Artificial Neural Network-Genetic and PSO Algorithm for Optimization of Multivariate Function: An Application to Lactic Acid Production

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Outline

- Introduction and Motivation
- Objectives
- Artificial Neural Networks (ANN) Model
- Genetic Algorithm (GA) and Particle Swarm Optimization (PSO)
- Application to Lactic Acid production Optimization

INTRODUCTION

Introduction

Lactic Acid

- Lactic Acid is an organic compound that was first discovered by a Swedish Chemist Carl Wilhelm Scheele in 1780 from sour milk
- In 1857, Louis Pasteur discovered the organism involved in lactic acid production
- Then in 1881, first commercial production of lactic acid was started by M/S Clinton Processing Company, Clinton, Iowa (USA)
- Since then lactic acid has found its use in wide range of applications as in pharmaceuticals, cosmetics and textile industries (Roukas and Katzekidou, 1998)
- Lactic acid is also useful in food and beverages and used as a monomer of Poly-Lactic Acid (PLA). According to Grand View Research, Inc. USA, the global demand of lactic acid is expected to rise by USD 9.8 billion by 2025 A.D

Application Lactic Acid

Lactic acid has wide range of applications in diverse fields:

- **Pharmaceuticals:** as pills, for dialysis, medical implants, as a self-dissolving surgical suture and for controlled release of drugs
- **Cosmetics:** moisturizing and antibacterial effects and rejuvenating effects on the skin
- **Textile industry:** as a mordant for dye, as an antifreeze, its derivatives are used as emulsifiers, solvents and plasticizers
- **Food and beverages:** as acidulant, preservative, flavoring, pH regulator, and inhibitor of residual microbes

Lactic Acid Production Process at KU-Biotech LAB

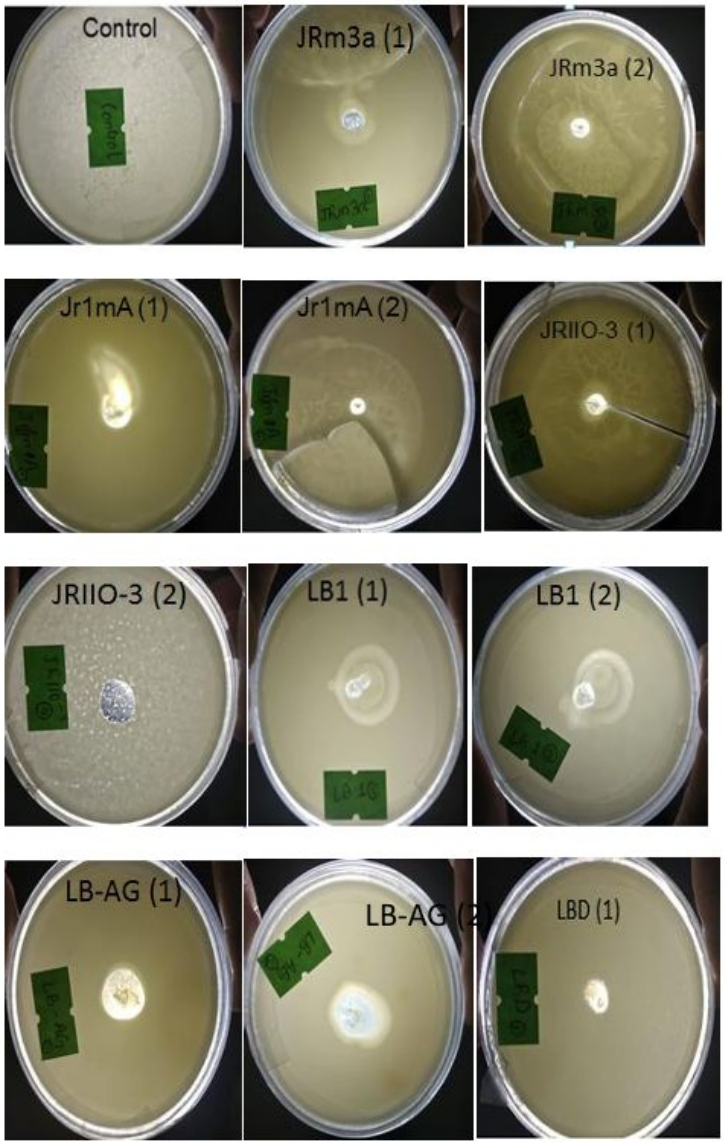
Cheese Whey (Lactose) —Lactobacillus (LB)→ **Lactic Acid**

