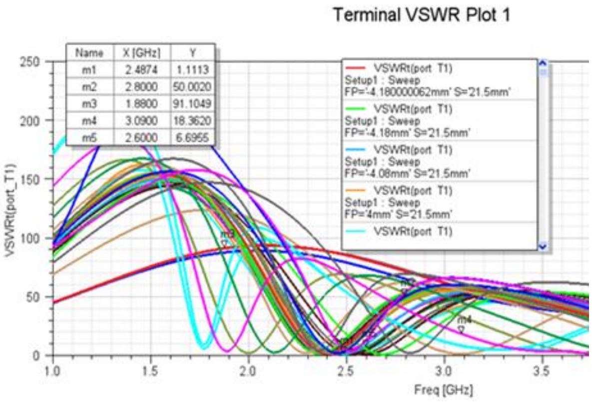

Fig 14. Consolidated VSWR of ACO optimized antenna

Table 2. optimized antenna for resonating frequency of 2.48GHz and fed at (x= - 4.18, y=0) compared with other feed position and side length of antenna

Side length in mm	(X, Y) position	Return loss S11indB	VSWR	Resonating frequency in GHz
21.50	-4.18	-25.5	1.11	2.48
18.52	-2.09	-7.44	50	2.8
27.15	-3.055	-4.67	1.88	1.88
16.70	-3.58	-13.60	18.36	3.09
20.35	-3.61	-19.32	2.60	2.60

The above Table 2 shows that to get the required antenna working at 2.48Ghz with good return loss and VSWR the side length should be 21.50 and feed position should be (X=-4.18,Y=0)

The distribution of current density for the ACO optimized antenna, which is constructed with a 2.48 GHz resonant frequency, Figure 15 shows its representation

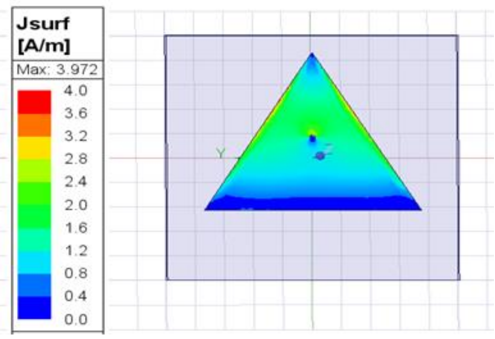

Fig 15. Distribution of current density

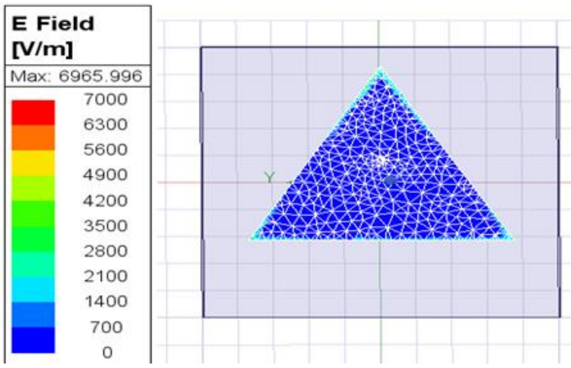

Fig 16. Distribution of electric field

The distribution of electric for the ACO optimized antenna, which is constructed with a 2.48 GHz resonant frequency, Figure 16 shows its representation, Figure 17 shows the distribution of magnetic field for the ACO optimized antenna, which is constructed with a 2.48 GHz resonant frequency,

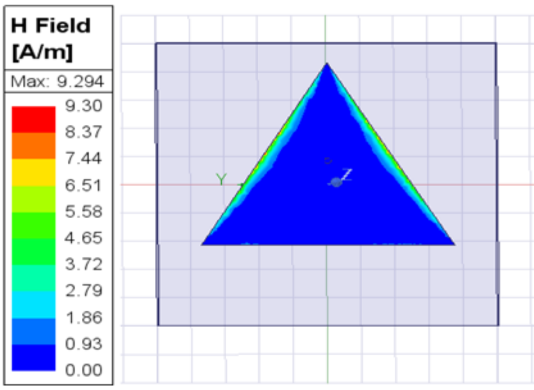

Fig 17. Magnetic field distribution

8. Equivalent Circuit Modeling

Equivalent circuit model of return loss plot for ACO optimized antenna can be achieved effectively by using RLC circuit which is presented in Figure 18. The modelling was done using Advanced Design System (ADS) software. Fig 19 shows the return loss of the optimized antenna which is almost resembles the fabricated antenna

