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Positioning of sensor nodes in body area network for bioheat reduction using swarming algorithm

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Abstract— The body area network (BAN) is an emerging field in last decade with the evolution of mobile networks and wireless sensor networks. Body area network is a special type of body sensor network where wireless wearable computing devices are put up on to the human body to compute different medical parameters. These healthcare parameters involve heart rate, body temperature, pulse, etc. The main focus of the current work is to reduce the bioheat produced due to the wireless sensor nodes placed on the body. The swarming algorithm allows equal distributed placement of BAN sensor nodes on the body. The algorithm uses single node to modify and find the optimum position of all other nodes in the BAN, such that the bioheat and the SAR value is minimized throughout the interconnected network on the body. We could reduce up to 40% of bioheat produced with the help of swarming algorithm, the position obtained for leader movable sensor is around the neck which measures respiration rate. Furthermore, it is recommended that 5 nodes are to be connected in BSN, which could result in the production of bioheat within acceptable SAR limits. We expect this algorithm to give away the optimum position of placement of wireless sensor nodes in BAN according to the body type which will minimize bioheat production.

1. INTRODUCTION

Body area network (BAN) popularly known as wireless body area network is the combination of sensors and wireless systems designed to be mounted on to the body, such that, the body parameters can be measured. The BAN sensors can be implants inside the body or wearable sensors from outside the body which touches the surface of the body. All the sensors in BAN transmit data to the central unit. The central unit acts as a data hub and data gateway for all other body sensors. With the help of the central gateway, it is possible to connect internet to BAN and send the data to the medical officer for inspection.

The concept was BAN was introduced in 1995 [1] with an idea called wireless personal area network (WPAN). Around 2001 WPAN was further divided into BAN and PAN. BAN focuses only on intercommunication between nodes which are in immediate proxy with the body. The BAN communication range is very short. There a huge amount of recent literature reported about miniaturization of the sensors and communication protocol to maximize data transfer in the BAN. But bioheat produced due to radiation during wireless transmission for interconnection between different sensors and the central unit of the body still remains a weak link in the research field.

We used modified swarming algorithm to find the position of nodes in BAN such that bioheat produced inside the body is reduced to minima. Swarming algorithm is the self-organized positioning of all the nodes depending on the positioning based on artificial intelligence or neural networks. The swarming algorithm was first introduced in 1989 [2] for the use in the field of robotics. In swarming algorithm, the nodes are called simple agents which interact with each other without centralized control asking each node to move at the particular position in the network. The inspiration of swarming algorithm comes from nature like ant colonies, bacterial growth or even flocking of birds.

2. LITERATURE REVIEW

There are few reports available on bioheat production in wireless body area networks. Latre et al. [3] presented the review on wireless body area networks, where they briefly mentioned a model predicting bioheat production in the BAN. Ullah et al. [4] shown that SAR value reduction due to tissue loss. Movassaghi et al. [5] showed the positive side of WBAN by showing the reduction in the rate of fainting by proper dosing. On another hand, they have also mentioned about the loss in circulatory tissues caused due to overexposure to the WBAN. Jiang et al. [6] showed that ohmic loss which is the cause of bioheat can be reduced by 95.3% to 83.4% with the help of compact metastable surface antenna.

3. METHODOLOGY

We have used swarm optimization method to iteratively improve the specific absorption rate in the simplified human model. The simplified 2D human model was created in AutoCAD 2018 with the use of rectangles. The model was then imported to COMSOL Multiphysics and extruded to get the 3D model from simple 2D geometry. All the body sensor network nodes were placed on to the body according to the swarm optimization with respect to the first node, for simplicity, we have chosen four followers and one leader node. We have simulated three different configurations according to the swarm optimization to find the best position of the wireless node on to the body. All of the three node configurations were solved for SAR using RF module and Heat Transfer module inbuilt into the COMSOL Multiphysics software. Nodes were simulated with respect to conductivity, permittivity, and perfusion rate. The vector Helmholtz wave equation was used. The relative permittivity of tissue was chosen to be 58.13 and conductivity is 1.15 Siemens per meter, perfusion rate for the body was chosen to be 3 x 10^{-4} (ml/sec)/mm. Heat capacity of the blood was set to 3639 joules/kg kelvin and density of the blood was chosen to be 1000 kg/m^3. The density of the body was chosen to be 1030 kg/m^3. Finally, a stationary solver is used to solve the model and temperature fields as a surface slot were computed.