- 19 different LB strains were received from Shubham Biotech Pvt. Ltd.
- Out of 19 strains, 4 strains were selected based on the Lactic Acid production in M_5 medium
- Out of 4 strains, the strain LB-a has shown the best growth rate in Whey and selected for further experiment for production Lactic Acid by varying the medium 10 different medium factors:

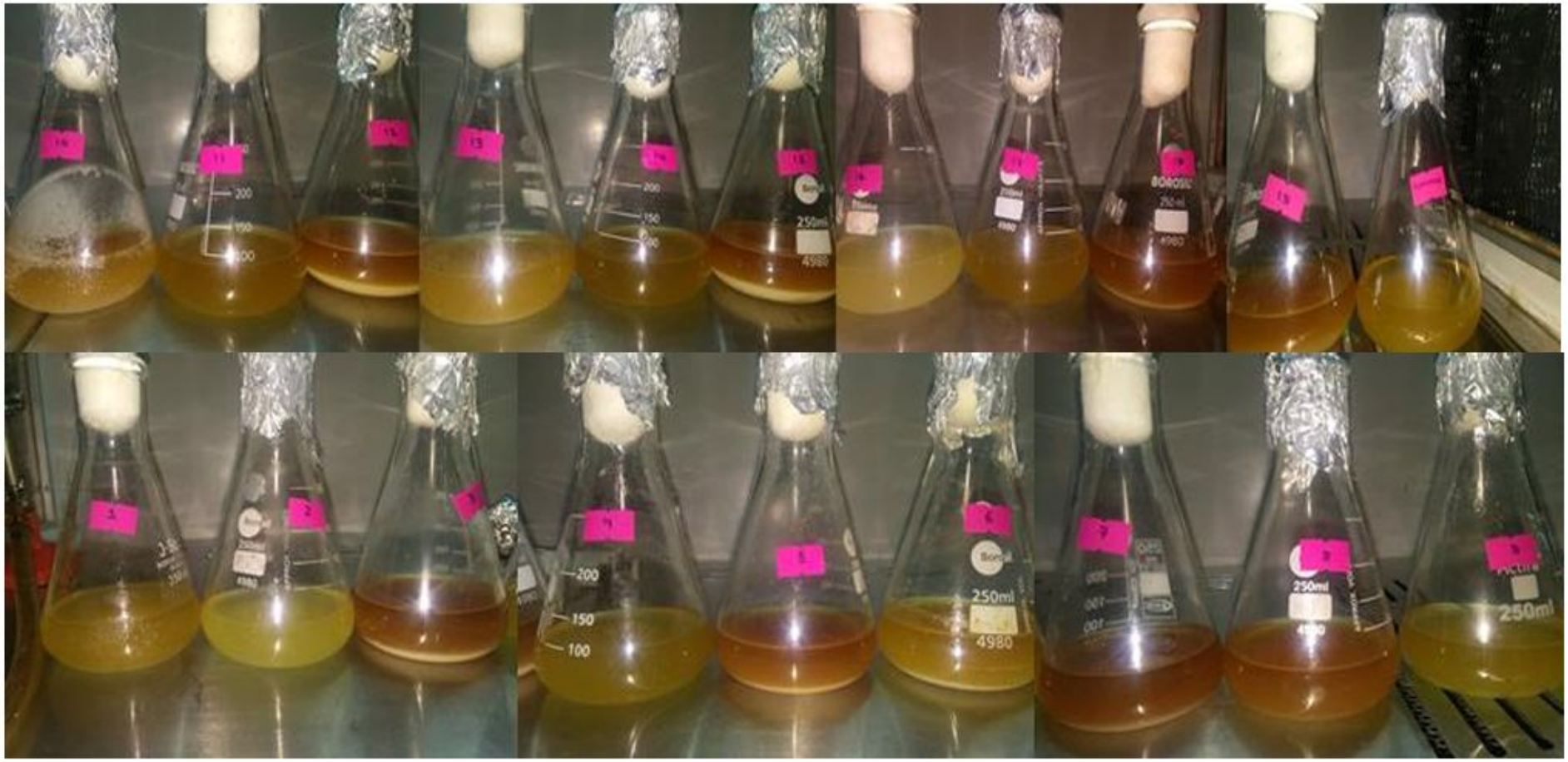
PH, Temperature, $MnSO_4$, $MgSO_4$, K_2HPO_4, $CaCO_3$, Tween80, Glycerol, Yeast Extract, $(NH_4)_2SO_4$

Whey Treatment for Solid Liquid Separations

Selection Process of Lacto Bacillus Strains



Optimization Experimental Setup using LB-a Strain



MOTIVATION

Motivation

Maximizing the Lactic Acid production by choosing the optimal factors through Machine Learning approaches.

