Journal of Engineering Science and Technology
Vol. 10, No.10 (2015) 1293 - 1309

DESIGN AND OPTIMIZATION OF VALVELESS MICROPUMPS BY USING GENETIC ALGORITHMS APPROACH

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Abstract

This paper presents a design optimization of valveless micropump using Genetic Algorithms (GA). The micropump is designed with a diaphragm, pumping chamber and diffuser/nozzle element functions as inlet and outlet of micropump with outer dimension of (5×1.75×5) mm^3. The main objectives of this research are to determine the optimum pressure to be applied at micropump's diaphragm and to find the optimum coupling parameters of the micropump to achieve high flow rate with low power consumption. In order to determine the micropump design performance, the total deformation, strain energy density, equivalent stress for diaphragm, velocity and net flow rate of micropump are investigated. An optimal resonant frequency range for the diaphragm of valveless micropump is obtained through the result assessment. With the development of GA-ANSYS model, a maximum total displacement of diaphragm, 5.3635 μm, with 12 kPa actuation pressure and optimum net flowrate of 7.467 mL/min are achieved.

Keywords: Valveless micropumps, Optimization, Genetic algorithms (GA), Fitness functions.

1. Introduction

In recent years, micropumps are important aspects of microelectromechanical system (MEMS) and microfluidic component because of the ability to control fluids transport in microscale [1-4]. Micropump has to control the flow of fluidic accurately and efficiently. In contrast to other microfluidics devices, micropump

Nomenclatures

A	Narrowest cross-section area of diffuser
E	Young's Modulus
F_1	Fitness function for total deformation
F_2	Fitness function for strain energy density
F_3	Fitness function for equivalent stress
F_4	Fitness function for resonant frequency
F_5	Fitness function for flow rate
F_6	Fitness function for velocity
F_m	Fitness value for the specification m
$F_{maverage}$	Average value of specification m at Generation 1
P	Distributed pressure
P_{in}	Static pressure at inlet
P_{out}	Static pressure at outlet
P_m	Mutation probability
P_x	Crossover probability
Q	Flow rate
R	Diaphragm radius
t	Diaphragm thickness
v	Material's Poisson Ratio
$V_{d/n}$	Fluid velocity of diffuser or nozzle
W_m	Weight for specification m
y_{max}	Diaphragm displacement

Greek Symbols

$\xi_{d/n}$	Pressure loss coefficient of diffuser or nozzle
ρ	Fluid density
θ	Diffuser angle
$\Delta P_{d/n}$	$P_{in} - P_{out}$ of diffuser or nozzle

Abbreviations

AI	Artificial Intelligence
ANN	Artificial Neural Network
CFD	Computational Fluid Dynamic
EHD	Electrohydrodynamic
FPW	Flexural Planar Wave
GA	Genetic Algorithms
ICPF	Ionic Conductive Polymer Film
MEMS	Microelectromechanical System
MHD	Magnetohydrodynamic
SMA	Shape Memory Alloy

is a component that has several operating principles and consists of various actuation mechanisms according to its application.

The ideas of micropumps have been developed since 1980's by Smits et al. [5]. Basically, there are three classes of micropump which are check-valve pump, peristaltic pump and valveless pump. Check-valve micropumps are very sensitive to bubbles and small particles whereas peristaltic pump requires periodic replacement of flexible tubing. Besides, fatigue, wear and fragile are the critical problems that could decrease the micropump performance. In order to prevent these issues, the valveless micropump is used in this research.

Valveless micropump consists of two fluid flow rectifying diffuser and nozzle elements which are connected to the inlet and outlet of a pumping chamber with an oscillating diaphragm. It does not use check-valve to rectify flow. A valveless micropump was introduced by Stemme et al. [6-7] in 1993 using nozzle/diffuser as flow rectifying elements. In 1997, Olsson et al. [8] proposed a valveless diffuser micropump using silicon material. Such diffusers are used to affect flow rectification and thus lead to pumping action in one preferential direction [9].

Generally, micropumps can be mechanical and non-mechanical according to the actuation methods of the micropump. A mechanical micropump needs a physical actuator or mechanism to perform pumping action such as electrostatic, piezoelectric, thermopneumatic, shape memory alloy (SMA), bimetallic, ionic conductive polymer film (ICPF), electromagnetic and phase change [1, 3, 10-12]. On the other hand, non-mechanical micropump needs to transform certain available non-mechanical energy into kinetic momentum so that the fluid in microchannels can be driven into the pumping chamber. The most popular non-mechanical micropumps are magnetohydrodynamic (MHD), electrohydrodynamic (EHD), electroosmotic, electrowetting, bubbletype, flexural planar wave (FPW), electrochemical and evaporation based micropump [1, 3, 12-13].