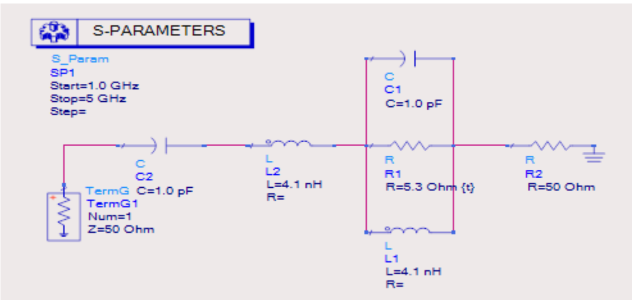

Fig 18. Equivalent RLC circuit for ACO Algorithm optimized antenna

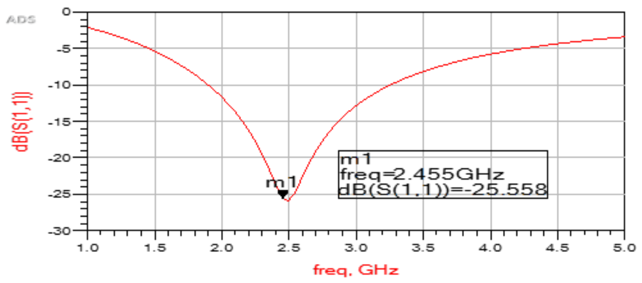

Fig 19. Equivalent RLC circuit Return loss (S_{11}) of ACO Algorithm optimized antenna showing -25.558 dB at resonating frequency of 2.45GHz

9. Prototype results of ACO Optimized antenna

Using FR4 substrate, a prototype of the resulting patch antennas created using ACO was constructed. Figures 20, illustrate it

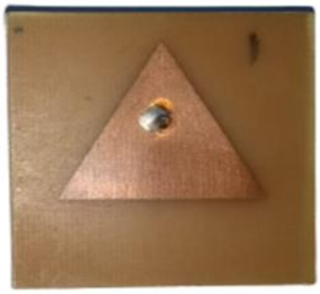

Fig 20. Fabricated of patch antenna optimized using ACO algorithm

To measure scattering parameters, Rohde & Schwarz vector network analyser having frequency range constrained to value of 20 GHz was used. The Return Loss (S11) and VSWR result for the fabricated antenna optimized using ACO is dissipated in Figure 21 and Figure 22 .We can see that the return losses (S11) is -27.30dB and VSWR is 1.10 at resonating frequency of 2.4GHz

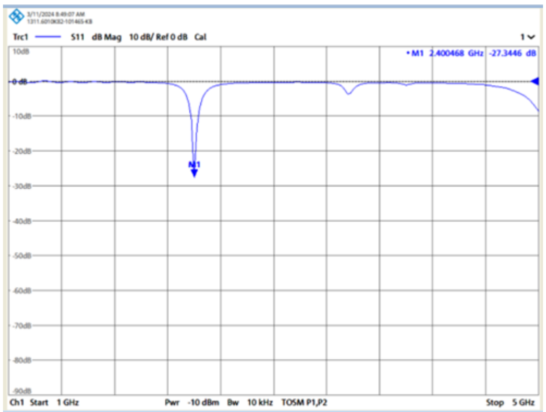

Fig 21. Return loss (S11) of ACO Algorithm optimized antenna Fabricated antenna of -27.344 dB at resonating frequency of 2.4GHz fed at (X= - 4.18, Y=0,S=21.5)

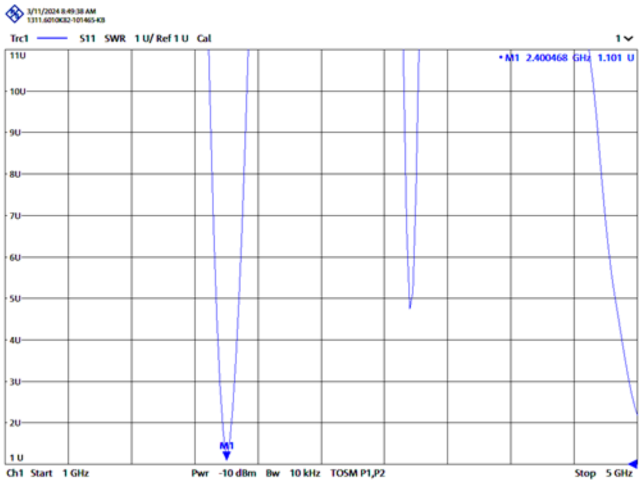

Fig 22. VSWR of ACO Algorithm optimized Fabricated antenna of 1.10 at resonating frequency of 2.4GHz fed at (X= - 4.18, Y=0,S=21.5)

Table 3. Comparison of Prototype and simulated Antenna Measurements

HFSS Simulated ACO Optimized antenna		Fabricated ACO Optimized antenna	
Resonant frequency	2.48GHz	Resonant frequency	2.48GHz
Return loss (S11)	-25.55dB	Return loss (S11)	-25.55dB
VSWR	1.13	VSWR	1.13

Table 3 shows that the manufactured (fabricated) and simulation information results were much identical, but there was a small difference in VSWR OF 0.03 in the fabricated antenna compared to that of the simulation result. Therefore, this antenna can be employed for wireless transfer of physiological body information in health care applications

10. Embedded Transceiver design for health care application

The ACO Optimized antenna was made used in transmitting physiological information of patient. The block diagram of transmitter is as presented in Figure 23 where the physiological information of patient like heart rate and body temperature is collected using heart rate sensor and temperature sensors. Then these measuring sensors were connected to a microcontroller (Arduino) which receives the physiological information of patient in analog form and is converted to digital form. This information is fed to RF Transmitter (NRF24L01 transceiver) module by microcontroller. The RF Transmitter module feed this information to the ACO Optimized antenna which converts the physiological information into electromagnetic wave and is transmitted into air (space). Its implementation diagram is shown in