- Artificial Neural Network and Genetic Algorithm (GA) /Particle Swarm Optimization (PSO) Algorithms are employed

Mathematical Validation:

- Does ANN model multivariate function?
- Does the function modeled using (ANN) be optimized by Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) Algorithm?
- Does the obtained maxima approximate with the actual maxima?

OBJECTIVES

Objectives

- Model multivariate functions using ANN and Optimization via ANN-GA-PSO approach.

- Optimize Lactic Acid production using hybrid ANN-GA-PSO approach.

ANN MODEL

ANN Model

- A Artificial Neural Network (ANN) is represented mathematically as a function $f(\boldsymbol{x}; \boldsymbol{\theta})$, where $\boldsymbol{x}$ is the input vector to the network, $\boldsymbol{\theta}$ represents the matrix of parameters of the network, and f is a composition of multiple functions
- Let $\boldsymbol{Z}^{(l)}$ be the input vector to layer l, and $\boldsymbol{a}^l$ be the output vector of layer l after applying a non-linear activation function g:

$$\boldsymbol{Z}^l = \boldsymbol{W}^l \boldsymbol{a}^{l-1} + \boldsymbol{b}^l, \text{ and } \boldsymbol{a}^l = g(\boldsymbol{Z}^l)$$

where $\boldsymbol{W}^l$ is the weight matrix and $\boldsymbol{b}^l$ is the bias vector for layer l

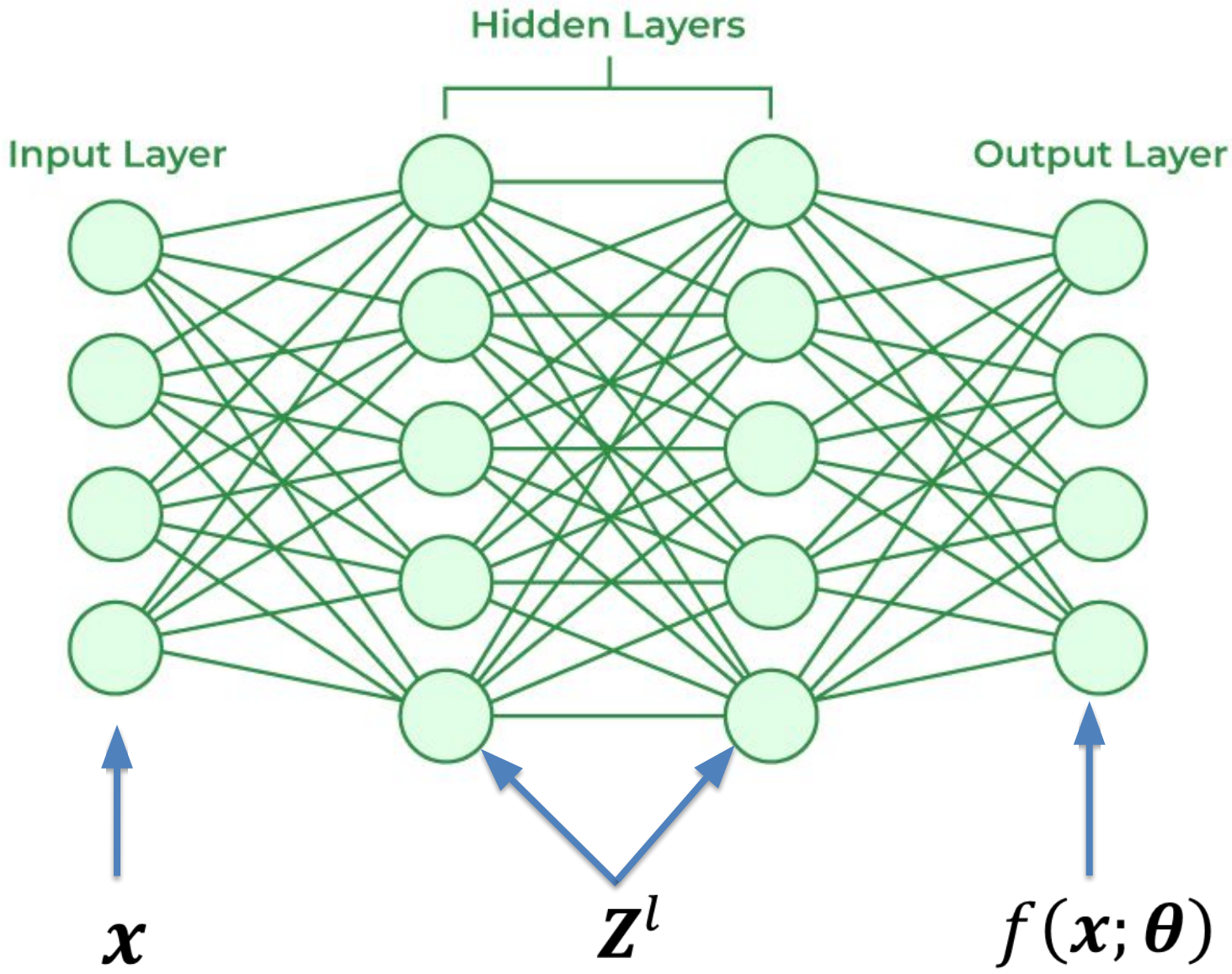
- The input to the first layer is simply the input $\boldsymbol{x}$ that means $\boldsymbol{a}^0 = \boldsymbol{x}$