Recently, micropumps have been designed with various types of actuator used as a device for control on mechanical movement according to the micropump's application. Valveless micropumps are commonly driven by a piezoelectric element attached on the flexible diaphragm. By applying voltage on the piezoelectric material induces deformation on the diaphragm which creates displacement and generates pressure head inside the pump chamber. The ability of the micropump to direct the working fluid inside the chamber is based upon the flow resistance in the diffuser elements. Typical characteristics of piezoelectric actuators include large actuation force, fast response time and simple structure. Figure 1 shows the cross-section of piezoelectric micropump with piezo disc on the diaphragm.

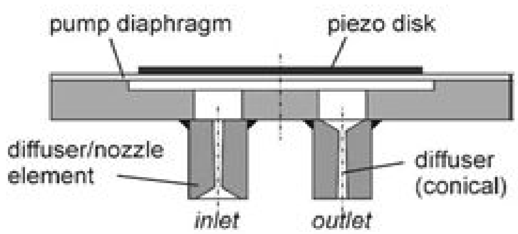


Fig. 1. The cross-section of piezoelectric micropump [14].

Micropump design often involves optimum setting of various design variables. Recently, computational approaches based on artificial intelligence (AI) have been used in biomedical and MEMS applications. Various approaches have been proposed to optimize a micropump with different design parameters. In this study, micropump is designed to optimize the diaphragm and diffuser/nozzle element.

From the literature review, Lee et al. [15] used hybridized neuro-genetic optimization approaches to simulate and optimize the performance of the diffuser elements for applications in valveless diaphragm micropumps. In the research, artificial neural network (ANN) has been trained as a fitness function into GA to optimize the flow rectification efficiency of diffuser element. On the other hand, Hidetoshi et al. [16] proposed GA for the optimization of thickness distribution of micro-membrane. In their study, GA is used to reduce the search space for optimizing the thickness distribution of a micro-membrane. In addition, from the paper of Ravi et al. [17], GA is recommended as the optimization method to optimize the geometrical parameters of peristaltic micropump to improve flow rate.

In this research, the GA technique is introduced to optimize the micropump diaphragm and performance of the diffuser/nozzle elements. The GA is stochastic in nature and has been widely accepted for its capability to obtain near optimum solution without the requirements of complex mathematical formulation. Due to the robustness of GA, this research develops a GA-ANSYS model to run the GA optimization in conjunction with the ANSYS simulation system.

2. Research Motivation

This paper proposed the optimization of valveless micropump using GA. The differences of this work with others are the parameters, structure, materials and design of micropump to be optimized. Furthermore, the micropump structure is designed and analyzed by using ANSYS and optimized by using MATLAB.

Table 1 shows the micropump optimization comparison. In 2009, Lee et al. [15] proposed optimization of valveless micropump diffuser by using the combination of ANN and GA. In 2011, Nikhil et al. [14] proposed optimization of valveless micropump using a SIMULINK model based on its mathematical model. Based on this study, the SIMULINK model is used to obtain diaphragm deflection, volumetric discharge and pressure. The optimization of micropump is often critical. Therefore, only certain optimization scopes like diaphragm or diffuser element are focused in the previous micropump studies. In the optimization of micropump, actuation pressure is a parameter of concern that will cause high power consumption. From Table 1, the actuation pressure applied at micropump by [14] is large. Considering the importance of many design parameters, the current research study optimizes the diaphragm and diffuser of micropump simultaneously together with actuation pressure, strain energy and stress of diaphragm.

3. Working Principle

Working principle of micropump might be the most important to obtain the performance behavior of micropump. The working principle of the diffuser/nozzle elements in a valveless micropump is schematically shown in Fig. 2. In the “supply mode”, the diaphragm moves vertically upwards increasing the chamber volume and causes reduction in the chamber pressure. Pressure difference between the pump chamber and inlet/outlet enables the fluid to flow into the pump chamber from both the inlet and outlet. At this instance, fluid will enter the pump chamber from the inlet through the diffuser direction while at the outlet; fluid will enter through the diffuser element at the nozzle direction instead. For the “pumping mode”, the reverse phenomenon occurs [14, 18-22].

Table 1. Optimization Comparison of Micropump.