The three configurations used are described below. Configuration 1 is a respiratory sensor, artificial knee sensors, and motion and blood pressure sensor as shown in fig. 1. Nodes are placed as per the swarming algorithm The four node positions (x,y) coordinates are given by the equations below:

P1(x,y) = (75 + (120* Yi / 50)), 285
P2(x,y) = -75- (120* Yi / 50),285
P3(x,y) = 50,(-150-(150*Yi/50))
P4(x,y) = -50,(-150-(150*Yi/50))

Configuration 2 shows respiration sensor, ECG measurement sensor, motion sensor and glucose sensor. Configuration 2 is depicted in figure 4. The set of equations in configuration 2 are mentioned below:

P1(x,y) = Xi,Yi + 20
P2(x,y) = Xi+10, Yi-10
P3(x,y)= Xi,Yi - 20
P4(x,y) = Xi-10, Yi-10

Configuration 3 shows a combination of EEG, foot pressure sensors for diabetic patients and blood oxygen sensor. Figure 3 is as shown in figure 5. The set of equations for x,y coordinated is given below:

P1(x,y) = 135 + (Yi*30/50),285
P2 (x,y) = -135 - (Yi*30/50),285
P3(x,y)= (150-Yi*3),50
P4(x,y) = (150-Yi*3),50

4. RESULTS

Figure 1 shows results obtained after simulating configuration one positions. The time domain effect after Turning on the BAN sensors on the bioheat production is shown in figure 1, 2, and 3 at t= 0 min, 1min, and 2min respectively. It can be observed that the heat moves very slowly and remains very strong near the sensor while the strength of bioheat is weakened as we move away from the sensor node. the heat diffusion rate is 12mm/min while a node is on and goes up to 30 cm maximum with 0.5 watt nodes (which is the maximum power a sensor node in a BAN can be used). The heat generated could go up to the maximum of 0.145 degrees K. The configurations main aim was to obtained minima of SAR value which was achieved in configuration 1. Although the set of x,y coordinates of configuration 1 in swarming algorithm is found out to be the best ones in simulation, It is recommended that configuration 2 and 3 should be used in case of the special sensors such as EEG (configuration 3) and toe pressure measurement (configuration 2). Figure 4 shows the results obtained from configuration 2.

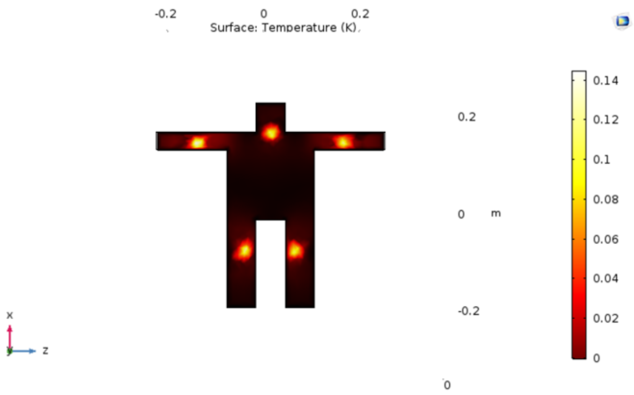

Fig. 1 Configuration 1 showing respiratory node in the centre, Motion node and blood pressure measurement sensor nodes on shoulders and artificial knee sensors on both knees. The simulation is at t=0 min, just after sensor node is turned on.

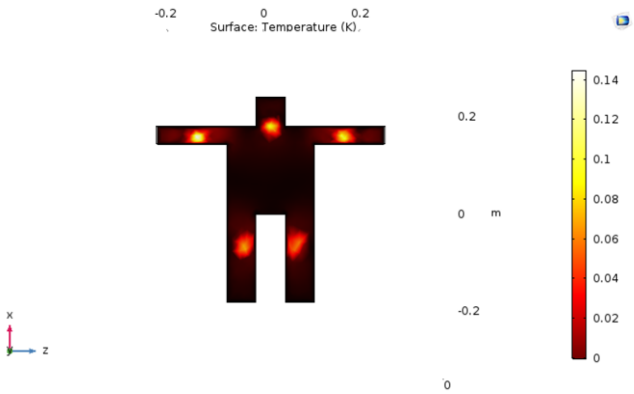

Fig. 2 Configuration 1 showing respiratory node in the centre, Motion node and blood pressure measurement sensor nodes on shoulders and artificial knee sensors on both knees. The simulation is at t=1 min after sensor node is turned on.

