Design and Optimize Solid Microneedle using Genetic Algorithm

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Abstract. Microneedle is an example of Transdermal drug delivery (TTD) device. It is known for eliminating pain and inconvenient intravenous injections. This study presents a work on design microneedle and optimize the designs using Genetic Algorithm (GA). At first, a few solid microneedles are designed with difference parameters, and the considered parameters involve are shape of the needle, materials, size of array, base of microneedle, height of microneedle and number of needles on the microneedle's array base. The microneedle is designed to meet the output requirement which are the total deformation and equivalent stress. Pressure on the tip and size of microneedle base are set to be constant which are 3.18 MPa and 2500 µm x 2500 µm x 50 µm, respectively. Then, optimisation process is conducted on the designs using Genetic Algorithm. Based on the optimisation results, it showed that the optimum structure for the studied microneedles is canonical type, diameter and needle height are 500 µm and 500 µm, respectively, PVA material and involve with 3 number of needles. The results showed that GA is capable to achieve the output requirement and able to optimize the parameter of the microneedle structure.

Keyword: Microneedle, Genetic algorithm, Optimisation and Medical device

1. Introduction

Microneedle is a micron-scale device which has been introduced to increase the ability to deliver a drug while improving the patient compliance. In medical field, microneedle patch is designed to provide an alternative method to conventional needle and syringe [1]. The advantage of this micron-scale device is painless, able to reduce the risk of diseases transmissions through the needlestick injury and wrong way to dispose the needle also to increase the accessibility of the drug into the skin. There are a few types of microneedle such as solid microneedle used for skin penetration, coated microneedle with drug that will dissolves into the skin, polymer microneedle that encapsulated with a drug and fully dissolve in the skin and lastly hollow microneedle which for the drug to infuse into the skin as shown in the Fig. 1 [2].

The studies on Microneedle mostly are of are hollow types, which were designed to be used to deliver liquids such as medicines to blood vessel [3-4]. However, there are solid type of microneedle that also can be applied in medical practice and the studies of it are still lacking. The solid microneedle

is more related to the current implementation which is very similar to lancet to drawing blood. Both adults and children use the same size lancets as there is no lancets specific for baby and adult. A typical stainless-steel lancet has a diameter of 0.3–0.8 mm and penetrates 0.7–2.3 mm, still, the pain is real [5-6]. According to [7], 35 from 37 patients reported that they feel pain when using their own lancet.

The study presents an optimisation work of a few microneedle designs. The designs consist of a few parameters such as shape of microneedle, materials, diameter and height of microneedle. The optimisation is conducted by implementing Genetic Algorithm (GA). GA is a computational model which is inspired by the natural evolution. This algorithm can generate a better solution to the optimisation problem [8-9].

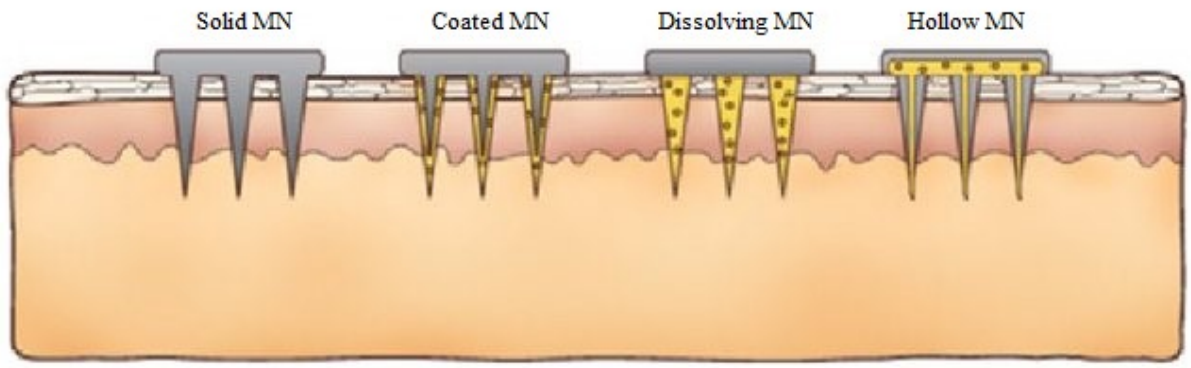

Figure 1. Types of microneedle [2]