ANN Model

- The output of the neural network is given by the output of the last layer: $f(\boldsymbol{x};\boldsymbol{\theta}) = \boldsymbol{a}^L = g(\boldsymbol{Z}^L)$ where L is the index of the last layer
- The parameters $\boldsymbol{\theta}$ of the neural network consist of all the weight matrix $\boldsymbol{W}^l$ and bias vector $\boldsymbol{b}^l$, that means $\theta = [\boldsymbol{W}^l, \boldsymbol{b}^l]$
- The Neural Network is trained in such a way that it is to minimize a loss function $J(\boldsymbol{\theta}) = \left\| f(\boldsymbol{x};\boldsymbol{\theta}) - \boldsymbol{y}_{\boldsymbol{AO}} \right\|^2$ which measures the difference between the predicted output $f(\boldsymbol{x};\boldsymbol{\theta})$ of the network and the actual output $\boldsymbol{y}_{\boldsymbol{AO}}$
- This is typically done using back propagation, which involves calculating the gradient of the loss function with respect to the parameters, and then updating the parameters using an optimization algorithm such as stochastic gradient descent:

$$\theta \leftarrow \theta - \alpha \frac{\partial J(\theta)}{\partial \theta}$$, where α is the learning rate

ANN Architecture



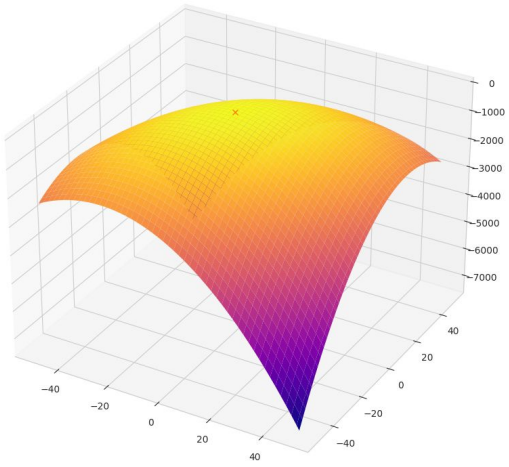
Source: https://www.geeksforgeeks.org/artificial-neural-networks-and-its-applications/

VALIDATION OF ANN MODEL

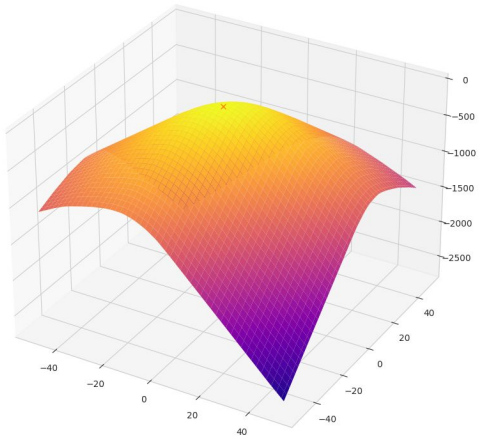
Validation of ANN Model for Mathematical Functions