Variable	Lee *et.al* (2009) [15]	Nikhil *et.al* (2011) [14]	Current Study
Method	ANN-GA	Without AI	GA
Actuator	Piezoelectric	Piezoelectric	Piezoelectric
Actuation Pressure (kPa)	1 - 20	100	1 – 30
Material	nr	Si, Al, Copper	Si, SiO_2,Steel
Diaphragm Thickness (µm)	nr	100	50 - 100
Diaphragm Diameter (mm)	5	7.5 - 15	4.5 - 5
Diffuser Angle (°)	2 - 25	nr	3 - 30
Diffuser Width (µm)	50 - 100	100	50 – 250
Diffuser Length (mm)	2	nr	1 -1.5
Diffuser Thickness (µm)	150	nr	2000
Flow rate (mL/min)	0.01	40	7.467

nr = not reported

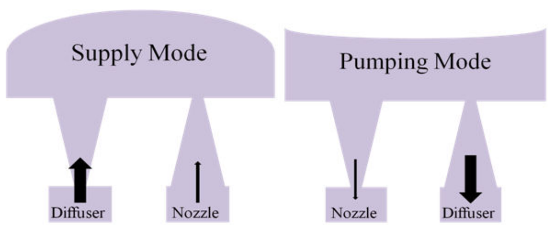


Fig. 2. Pumping principle of valveless micropump.

4. Genetic Algorithm

Genetic Algorithm (GA) is a heuristic computational search technique used to find exact or appropriate optimized solutions based on evolutionary concepts of the survival of the fittest [23-25]. GA is categorized as a population based search method and allows the algorithm to explore and evolve many potential solutions simultaneously. GA starts with an initial population of likely problem solutions and then evolves towards better solutions. Figure 3 shows the general schematic of Genetic Algorithm as a flow chart.

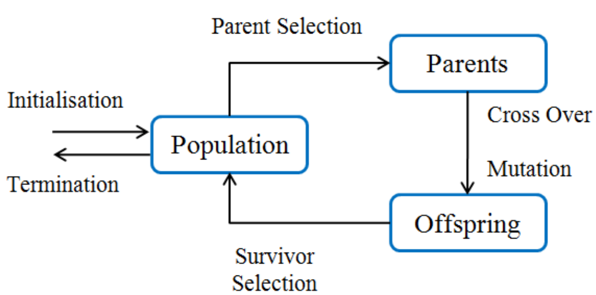


Fig. 3. General schematic of Genetic Algorithm as a flow chart [26].

GA works by combining the genetic properties of two existing parent solutions to create offspring that inherit some characteristic of the parents. The inheritance of genetics and sharing of certain gene characteristic provide chances to produce better children. The concept of survival of the fittest is applied to allow reproduction of better fitness solutions to the next generation with the idea to inherit some good genetic properties from the parents. To reproduce new individuals, GA required a mechanism, so-called genetic operation, to manipulate and modify the genes. The common genetic operators are selection, crossover and mutation.

Throughout the GA reproduction process, each chromosome is rated based on its fitness. Based on the evaluation, the fittest chromosomes have a higher chance to be reproduced to the next generation. The selected chromosomes are manipulated using genetic operators such as crossover or mutation to generate new offspring. Crossover creates two new offspring by randomly choosing a locus and exchanging subsequences to the left and right of that locus between two parent chromosomes. As for mutation, the bits or digits at a particular locus in a chromosome are randomly modified from the parents. Mutation motivates the gene's potential to produce new genetic information that is different from the existing information, facilitating escape from local optimum solutions and expanding search space to find an optimum solution. This process of reproduction continues from generation to generation until a desired solution or maximum evaluationis achieved. Termination criteria such as the satisfaction of the target, achievement of maximum number of generations and convergence of population have been considered in many previous researches. Generally, GA is terminated based on the achievement of these termination criteria. Figure 4 shows the standard procedure of a GA.

GA has been claimed to be able to handle both minimizing or maximizing functions, various types of constraints and linear as well as nonlinear problems. In addition, GA is robust in locating optimum solution and reducing computational effort comparing to some conventional methods. Therefore, this research developed GA-ANSYS model for optimizing valveless micropump.