2. Description of genetic algorithm

Genetic algorithm (GA) is a computing search technique to find approximate solution to optimisation and search problem. It is inspired by the process of natural selection that belongs to larger class of evolutionary. Two main requirements in GA algorithm; i. genetic representation and, ii. fitness function. Usually, the evolution starts from a population of randomly generated individuals through an iterative process. The population in each iteration is called a generation. The population consists of a set of chromosomes that carry the behaviour and characteristic of the system and design. In each generation, the fitness of every individual in the population is evaluated. The fitness is usually the value of the objective function in the optimization problem being solved. The more fit individuals are selected from the current population, and each individual's genome is modified to form a new generation. The new generation of candidate solutions is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. Below is the typical step of GA algorithm [9]:

i. input GA algorithm
ii. generate initial chromosomes (parents)
iii. measure fitness of parents
iv. GA operation process (mutation, crossover and cut-and-paste)
v. measure fitness of offspring and compare with parents
vi. retain the best population of the chromosome
vii. output of best solution

3. Methodology

The work on optimisation of microneedle has three stages; i. Design the microneedle using a few parameters and variables, ii. Conduct analysis on output requirement which is included total deformation and equivalent stress, and iii. Perform genetic algorithm at the proposed parameters of microneedle. The description methods are illustrated as follow.

3.1 Microneedle parameters design

Six manipulated parameters such as shape of microneedles, materials, array of the needles, microneedle base, microneedle height and number of needles on the microneedle's array base are considered to be analysed as shown in Table 1. These parameters are typical parameters that used when design microneedle [3,9]. While, pressure applied at the tip and microneedle array base parameters are set up to be constant. The constant pressure is used because it is included in the range of the value of penetration pressure of needle at skin [10]. These parameters are considered in order to achieve the output requirement as stated in Table 2.

Table 1. Microneedle parameters structure

Microneedle Design Variables	Range		Types of Variables
	Minimum	Maximum	
Shape of microneedle	Canonical, Pyramidal		Manipulated
Materials used	ABS, PVA, Polyester resin		Manipulated
Size of array	1x1, 2x2		Manipulated
Diameter of the microneedle's base(μm)	500	1000	Manipulated
Height of the needle(μm)	500	1000	Manipulated
Number of the needle	1	3	Manipulated
Pressure applied at the tip of microneedle	3.18 MPa		Constant
Microneedle's array base	2500 μm x 2500 μm x 50 μm		Constant

3.2 Output requirement

In this study, microneedle is required to have a low value of the total deformation and equivalent stress. If these parameters values are higher than strength of microneedle material, hence, it will contribute to the microneedle failure. Table 2 shows the output requirement for the microneedle. Scale weight indicates the level of the necessary to the parameters, level 1 indicates the lowest necessary, and 10 indicates the highest necessary. In Table 2, it shows that the total deformation of necessary is about 6 from 10, and the equivalents stress is set to be 8 from 10.

Table 2. Output requirement.

Parameter	Range		Optimization	Scale Weight
	Minimum	Maximum		
Total Deformation (μm)	-	-	Minimize	6/10
Equivalent Stress (MPa)	-	-	Minimize	8/10

3.3 Genetic algorithm optimization set up

The genetic algorithm optimization is started with the initial population. 30 chromosomes are initialized randomly and a data set is created. In genetic algorithm, each chromosome in the population represent a possible solution for the setting of microneedle design variables. The generated candidate solution is being fed to the Solidwork simulator in order to get the output specification which are the total deformation (μm) and the equivalent stress (MPa). Both requirements are represented as *F1* and *F2* as shown in Equation (1) and (2).

$$F1 = \text{Total Deformation} \quad (1)$$

$$F2 = \text{Equivalent Stress} \quad (2)$$

Each of the measurement have different unit, to overcome this problem, a normalized approach is used to divide the fitness for each specification with the average specification fitness. Equation (3) shows the normalized approach for overall fitness function.

$$F_{tot} = \sum_{m=1}^{z} Wm \frac{Fm}{Fmaverage} \quad (3)$$

where,
m = specification (*F1, F2*);
z = total specification (which = 2);
Wm = weight for output requirement m;
Fm = fitness value for the output requirement m;
Fmaverage = average value of output requirement m at first iteration

The GA control parameter have been proposed based on the former research as shown in Table 3.

Table 3. The proposed GA control parameter.

Control Parameter	Value
Population Size	30
Maximum Iteration	10
Generation Gap	0.9
Crossover Probability	0.7
Mutation Probability	0.3
No. of Crossover	3
No. of Mutation	3

4. Result and discussion

According to [9], the best result is chosen based on the lowest fitness values which is obtained from Equation (3). If the value of F_{tot} is low, it shows better microneedle structure. Table 4 shows the results of optimization. In the table, it consists the best of six individuals that have been processed for optimization. Among these six sets, the second set of individuals is the best optimised result with the total deformation, stress equivalent and F_{tot} values are 0.011 µm, 0.740 MPa and 0.406, respectively.

