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Swarm-Based Multi-Objective Design Optimization of Single-Plate Condenser MEMS Microphone

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Summary:

This work presents a multi-objective optimization of MEMS microphone using the PolyMUMPS fabrication technology. The proposed method handles simultaneous optimization of performance parameters such as sensitivity, lower cut-off frequency, resonance frequency, linearity and noise level. An agglomerative method is being used for multi-objective optimization due to its simplicity. While for efficient exploration of complex search space of MEMS microphone, the traditional particle swarm optimizer has been amended by adaptively adjusting its social and personal best coefficients.

Keywords: MEMS condenser microphone, Machine learning for microsystems, An agglomerative method, Particle swarm optimizer, Multi-objective optimization, PolyMUMPS technology

Background, Motivation an Objective

A microelectromechanical system (MEMS) based condenser microphone also known as silicon microphone [1] is widely used as an acoustic wave (sound, pressure waves, etc.) sensor [2]. The applications of a MEMS microphone include hearing aids, vibration, security surveillance instruments, voice control devices and machine conditioned monitoring in industry 4.0 [3,4]. The main reasons for this trend are their small size, compatibility with the standard CMOS process, low noise level, low power consumption, flat frequency response and high sensitivity [5].

Several parameters (sensitivity, lower cut-off frequency, resonance frequency, linearity and noise level) affect the performance of MEMS-based microphones [6]. Hence, multiple objectives need to be explored simultaneously. So, the main objective of this research is to analyze the multi-objective performance optimization of a MEMS-based microphone. Many researchers have worked on the optimizations of the MEMS microphone [1] [6-10] but none of them covered all the optimization parameters at the same time. MEMS design implies a search space complexity, that makes it challenging to find the suitable optimum using traditional optimization algorithms [8]. To handle this problem, metaheuristic and evolutionary algorithms are found promising alternatives for the optimization of such a complex landscape. Additionally, they showed promising results in many engineering optimization problems. For this reason, Particle Swarm Optimizer (PSO) is selected as an evolutionary optimizer for this research. The multi-objective optimization of a microphone is presented in [8] that simultaneously considers the trade-off between noise floor and sensitivity. Similarly, [1] used evolutionary genetic algorithm to optimize three objective functions for MEMS microphone but did not consider linearity and noise level optimization.

Proposed Methodology

The proposed work presents a novel PSO method to optimize a microphone due to its enhanced exploration capabilities through adaptive value adjustment of personal and social coefficients presented in [11]. PSO begins with random initialization followed by the evolution of cost function. Then the particle's personal or global best is being amended in case of better fitness value. The cognitive and social scaling factors are being updated according to the following equations

$$c_1 = c_2 = F(D) = \frac{a}{1+e^{-c(D-d)}} + b$$

where $a = 0.5$, $b = 1.5$, $c = 0.000035 \times$ search range (distance between upper & lower bound of particle), $d = 0$ and $D = P_{p\,or\,g}(k) - x_i(k)$ which represent the distances of the particle to its p_{best} or g_{best} at k_{th} iteration. After that, the particle's velocity and position are being updated, this procedure continues until maximum iterations.

Also, we applied an agglomerative method for multi-objective optimization [12] of a microphone. The weight parameters of all optimization objective for an agglomerative method are defined equally. The 3D structure of a microphone is designed in coventor mems+ [13] using PolyMUMPS technology as shown in Fig. 1.

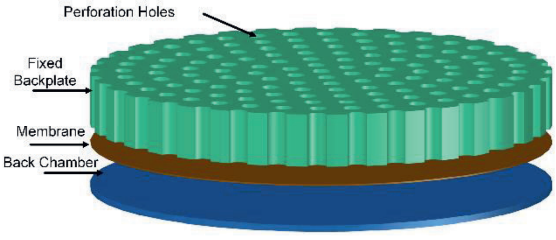

Fig. 1. A 3D structure of condenser MEMS microphone.

Results

The design specification for MEMS microphone and results achieved after optimization along with search variables' range and step size are presented in Tables 1 and 2 respectively. For this experiment we used 10 particles and 100 number of iterations.

Tab. 1: Design specifications for MEMS microphone.

Specifications	Target design	Achieved
Sensitivity	$\geq 5\ fF(Pa)^{-1}$	$\geq 5.34\ fF(Pa)^{-1}$
-3dB low frequency (f_1)	$\leq 20\ Hz$	$3.433\ Hz$
Resonance frequency (f_2)	$\geq 20\ kHz$	$59.71\ kHz$
DC capacitor	$\geq 1\ pF$	$2.13\ pF$
Linearity	$1\ to\ 20\ Pa$	$1\ to\ 20\ Pa$
Noise level	$\leq 40\ pV(Hz)^{-1/2}$	$37.11\ pV(Hz)^{-1/2}$

Tab. 2: Range of search space variables.

Design Variables	Range		
	From	To	Step Size
Membrane thickness	0.5 µm	5 µm	100 nm
Membrane Radius	500 µm	750 µm	100 nm
Backplate thickness	2.5 µm	8 µm	100 nm
Backplate conductive factor	0.5	0.75	0.05
Air gap thickness	1 µm	8 µm	100 nm
Perforation hole radius	2.5 µm	25 µm	100 nm
Perforation distance	2.5 µm	25 µm	100 nm
Ventilation radius	1 µm	5 µm	100 nm

The output sensitivity graph is shown in Fig. 2 which clearly illustrates the flattened response of sensitivity and makes it perfectly applicable for audio frequency applications. The outlook to this work will be the introduction of self-x (self-calibration, self-healing) properties to the MEMS microphone [14] along with its electronic readout circuit to address the problem of device performance tolerances or drift due to static and dynamic effects.

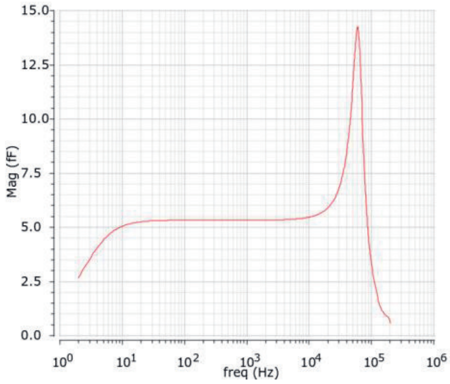

Fig. 2. Frequency response of output sensitivity.

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