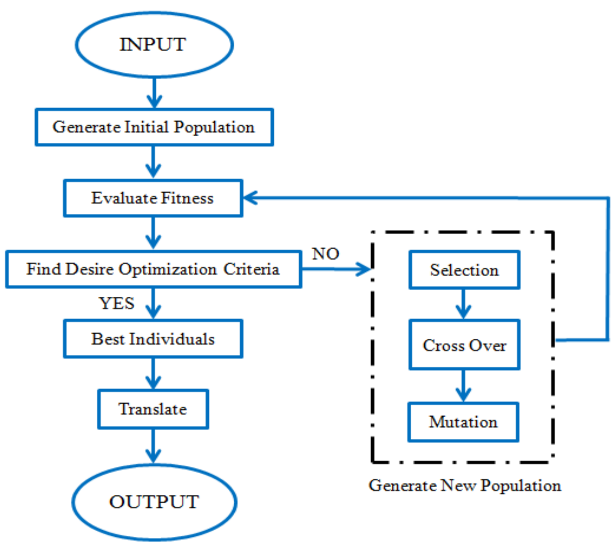


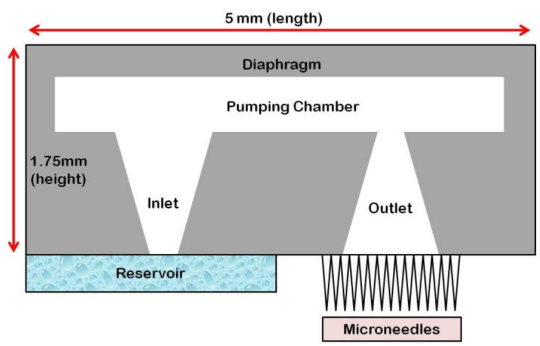
Fig. 4. Standard procedure of a Genetic Algorithm.

5. Methodology

5.1. Design of Micropumps

Basic components of micropump consist of actuator mechanism, diaphragm, inlet, outlet and pumping chamber. These components have their own individual functions to suit the variable applications in MEMS such as biomedical applications, automotive applications, telecommunication applications and etc. [22]. The valveless micropump considered here is actuated by piezoelectric actuation. The pressure produced by piezoelectric elements will make deformation on the micropump diaphragm and cause pressure difference in the pump chamber. Pressure difference between the pump chamber and inlet/outlet enables the fluid flow into the pump chamber from both the inlet and outlet in positive or negative direction.

Figure 5 shows the cross-section view of valveless micropump with outer dimension of micropump is 5 mm length, 1.75 mm height and 5 mm width (5×1.75×5) mm^3. Figure 6 shows the two-dimensional schematic of diffuser/nozzle element of valveless micropump. In this work, the planar diffuser elements are considered as it is easier in fabrication using silicon microfabrication techniques. Besides, the valveless micropump is designed with a pumping chamber, an inlet and an outlet. The pumping chamber is fixed at 150 µm thickness with a circular shape design. The purpose of circular shape design is to reduce leakage of the fluid and bubbles at micropump edges and walls, thereby allows the fluid flowing smoothly from inlet to outlet of micropump.



5 mm x 1.75 mm x 5 mm

Fig. 5. Cross-section view of valveless micropump.

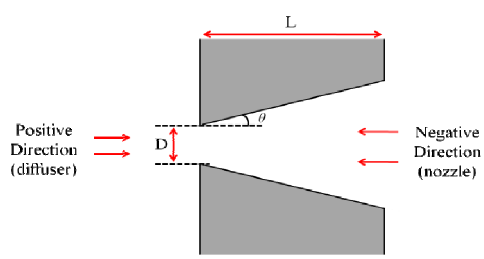


Fig. 6. Two-dimensional schematic of diffuser/nozzle element of valveless micropump.

5.2. Theoretical and Dimensional Analysis of Diaphragm

As stated before, the valveless micropump is actuated by piezoelectric actuation. Actuation pressure causes deflection on piezoelectric material and hence deflecting the diaphragm that attached to it. Thus, fluid will be pumped inside the pumping chamber through inlet to outlet. Oscillation of diaphragm will occur when diaphragm deflects periodically. Displacement (also known as deflection) of diaphragm depends on dimension of diaphragm and actuation pressure produced by piezoelectric actuator. In addition, materials used were affecting the displacement of the micropump's diaphragm according to the materials elasticity. It is important to determine the material, actuation pressure and dimension of diaphragm to find the optimum displacement.

Based on [1], the following equation shows the displacement theory of circular membrane with distributed load (pressure *P*):

$$y_{\max} = \frac{3(1-\mathrm{v}^2)}{16\mathrm{Et}^3} R^4 P \tag{1}$$

where y_{max} is the diaphragm displacement, *v* is the material's Poisson Ratio, *E* is the Young's Modulus, *t* is the diaphragm thickness, *R* is the radius of the diaphragm and *P* is the distributed pressure acting on the diaphragm due to piezoelectric actuation.

5.3. Theoretical and Dimensional Analysis of Diffuser/Nozzle

Diffuser/nozzle elements are important properties of performance for valveless micropump. In order to obtain the best performance of diffuser/nozzle, optimization of the diffuser/nozzle elements is important to determine the maximum pumping rate that the micropump is able to generate. Figure 7 shows the diffuser and nozzle direction for valveless micropump.

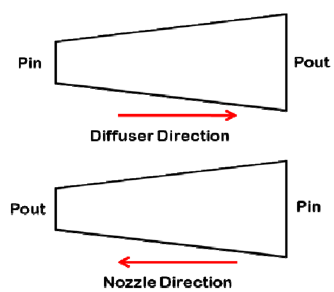


Fig. 7. The diffuser and nozzle direction for valveless micropump [27].