Validity of the ANN model is checked with two variable function 1:

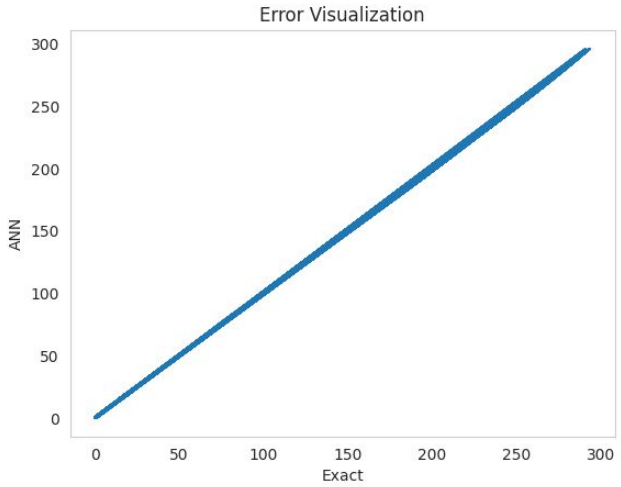
$$f(x, y) = xy - x^2 - y^2 - 2x - 2y + 4$$



Exact Surface Plot



ANN Surface Plot



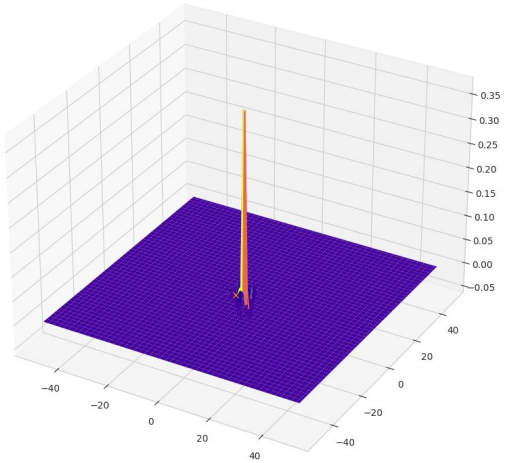
Error Plot

Root Mean Square Error (RMSE) = 0.5179

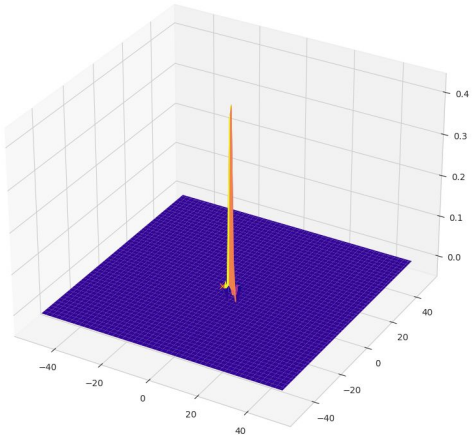
Validation of ANN Model for Mathematical Functions

Validity of the ANN model is checked with two variable function 2:

