Wound Healing Based Optimization – Vision and Framework

SeemaChawla, Jasbir Singh Saini, Manish Kumar

Abstract*—*The engineering society is looking towards nature – the greatest developer & teacher of the mankind, for finding solutions to its day-to-day problems. Like many concepts proposed till date, the ideas of which have been taken from none other than the nature, we propose another optimization technique based on a biological phenomenon – the complex but an advanced and well organized process of wound healing. An extensive study, of wound healing processes and the factors affecting it, shows that the process is a highly organized, efficient and robust one. The process of wound healing, which involves synthesis, production, degradation, necrosis, etc., is handled by nature in a wonderful way. This flawless working of nature and the many types of models proposed till date for the process are an inspiration for us to develop the process into an optimization technique for solving our practical problems. Thus, in this work, we envision and implement a new optimization technique based on wound healing. We term it as Wound Healing Based Optimization (WHO). Fairly good results have been obtained by applying the proposed algorithm onto the sphere problem. However, it is also observed that there is a scope for improvement and we are working towards a more robust and generalized algorithm. Our future research agenda includes the same.

Index Terms- Elements, Parameters, Wound

I. INTRODUCTION

In this fast developing world, engineers and technical personnel owe a responsibility of ushering the society towards wholesome growth, i.e., they need to work towards new techniques which not only ensure some improvements over the previous ones, but also give rapid results. This trade off between good and rapid changes has brought the engineers closer to nature. It has been proven that nature is the best creator, manager as well as the destroyer. Now, knowing the fact that nature is the best teacher, the engineering society is utilizing the principles of nature for developing new techniques. On the same lines, we have, in this paper, envisioned a new optimization technique, which is based on the principle of wound healing. 'Wound' in the paper is referred to an injury in the epidermal, and a bit dermal, region of the skin. When we study the detailed process about how our body reacts to an injury, we find that the body shows a very complex, but a well organized sequence of overlapping events, which we refer to in this dissertation as wound healing process. Assuming a stable state initially at the injury site (i.e., prior to injury), we find that the environment around the site starts changing immediately. We focus on the changes over the sequential phases of the wound healing process and try to incorporate the principles of these changes, for developing a framework for a new optimization technique, i.e., *Wound Healing Based Optimization* (WHO).

Four attributes have been identified, over the four phases of wound healing, which show significant changes and, therefore, we have utilized these changes as our basic *elements*. The factors which further affect these changes are referred to as *parameters* in this paper. As we will study in subsequent sections, from the detailed process of wound healing, the four elements are identified as Change in Cell Density (N), Change in Matrix /Base Density (B), Displacement (U), and Development of Strain (S). Similarly, we have identified six parameters, which further affect the four elements, or we can say, the parameters are the reasons for the observed changes in the elements. Observing the pattern of the changes, an analogy has been attempted to be established between the process of wound healing and a practical problem. Keeping the existing wound healing models as the basis of our studies and work, a simplified model and set of equations have been proposed. Based on the elemental changes, a framework for the WHO has also been proposed, which is further used to develop an algorithm. The algorithm has been applied on to the problem of a d-dimensional sphere (to find out the minima) for testing the optimization characteristics of the algorithm.

The results obtained are analyzed and compared with those of other optimization techniques. The results are satisfactory at this stage and we hope to improve them further by a more robust and generalized algorithm.

II. SIMPLIFIED WOUND HEALING MODEL

The wound healing models available in the literature incorporate the effects of cytokines and transglutaminase which has been shedded off for the proposition, as the effects can be incorporated in the form of cellular and fibrous changes in the model. However, the effects of various types of flux have been added to the proposed model and the subsequent equation (as discussed in the next section).

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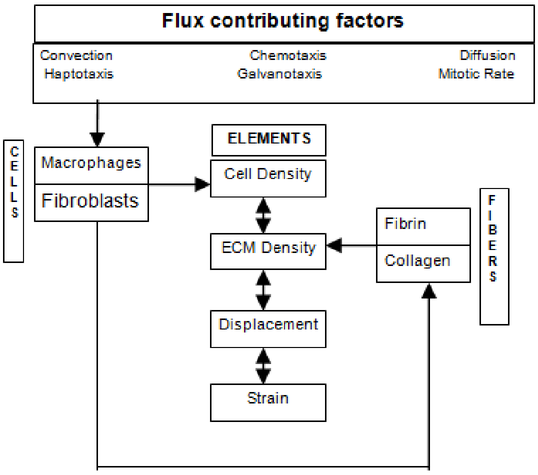