Valveless micropump uses geometry structure of diffuser/nozzle elements to replace cantilever valve or check-valve structure to control and limit the direction of fluid flow [1, 28]. As the fluid flows through the diffuser to nozzle direction, the pressure loss coefficient, ξ of diffuser and nozzle would be stated as the following terms:

$$\Delta P_d = \xi_d \frac{1}{2} \rho V_d^2 \tag{2}$$

$$\Delta P_n = \xi_n \frac{1}{2} \rho V_n^2 \tag{3}$$

where $\Delta P = P_{in} - P_{out}$ is the static pressure, ρ is the fluid density, V is fluid velocity and the subscript d and n refers to the diffuser and nozzle respectively. From continuity equation, flow rate of micropump can be expressed as:

$$Q = A \times V \tag{4}$$

where Q is flow rate of the diffuser or nozzle, A is the narrowest cross-section area of diffuser or nozzle and V is the velocity of fluid through the diffuser and nozzle. Therefore, optimization based on design parameters of diffuser/nozzle elements is necessary in order to obtain the best performance of valveless micropump. In this work, water is used as pumping medium.

5.4. Optimization of Micropump

In the current study, GA is applied to optimize the designed micropump. The solution search mechanism of GA mainly depends on the reproduction operator's namely selection, crossover and mutation. The candidate solutions (chromosomes) with better fitness are selected to undergo the process of crossover and mutation with a crossover probability of P_x and mutation probability of P_m. These operators create diversity to the solution search and thereby lead to the exploration of possibly better candidate solutions.

GA starts with the identification of genotype and phenotype. The genes (design variables) considered are actuation pressure, thickness and diameter of micropump diaphragm, throat width, D, diffuser angle, θ, materials and length of diffuser, L. The flow of GA can be summarized as follow:

Step 1: Initialize population

In the initial stage, the operation parameters such as population size, crossover probability, P_x, mutation probability, P_m, and maximum generation are identified. Then, an initial population of candidate solutions (chromosomes) is randomly generated according to the specific ranges in Table 2.

Step 2: Fitness Evaluation

Fitness of each individual chromosome in population is evaluated. The fitness or objective function establishes the basis for selecting chromosomes that will be mated during reproduction.

Step 3: Reproduction

The fittest chromosomes have a higher chance to be selected for crossover and mutation. In this study, the crossover probability is set at 0.8 and mutation probability is set at 0.2. The created new offspring are used for new population to generate other new parent chromosome.

Step 4: Repeat

Repeat Step 3 until the desired specifications of micropump are achieved or maximum number of generation is met. The required specifications are listed in Table 3.

Table 2. Synthesis Setup of Design Variables.

INPUT	Range
Actuation Pressure (kPa)	1 – 30
Diaphragm Thickness (µm)	50 – 100
Diaphragm Diameter (mm)	4.5 – 5
Throat Width (µm)	50 – 250
Angle, θ (°)	3° - 30°
Material	Silicon, Silicon Dioxide, Steel
Diffuser Length (mm)	1 – 1.5 mm

Table 3. Required Specification for the Micropump Optimization.

Parameters	Value Range		Optimization	Weight
	Min	Max		
Total Deformation (µm)	...	max	Maximize	5
Strain Energy Density (pJ)	...	500	Minimize	1
Equivalent Stress (MPa)	min	...	Minimize	1
Resonant Frequency (kHz)	min	...	Minimize	1
Net Flow Rate (mL/min) ΔQ	...	max	Maximize	5
Velocity (m/s)	...	max	Maximize	1

Table 2 depicts the synthesis setup of design variables (input parameters) for the micropump. Actuation pressure, materials, thickness and diameter of diaphragm are the important elements in optimizing the structure of micropump diaphragm. Likewise, in optimizing the diffuser part; angle, throat width and diffuser length play the important role to obtain the optimum diffuser performance. Table 3 shows the required specifications for the micropump optimization. All these specifications are considered to obtain the best performance of micropump.

Figure 8 shows the process flow of micropump optimization. The process starts from design and simulation of micropump by using ANSYS Workbench. Input parameters generated from GA are used to design and simulate the micropump.