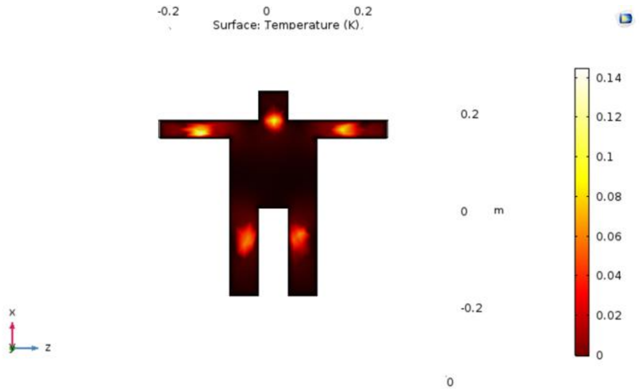

Fig. 3 Configuration 1 showing respiratory node in the centre, Motion node and blood pressure measurement sensor nodes on shoulders and artificial knee sensors on both knees. The simulation is at t=2 min after sensor node is turned on.

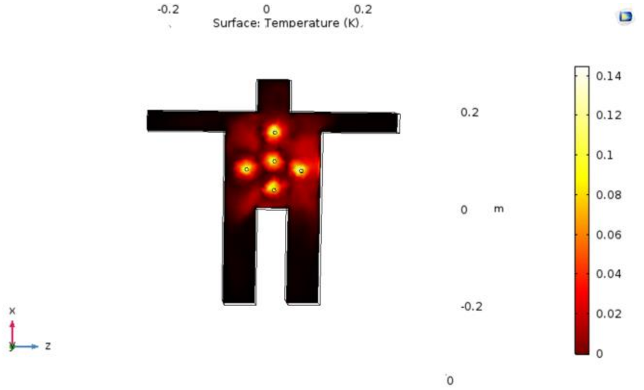

Fig. 4 Configuration 2 showing respiratory node in the top, ECG sensor in left, Motion sensor in the right and glucose sensor at the bottom. The simulation is at steady state achieved after all the sensor node is turned on.

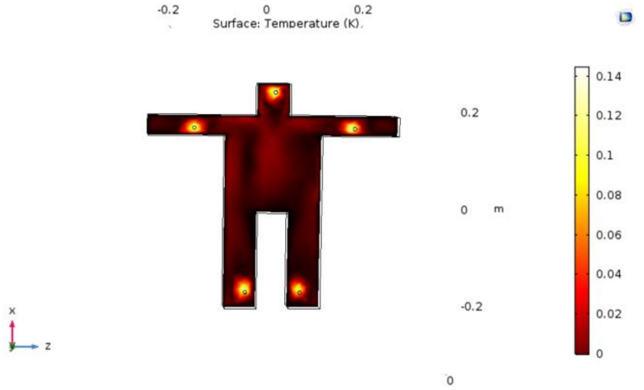

Fig. 5 Configuration 3 showing EEG sensor in the top, pressure sensors on both toes and blood oxygen sensor on the arms. The simulation is at steady state achieved after all the sensor node is turned on.

Figure 5 shows the results obtained with configuration 3. All the figures represent the position of nodes in which minima of bioheat i.e. lowest SAR value of the network was obtained.

5. CONCLUSIONS

In the current manuscript, we have used 3 set of configurations using swarming algorithm for minimizing bioheat production using simulation. The multiphysics simulation allowed us for the parametric sweep and to obtain best results using all the configurations possible. After running all the simulations, we found that configuration 1 equations are the best set of equations. We have used 5 node configuration and 3 different configurations in the present report. Readers are not limited to these set of equations or number of nodes, in fact, the user can use any number of nodes and any swarming equation as per requirement. The current work is only the guideline of how to optimize BAN node for minimum bioheat using simulations.

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