Fig. 2 shows that distribution of the chromosomes in a GA model. The figure shows the chromosome's distribution is collected from the generation 2, 5, 7 and 10. The maximum generations of this study is 10. Each of the generations consists of 30 chromosomes and in the figure, it is indicated as red dot. It can be clearly seen that at the second generations, the chromosomes are distributed randomly. As the number of the generations increase, the chromosomes will be started to move at the same point. At the second chromosome, it shows that only one of the chromosomes achieve the maximum fitness value meanwhile at the generation 7, there are three chromosome that achieve the maximum fitness value. Lastly, it is observed that almost all the chromosomes are being joined towards the centre of the solution space, which should be converged optimum solution.

5. Conclusion

MEMS device are involved multiple variables which is difficult to be optimized. The improvement of the structure of microneedle have been shown in terms of total deformation and equivalent stress that have been minimized. GA shows that it is capable in finding a satisfactory solution during a suitable amount of time. Furthermore, it is designed to solve the optimization problems. In order to deal with a problems and constraints, future work will propose on the other optimiser and hybridization to solve more complex microneedle structure such as particle swarm optimisation (PSO).

Table 4. Microneedle Structure which have been optimized using GA (Six best individuals).

Design Variable	GA Optimized Value					
	1st	2nd	3rd	4th	5th	6th
Shape of microneedle	Canonical	Canonical	Canonical	Canonical	Pyramidal	Canonical
Materials used	PVA	PVA	Polyester Resin	ABS	ABS	ABS
Size of array	1x1	2x2	1x1	1x1	2x2	1x1
Diameter of microneedle (µm)	500	500	1000	500	500	1000
Height of microneedle (µm)	500	500	1000	500	500	1000
Number of needle on the microneedle's array base	1	3	3	1	3	1
Total deformation (μm)	0.016	0.011	0.049	0.011	0.097	0.028
Equivalent stress (MPa)	0.344	0.740	1.370	0.500	0.217	0.329
F_{tot}	0.418	0.406	0.414	0.409	0.524	0.442

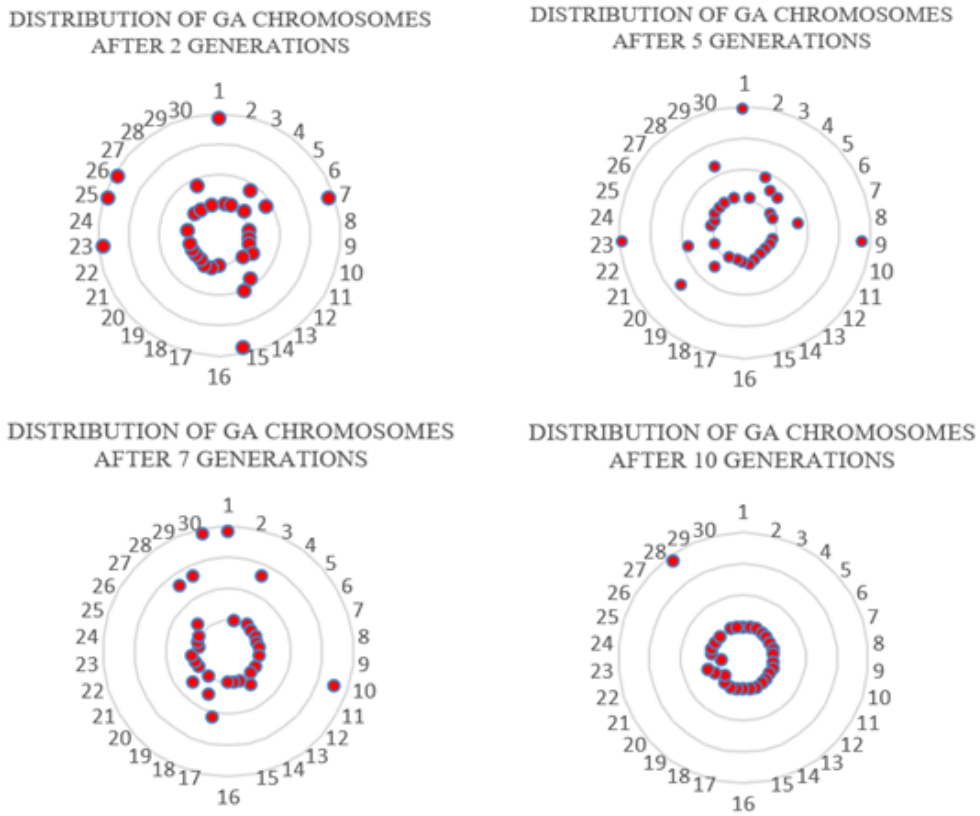

Figure 2. Distribution of the GA model after the 2, 5, 7 and 10 generations.

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