5.5. Objective Function

Objective function is developed to evaluate the fitness of an individual (candidate solution). In fitness evaluation, a penalty value is given to the individual whose specification does not meet the constraint in Table 3. In Table 3, weight for total deformation and net flow rate are given 5 respectively because these two output properties are of higher priority in the design of micropump. For Eqs. (5-10), *F1, F2, F3, F4, F5*and *F6* are fitness function for total deformation (µm), strain energy density (pJ), stress (MPa), resonant frequency (kHz), flow rate (mL/min) and velocity (m/s) respectively.

$$F1 = \frac{1}{total\ \ deformation} \tag{5}$$

$$F2 = \begin{cases} 1000 + strain\ \ energy, if\ \ \ strain\ \ energy > 500 \\ strain\ \ energy, if\ \ \ strain\ \ energy < 500 \end{cases} \tag{6}$$

$$F3 = stress \tag{7}$$

$$F4 = resonant\ \ \ frequency \tag{8}$$

$$F5 = \begin{cases} \dfrac{1}{flow\ \ rate}, if\ \ \ flow\ \ rate > 0 \\ 1000 + (0 - flow\ \ rate), if\ \ \ flow\ \ rate < 0 \end{cases} \tag{9}$$

$$F6 = \frac{1}{velocity} \tag{10}$$

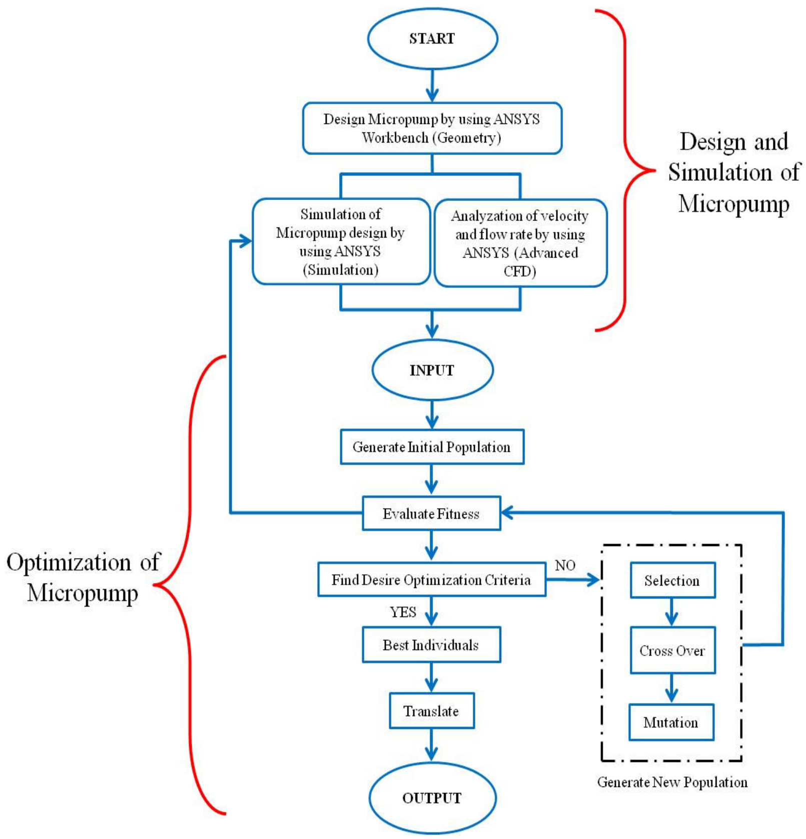


Fig. 8. Micropump optimization flow.

After obtaining all the fitness from different specifications, an objective normalization method used in [29] is applied to calculate the total objective value for individual to prevent bias of fitness value due to different unit of measurement. Equation (11) shows the calculation of total objective value by dividing the fitness value of each specification function by the average value of the specification.

$$F_{tot} = W_m \sum_{m=1}^{z} \frac{F_m}{F_{m_{average}}} \tag{11}$$

where, W_m is the weight for specification m; F_m is the fitness value for the specification m; $F_{maverage}$ is the average value of specification m at each Generation 1. From Eq. (11) and the objective weight given in Table 3, the total summation of all objective value, F_{tot} is derived in Eq. (12).

$$F_{tot} = 5\frac{F1}{F1_{avg}} + \frac{F2}{F2_{avg}} + \frac{F3}{F3_{avg}} + \frac{F4}{F4_{avg}} + 5\frac{F5}{F5_{avg}} + \frac{F6}{F6_{avg}} \tag{12}$$

6. Result and Discussion

Based on the fitness of candidate solutions, GA evolves from generation to generation to obtain better micropump design. Furthermore, GA optimizes the design in a more systematic manner as compared to the conventional design that is solely based on experiment and experience.

