# A MULTIDIMENSIONAL OPTIMIZATION PROCESS FOR ENHANCING ELECTROACUPUNCTURE EFFICIENCY


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## ABSTRACT

Most electroacupuncture devices function by adjusting variables, such as current strength (c), frequency (f), stimulating pattern (p), and duration (d). To achieve a therapeutic result, usually we have to apply stimuli to at least 10 acupuncture points in a patient each time [3]. Four variables on an individual point for more than 10 points would come out numerous possible combinations and make the therapy too time consuming. The aim of our study is to improve the acupuncture efficiency by finding best combinations of those variables. To do this, we first quantify the therapeutic effect/stimulated feeling as a comfort level (Com) and determine this comfort level as a function of those variables for each acupuncture point. Experiments are conducted on a subject. Least-squares multidimensional curve fitting method and multivariable optimization technique (Quasi-Newton method) are applied to these experimental data to find the value of c, f, p and d, which give the best comfort level (Com) in terms of a comprehensive effect for n points.


## INTRODUCTION

Five thousand years ago acupuncture found its beginning amongst the Chinese. It entered modern western consciousness in the 1970's and for the past thirty years, western doctors have been studying and incorporating acupuncture into western medical culture, successfully complementing modern medicine with the ancient Chinese techniques [1]. Basically, acupuncture is the insertion of very fine stainless steel needles at particular locations called acupuncture points on the body surface, in order to influence physiological functions of the body. According to traditional Chinese medicine, a form of bodily energy is generated in internal organs and systems. This energy combines with the breath and circulates throughout the body, forming paths called meridians [1].

In 1950's, based on extensive studies in the electrical properties of acupuncture meridians, electroacupuncture (EA) was introduced in connection with the development of acupuncture anesthesia in China. Most EA devices function by adjusting variables, such as current strength (c), frequency (f), stimulating pattern (p), and duration (d). To achieve a therapeutic result, usually we have to apply stimuli to at least 10 acupuncture points in a patient simultaneously. For example, Figure 1 shows the 14 acupuncture points for headaches [3]. The aim of our study is to improve the electroacupuncture efficiency by searching the best combinations of these variables. To do this, we shall first quantify the therapeutic effect/stimulated feeling as a comfort level (Com) and measure this comfort level as a function of c, f, p, and d for each acupuncture point. Least-squares multidimensional curve fitting method is applied to these experimental data to determine the closed-form of this function ($Com_k = f_k(c, f, p, d)$, $k = 1, 2, 3, \ldots n$, n is the total number of the acupuncture points, $n \geq 10$). Multivariable optimization technique (Quasi-Newton method) is then used to find the values of c, f, p and d, which give the best comfort levels in terms of a comprehensive effect for n points.

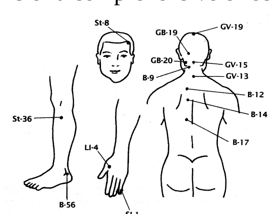


**Figure1. 14 acupuncture points for Headache treatment.**

## MATHEMATICAL MODELING

### Least-squares multidimensional regression method

We have m sets of observations of y and of p separate variables, $x_1, x_2 \ldots x_p$. For the *i*th observation, $y_i$ is a function of the independent variables $\mathbf{X}=[x_1,x_2\ldots x_p]^T$ and of the parameters $\mathbf{a}=[a_0,a_1\ldots a_p]^T$. $e_i = y_i - \hat{y}_i$ is the difference between the observed ($y_i$) and the fitted value ( $\hat{y}_i$ ). Our criterion for choosing **a** is that they should minimize the sum of the squares of the errors, which is denoted by SSE. Thus

$$SSE = \sum_{i=1}^{m} e_i^2 = \sum_{i=1}^{m} (y_i - \hat{y}_i)^2 \quad (1)$$

Then we define **e**, **y**, and **u** to be m×1 vectors: $\mathbf{e} = [e_1\, e_2 ... e_m]^T$, $\mathbf{y} = [y_1\, y_2 ... y_m]^T$, $\mathbf{u} = [1\ 1 \cdots 1]^T$ and $\mathbf{e} = \mathbf{y} - \mathbf{Xa}$, where $\mathbf{X}$ is a variable matrix. Differentiating SSE with respect to **a**, we get a vector of partial derivatives, as follows,

$$\frac{\partial(\mathrm{SSE})}{\partial \mathbf{a}} = -\mathbf{2X^T(y - Xa)} \tag{2}$$

Equating this derivative vector to zero, we have,

$$\mathbf{Xa=y} \tag{3}$$

These equations could be solved directly to obtain the coefficients **a**, which minimize SSE, the sum of squares of the errors.

For most EA devices, the largest current strength that a person can bear is roughly two milliamperes (mA) [4]. In our EA device, we rank the values from 0 to 9 with 0 represents no current and 9 represents 2mA current. The duration is normally from 5 to 30 seconds. In most cases, two frequency choices exist: $f_1$ = 50 Hz and $f_2$ = 100 Hz, and three pattern choices: double burst ($p_1$), train-of-four ($p_2$) and random burst ($p_3$). In our model, we assume that the therapeutic effect/stimulated feeling can be quantified as a comfort level (Com), and we can measure this comfort level as a function of c, f, p, d for each acupuncture point. Since we only have two frequency choices and three pattern choices, there are six combinations of f, p: $f_1p_1$, $f_1p_2$, $f_1p_3$, $f_2p_1$, $f_2p_2$, and $f_2p_3$. For each c and d at each acupuncture point, six independent functions of c and d can be obtained. We assume that c and d contribute equally to the comfort level, and a third order polynomial is applied to represent the fitting function,

$$\begin{aligned} Com_{k,i}^{j}(c_i, d_i) &= a^{j}{}_{0k} + a^{j}{}_{1k}c_i + a^{j}{}_{2k}c_i^{2} \\ &+ a^{j}{}_{3k}c_i^{3} + a^{j}{}_{4k}d_i + a^{j}{}_{5k}d_i^{2} + a^{j}{}_{6k}d_i^{3} \quad i=0,1,2\ldots \mathrm{m},\ \mathrm{j}=1,2\ldots 6,\ \mathrm{k}=1,2,\ldots \mathrm{n} \end{aligned} \tag{4}$$