Figure 24. At the receiver end the receiver consists of (NRF24L01 transceiver) connected to ACO Optimized antenna, it is as Figure 25 illustrates. This antenna receives the electromagnetic wave and converts it to electrical signal which is then fed to microcontroller (Arduino). The received physiological information of patient like heart rate and body temperature is displayed in serial monitor port, it is as Figure 26 illustrates

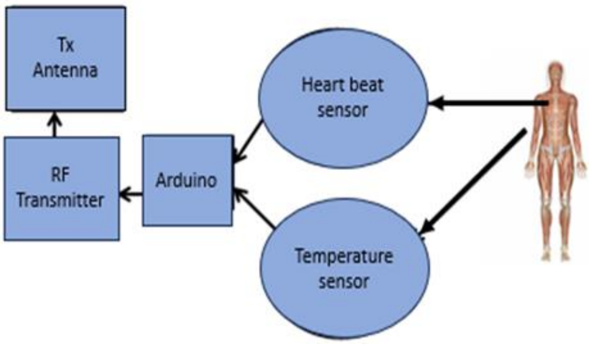

Fig 23. Transmitter Block diagram

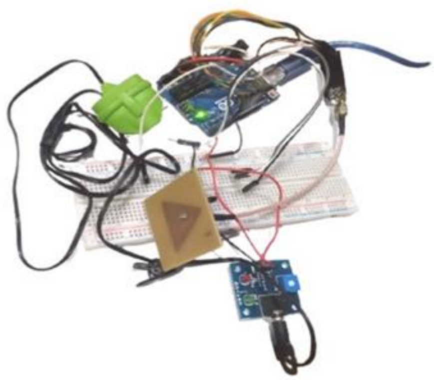

Fig 24. Transmitter with sensors and ACO Algorithm optimized antenna

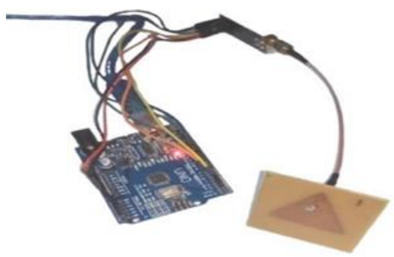

Fig 25. Receiver with ACO Algorithm optimized antenna

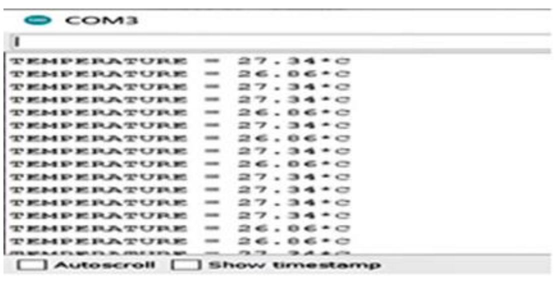

Fig 26. Sensor data displayed on serial monitor

11. Conclusion

In this paper the designing, simulation, fabrication and testing of an Ant colony optimization (ACO) Algorithm based optimization of an equilateral triangular shaped antenna was implemented effectively .The design and simulation of equilateral triangle shape antenna was done using ANSYS HFSS software. It converges after the 7th iteration, an embedded system was also assembled to implement the ACO optimized fabricated antenna to transmit heart rate and temperature information. The designed antenna operates in the ISM band and can be utilized in any application suitable; the antenna was implemented in a healthcare application to transmit and receive signals wirelessly to demonstrate its working.

ACO optimized Triangular shaped antenna was fabricated using etching technique. The 7th iteration was successful in operating at the desired frequency of 2.4GHz with reflection coefficient or return loss of (S11) of -27.34dB and VSWR of 1.10 at Coaxial cable feed position of (X = -4.08, Y = 0).ACO Algorithm was implemented using MATLAB software .The antenna designing software Ansys HFSS allows MATLAB to be interfaced with it for optimization purpose The adoption of ACO optimization allows improving the performance of antenna .The simulation results show that the ACO optimized antenna provides greater gain lower VSWR and good Return loss than conventional equilateral triangular patch antenna. The VSWR and return loss show better performance as the iteration increase

The temperature and pulse sensors with Arduino Uno Microcontroller successfully transmitted and received signals wirelessly. Arduino codes were written and were uploaded by making use of Arduino IDE. Real-time monitoring and debugging of the Tx and Rx values was done with the help of serial monitor of the Arduino IDE.

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Author contributions

Mahesh D S is the principal author responsible for the study's conception and design, overseeing experimental procedures, conducting data analysis, and composing the manuscript. He adeptly executed data acquisition and analysis, generated graphical representations, and made substantial contributions to manuscript development. He was actively engaged in study design, offering invaluable insights during data interpretation, and precisely revising the manuscript. Dr. Naveen K.B served as the Research supervisor, providing critical assessment of the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

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