Fig 3: A simplified Wound Healing Model

A. *Simplified Equations*

The two equations governing the whole system of changes and modifications during one complete time period of wound healing are:

<u>Cell Conservation Equation</u> (1)

$$\frac{\partial n}{\partial t} = -\left[\nabla J_c + \nabla J_{ch} + \nabla J_D + \nabla J_h + \nabla J_G\right] + rn(N-n)$$

$$= -\nabla J + M$$

<u>Matrix Equation</u> (2)

$$\frac{\partial B}{\partial t} = g_1(N,B) - g_2(N,B)$$

The equation (1) refers to the rate of change of cell density and incorporates the effects of rates of changes in Convective flux (J_c), Chemotactic flux (J_{ch}), Diffusion (J_D), Haptotactic flux (J_h), Galvanotaxis (J_G) and Mitosis [$rn(N-n)$ or M].

Equation (2) describes the rate of change of matrix density. Matrix density is dependent upon synthesis of fibers as well as the degradation of fibers, where g_1 is the rate of synthesis of fibers and is a function of cell density, N and matrix density, B whereas g_2 is the rate of degradation of fibers, again a function of cell density, N and matrix density, B.

B. *The Proposition*

Retaining the wound healing principles culled out from the vast literature and to move towards proposing the new optimization algorithm, we make the assumptions:That there is no infection or any other complications in the healing process, that the density of the Extracellular Matrix, i.e., the base density consists of two fibrous networks - fibrin and collagen, and the normal tissue is composed entirely of collagen, that the displacement term, implies the movements of cells (this movement is different from cell migration and flux, rather corresponds to the cell velocity depending upon the ECM density and fiber density) and fibers (alignment of fibers) at the wound site, tThat the force developed during the healing process is due to the alignment orientation of collagen fibers only, as fibrin fibers are very short and randomly oriented, even during the healing process.We propose the four basic elements in which substantial changes are observed during the wound healing process. These are Change in Cell Density (*N*)**,** Change in Matrix / Base Density (*B*)**,** Displacement (*U*)**,** Development of Strain (*S*)

The above mentioned four elements can be studied as the outcome of the changes in some parameters, which we have identified as the key factors, that result into a minimizing sort of phenomenon in the four events over time t = 0 to t =T, where

t = 0, corresponds to the instant at which the injury takes place, and

t = T, corresponds to the instant of complete wound healing.

The key factors identified, at a given position 'r' and time 't' are flux density, *J*, Mitotic / Proliferation Rate, *M*, Initial Cell Density, *n*, Fiber Density, *F*, Cell Velocity, *v*, Stress Tensor, σ. The first three factors contribute to the first element of cell density. Changes in the fiber density contribute to the second event, i.e., Matrix / Base Density. Whereas the changes in the cell velocity affect the displacement event, the stress tensor variations affect the strain event. Next, we move on to explain how we can utilize these variations for developing an optimization technique.

C. *The Proposed Framework for WHO*

The standard way of using an optimization technique as function optimizer is to keep track of the (globally) best individual produced so far regardless of whether that individual exists in the current population or not. That is, the population is viewed as a database (an accumulating world model) of samples from which potentially better individuals are to be generated. Hence, converged solutions represent a "focus of attention" in the sense that most new trials will share these values (i.e., live in the same subspace), while the residual diversity in other solutions provides the building blocks for creating new individuals. With this feature of an optimization technique, we proceed for a framework for WHO.

As the values of the key factors change with time, we generate a set of values for each of the key factors. Based on literature survey, the parameters are initialized. For each parameter, a set of random values, N_r, is generated between a given range. We select one element, let us say, Cell Density, N, and generate a large initial value, ΔN_{min}, for it. Now, each of the random values, N_r, is selected one-by-one and the corresponding value of N is computed. The change in the value of N is observed and compared to the initial value, ΔN_{min}. Since the initial ΔN_{min} was a large value, the next change is lower and the lower value is selected as ΔN_{min}. This process of selecting a random value of the parameter, measuring the change in the element value and assigning the lower among the two as ΔN_{min} is run till all the randomly generated values are tested. Each lowest value

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obtained for the four elements is applied onto the objective function to give optimum value. We aim to achieve the minima in this change at the earliest. ΔN_{min} is used as ΔX_{min} in the proposed framework for generalizing it.