Table 4 shows the suggested optimized micropump variables of the five best individuals of GA. According to Table 4, the optimum suggestion for actuation pressure is 12 kPa where all best individuals provide the same value. Likewise the throat width and angle of diffuser are suggested as 50 μm and 6º respectively. The proposed diaphragm thickness ranges from 60-70 μm and diameter ranges from 4.6-4.8 mm. The five best individuals are listed to give the designer a flexibility of design setting. However, the best proposed solution is the solution with the smallest total objective value. Table 5 shows the design specifications achieved by the five best individuals. The best individual with the smallest F_{tot} value shows the attainment of 5.3635 μm total displacement, 203.54 pJ strain energy density, 14.83 MPa stress, resonant frequency at 30.7 kHz, velocity at 7.782 m/s and flow rate 7.467 ml/min.

Table 4. Suggested Optimized Design Variables for Micropump.

Design Variables	GA Suggested Value				
	1	2	3	4	5
Actuation Pressure (kPa)	12	12	12	12	12
Diaphragm Thickness (μm)	60	70	70	70	60
Diaphragm Diameter (mm)	4.8	4.6	4.6	4.6	4.8
Throat Width (μm)	50	50	50	50	50
Angle, θ (º)	6	6	6	6	6
Material	SiO_2	SiO_2	SiO_2	SiO_2	Steel
Diffuser Length (mm)	1	1	1.5	1.5	1

Table 5. Value of the Best Individual Chromosome.

Parameters	Value Range				
	1	**2**	**3**	**4**	**5**
Total Deformation (µm)	5.3635	2.6996	2.6996	2.6996	1.8997
Strain Energy Density (pJ)	203.54	130.57	130.57	130.57	71.32
Equivalent Stress (MPa)	14.83	8.93	8.93	8.93	14.76
Resonant Frequency (kHz)	30.7	30.7	30.7	30.7	20.8
Velocity (m/s)	7.782	7.782	7.782	5.217	7.782
Net Flow Rate (mL/min) ΔQ	7.467	7.467	1.184	1.184	7.467
Total Objective Value	3.4859	3.4898	3.7233	3.7318	3.7732

According to Lee et al. [15], the net flow rate is around 0.01 mL/min at 10 kPa actuation pressure with angle of diffuser is 8º. Cui et al. [10] found that maximum displacement of pump diaphragm is around 0.7 µm at 140 V excitation voltage. This work claims that, higher excitation voltage gives the better result in diaphragm displacement. So the higher voltage gives a significant effect to the higher power consumption. In current study, actuation pressure is a parameter of concern that will cause high power consumption. The lower the actuation pressure lowers the power consumption. Based on Podder et al. [30], the best pump performance is achieved by having an excitation frequency which is close to the pump resonant frequency. The resonant frequency of the micropump is governed by the mass of the fluid in the diffuser/nozzle element and the elastic properties of the pump diaphragm [30]. This current study set the response frequency within 1 – 100 kHz. So, the lower the resonant frequency gives better result in pump performance.

In this work, the strain energy and stress of the diaphragm are considered because these two specifications are important elements in mechanical analysis. Theoretically, strain energy is the energy stored in a body due to deformation and stress is force per unit area. Strain energy and stress are closely related in mechanical analysis. Under small deformation, strain and stress terms are directly proportional to each other according to Hooke's law [31]. It has been discovered that the equivalent stress in five optimum individuals is under 15 MPa (refer to Table 5), while the Young Modulus, E of silicon dioxide, SiO_2 is 73 GPa. So, the stress level is certainly below the yield strength of the materials. This study also tested the effect of materials towards the micropump performance. The material chosen is needed to absorb enough pressure without failure. In this work, silicon, steel and silicon dioxide are tested. The optimum material chosen by GA is silicon dioxide. Figure 9 shows the simulation results for total deformation, strain energy and equivalent stress of the micropump diaphragm when the applied pressure of 12 kPa for the best suggested individual whereas Fig. 10. shows the velocity vectors and flow moving in the pump chamber when applied pressure of 12 kPa for the best suggested individual.

Figure 11 shows the resonant frequency of micropump diaphragm. Analysis result shows a resonant frequency of 30.7 kHz (as suggested by GA) gives a significant effect on deformation. At frequency 30.7 kHz, the diaphragm oscillated at maximum amplitude (maximum deformation). From Fig.11., it can be seen that the mechanical vibration amplitude (deformation) is sharply increased near the resonant frequency. The sharper the resonant peak, the higher the quality factor (Q factor) [31]. Figure 12 illustrates the diaphragm deformation curve according to the diaphragm position. It can be observed that the deformation at the middle position of micropump diaphragm is at the maximum. The deformation amplitude of micropump diaphragm is 5.3635 µm at actuation pressure 12 kPa.