Correspondingly, in our model, $\mathbf{y} = [Com^{j}_{k,1}, Com^{j}_{k,2}, \cdots Com^{j}_{k,m}]^T$, $\mathbf{X} = [\mathbf{u}\ \mathrm{c}\ \mathrm{c}^2\ \mathrm{c}^3\ \mathrm{d}\ \mathrm{d}^2\ \mathrm{d}^3]^T$ and $\mathbf{a} = [a^{j}{}_{0k}\ a^{j}{}_{1k}\ a^{j}{}_{2k}\ a^{j}{}_{3k}\ a^{j}{}_{4k}\ a^{j}{}_{5k}\ a^{j}{}_{6k}]^T$. Here, m is the number of measurements at each acupuncture point, n is the total point number. We can apply Eq. （3）to calculate all the constants in Eq. (4), and eventually, the comfort level function can be determined for each combination of f and p at an individual point.

## Quasi-Newton optimization method

The most favored optimization methods are the Quasi-Newton methods, which are based on the Newton's methods. Newton's method gives rise to a wide and important class of algorithms that require computation of the gradient vector and the Hessian matrix (H), $\nabla f(x) = \begin{pmatrix} \partial_1 f(\mathbf{x}) \\ \vdots \\ \partial_n f(\mathbf{x}) \end{pmatrix}$ and $H = \nabla^2 f(\mathbf{x}) = (\partial_j \partial_i f(\mathbf{x}))$. Newton's method forms a quadratic model of the objective function around the current iterate $x_k$. The model function is defined by: $f(\mathbf{x}) = f(\mathbf{x_k}) + \nabla f(\mathbf{x_k})^T(\mathbf{x}-\mathbf{x_k}) + \frac{1}{2}(\mathbf{x}-\mathbf{x_k})^T H_k (\mathbf{x}-\mathbf{x_k})$. At the optima, $\partial f(\mathbf{x})/\partial \mathbf{x_i} = 0$. Combing those equations, at the optima,

$$\nabla f = \nabla f(\mathbf{x_k}) + H_{\mathbf{k}}(\mathbf{x} - \mathbf{x_k}) = 0 \tag{5}$$

If H is nonsingular, the iterating formula for finding the optima is:

$$\mathbf{x_{k+1}} = \mathbf{x_k} - H_{\mathbf{k}}^{-1} \nabla f \tag{6}$$

Quasi-Newton methods seek to estimate the direct path to the optimum in a manner similar to Newton's methods. They attempt to avoid second derivatives by approximating H with another matrix, using only first partial derivatives of *f*. In our study, we use the algorithm in MATLAB 6.0 optimization toolbox to perform this process.

## RESULTS

For each acupuncture point k, we can get six fitting functions for six combinations of f and p: $Com_k^j(c, d)$, j = 1,2…6, and k = 1,2…n. n is the total number of points for a treatment. We use the five acupuncture points for headache, B-9, B-56, GV-19, St-36 and LI-4 (Figure 1), as an example to demonstrate our model results for a test on a young healthy male subject (25 yrs). These six functions are similar in shape, which indicates two parameters for stimulation, frequency f and pattern p, may not be sensitive in the electroacupuncture treatment for individual points. In this way, we can stimulate an individual point by adjusting other parameters to achieve the therapeutic effect without changing f and p. In order to decrease the cost and to make the treatment easier and more convenient, for each combination of f and p, we can define the comprehensive effect function at these n points as $\frac{1}{n}\sum_{k=1}^{n} Com_k^j(c,d)$, j = 1, 2...6. The comprehensive effect of our five testing points (n = 5) under $f_1p_1$ is shown in Figure 2. From this function, we can find out the maximum value for the comfort level, ~7, when the current strength is ~5 (~1.1 mA) and duration ~7 s by using Quasi-Newton's method. Comfort level ≅ 7 is the local optimum when c ≅ 5, d ≅ 7 s, f = $f_1$ (50 Hz), and p = $p_1$ (double burst) for the comprehensive effect. After obtaining the comprehensive effect functions for other five combinations of f and p, we can compare the six local optima for the six combinations of f and p to find the global optimum. So far, by using this optimization process on measured data from the subject, we can determine the best combination of four parameters, c, d, p, and f for the treatment. When the subject comes again due to the same illness, we can use this set of values for the treatment. In this way the treatment efficiency is improved.

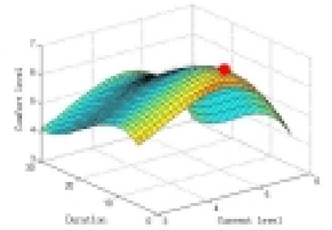

**Figure 2. Comprehensive effect of the 5 points for headache in Figure 1 under $f_1p_1$. The unit for duration is second. "•" indicates the optimal point.**

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