Identification of parameters / key factors mainly responsible for wound healing process.
Initialize the parameters by providing values based on literature review.
Generate set of random values, N_r, between the ranges specified, for each parameter.
Initialize first value, ΔX_{min} = some large value (say 10,000), and compute initial value of objective function, where X is an element of the wound healing process, i.e. N,B, S or U.
Select a random value from one set of values N_r and compute the corresponding value of X.
Compute the change in the value of function X, i.e., ΔX_1 = current value– previous value
Is $\Delta X_1 < \Delta X_{min}$?
If Yes, $\Delta X_1 = (\Delta X)_{min}$.
If No, select another random value.
The value of X corresponding to $(\Delta X)_{min}$ is selected as the optimized value &
The corresponding value of objective function is selected as the optimized value.

Fig. 4: The Proposed Framework for the Wound healing based Optimization Technique

The detailed algorithm may be asked from the authors if required

D. Simulation of the Wound Healing Process

The starting values of each set of parameters are selected from the background literature. The initially assigned values, as guided by literature, are as under:

$J = 0$
$M = 0$
$n = 20$ (some small value, compared to no. of cells post-injury)
$F = 0$, fiber density due to new formed fibers (fibrin and collagen)
$B = 10$, some small value
$u = 5$, some less value
$v = 0$
$\sigma = 0$
N_r = variable, No. of random values generated for each set of *J*, *M*, *n*, *F*, *v*, and σ.

A complete run over the main program and the four subroutines, we get four graphs for decreasing values of changes in the four elements, *N*, *B*, *U* and *S*. The value over which the change observed is least is selected and applied in the objective function for calculating its optimum value. In the results over a complete run, we get nfour graphs for decreasing values of changes in the four elements, N, B, U and S; the final value of objective function; the total no. of computations involved in the complete simulation, and the time elapsed in the process. The total no. of computations is dependent upon the no. of parameters selected, here six, and the no. of random values generated for each parameter, N_r, such that

Total no. of computations = No. of parameters x N_r

IV. SIMULATION ANALYSIS& RESULTS

We have chosen the problem of a d-dimensional sphere for applying onto the proposed algorithm because it fits into our requirements of flexibility in the number of elements. In our present work, we choose the value of 'd' as 4. The same can be changed as per the application requirements. A d-dimensional sphere is explained as a *circle* (or: a "*hypersphere in two dimensions"*) with the locus of points on a *plane* (2D-space) that have the same distance from a fixed center or a *sphere* (or: a "*hypersphere in three dimensions"*) with the locus of points in the *3D-space* that have the same distance from a fixed center. Therefore, by analogy it follows that a *4D-sphere* (or: a "*hypersphere in four dimensions"*) has to be the locus of points in the *4D-space* that have the same distance from a fixed center. A 4D-point is an entity that includes three spatial coordinates (*x*,*y*,*z*), plus a fourth one, which gives the time *t* during which the 3D-point (*x*,*y*,*z*) "occurs". It is the locus of events (*x*,*y*,*z*,*t*) that allow *d* to retain a constant value. Therefore, *d* plays the role of "radius" in our 4D-sphere. We aim to achieve a constant value of (1,1,1,1) for the co-ordinates using our wound healing based optimization. Over several numbers of simulation runs, by increasing the value of N_r, we conclude the following results.

Table 1 Results obtained for sphere problem

No. of random values generated (No. of iterations)	Value of Objective Function	Total no. of Computations	Elapsed time (in seconds)
10	0.0358	100	0.755435s
50	0.0010	500	0.738886s
100	0.0013	600	1.029151 s
500	2.4273e-006	3000	1.038121 s
1000	6.0694e-006	6000	1.036868 s
5000	7.7776e-008	30000	0.666134 s

The proposed algorithm shows good results for the d-dimensional sphere problem. However, the idea can be nurtured by researchers for, may be, an even better framework and wide practical applications

V. CONCLUSION

By using the proposed framework and subsequent algorithm, the condition to be achieved for the d-dimensional sphere problem, i.e., minima at (1,1,1,1) is nearly reached. As we go on increasing the no. of random values for each set of parameters, N_r, the condition of optimality is achieved to better extent (values get closer to 1,1,1,1). Upon increasing the no. of random values for each set of parameters, N_r, the value of objective function goes on decreasing, as desired. A very significant observation is with respect to the time elapsed during the complete process, which decreases, instead of increasing, with an increase in N_r. The proposed algorithm shows good results for the d-dimensional sphere problem which are comparable to those obtained by other techniques like PSO, but can be improved further.

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