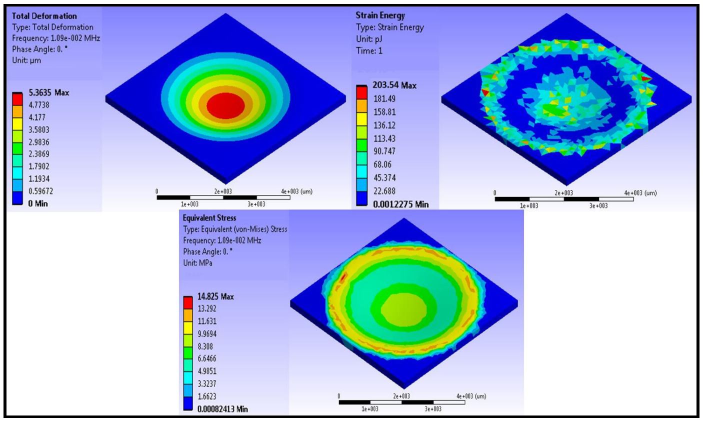


Fig. 9. Simulation results for total deformation, strain energy and equivalent stress of the micropump diaphragm when the applied pressure of 12 kPa for the best suggested individual.

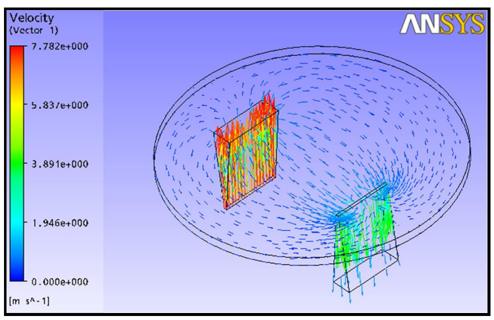


Fig. 10. Velocity vectors and flow moving in the pump chamber when applied pressure of 12 kPa for the best suggested individual.

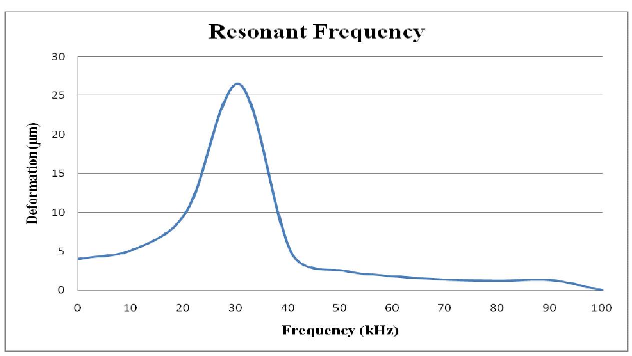


Fig. 11. Resonant frequency of micropump diaphragm.

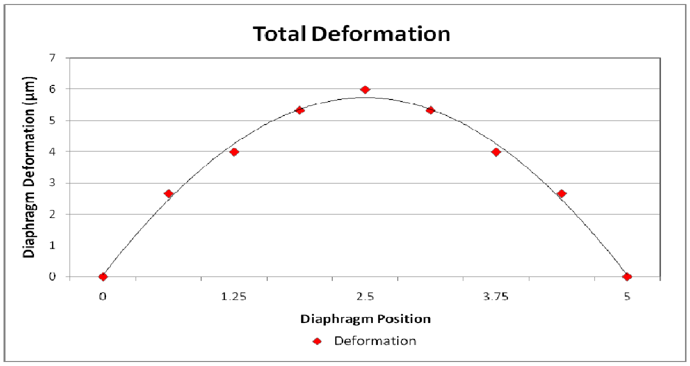


Fig. 12. Deformation curve of micropump diaphragm.

7. Conclusions

A new approach in designing a valveless micropump has been presented. The optimization of valveless micropump has been conducted using GA in conjunction with ANSYS MEMS simulation system. Based on the simulation result, a correlation between optimized diaphragm parameter and actuation pressure are presented. Velocity and fluid flow behavior through diffuser/nozzle element has been simulated using ANSYS Advanced computational fluid dynamic (CFD) for different parameter of diffuser/nozzle elements shown in Table 2.

The performance of valveless micropump depends on the geometry and actuation pressure of the pump. From the simulation result, the optimized result shows an optimum actuation pressure of 12 kPa, net flow rate of 7.467 mL/min, diaphragm displacement of 5.3635 µm and resonant frequency of 30.7 kHz. Therefore, this pump could be used in microfluidic area with high flow rate and low power consumption as compared to previous study.

In future work, the micropump will be fabricated based on the optimum simulation result. The other AI methods such as Particle Swarm Optimization and Ant Colony Optimization as well as hybrid evolutionary techniques will be investigated to solve more complicated micropump designs.

Acknowledgement

The authors thank to the School of Microelectronic Engineering, Universiti Malaysia Perlis (UniMAP) for giving opportunity to do this research as well as to Malaysian Government for funding the project based on FRGS (No. 9003-00261) and FRGS-KETTHA (No. 9003-00349).

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