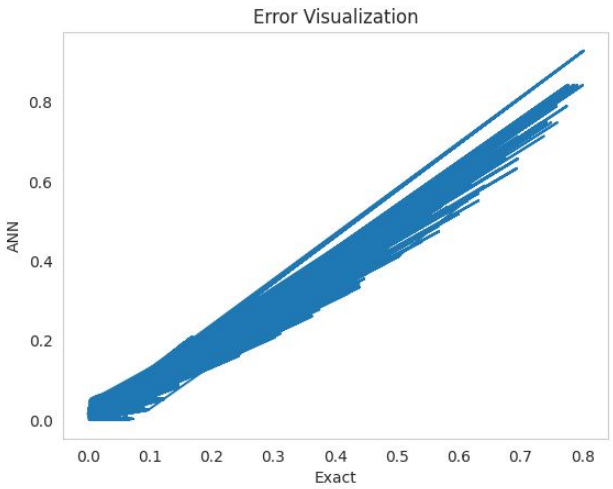
$$g(x, y) = (4x - x^2)\cos y$$



Exact Surface Plot



ANN Surface Plot



Error Plot

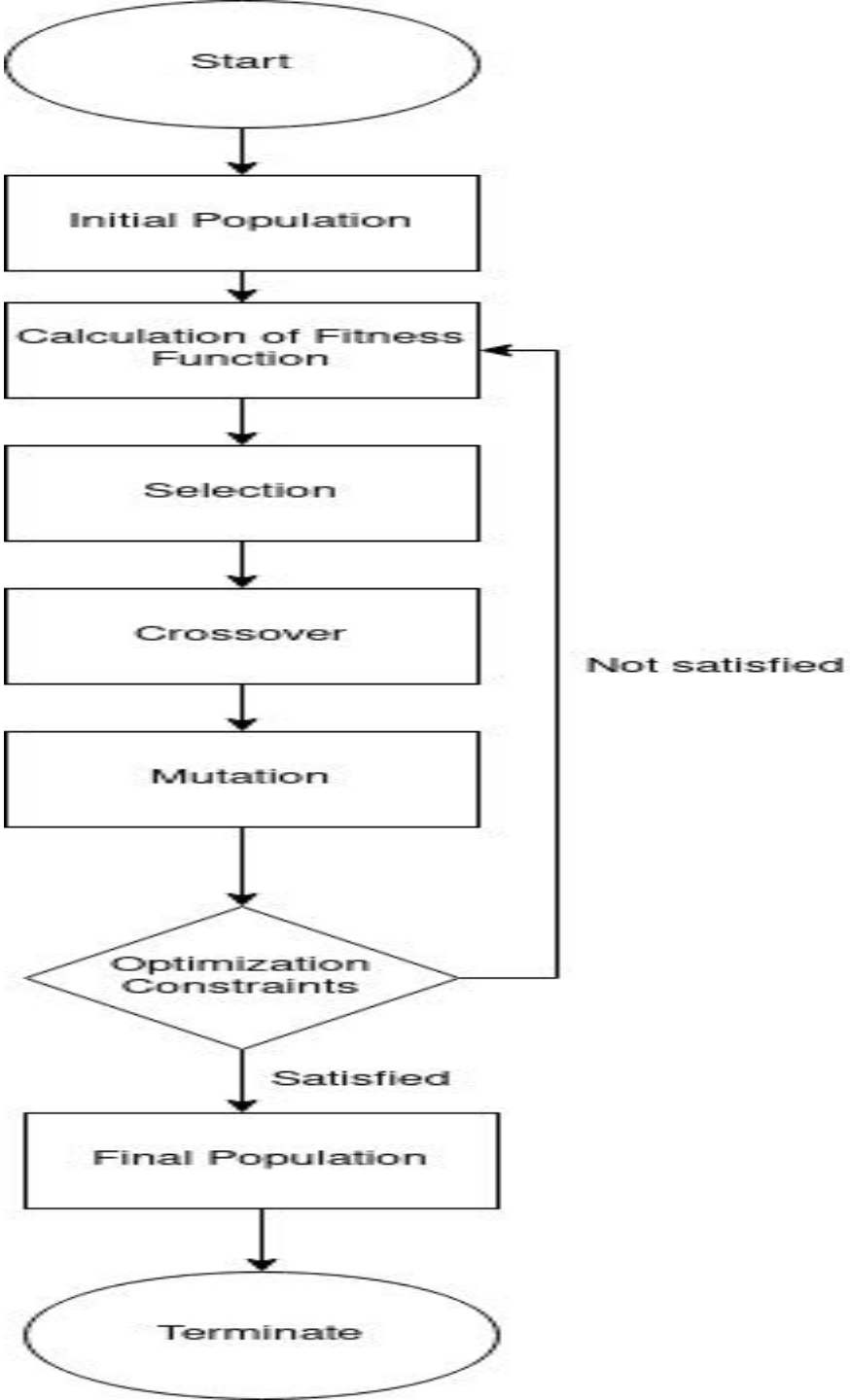
Root Mean Square Error (RMSE) = 3.3096

GENETIC ALGORITHM (GA)

Genetic Algorithm (GA)

A genetic algorithm (GA) is a search algorithm for **optimum value** that works by maintaining a population of candidate solutions and evolving the population over time using operations inspired by biological evolution, such as selection, crossover, and mutation processes to evaluate the fitness function (Objective Function) for optimization process.

Genetic Algorithm Flow Chat



PARTICLE SWARM OPTIMIZATION (PSO)

Particle Swarm Optimization (PSO)

- PSO is a population-based optimization algorithm that was introduced by Kennedy and Eberhart in 1995
- The algorithm is inspired by the collective behavior of social organisms, such as bird flocks and fish schools, which exhibit coordinated movements that enable them to find food, avoid predators, and migrate
- In PSO, a population of particles moves through the search space to find the optimal solution to an optimization problem

Particle Swarm Optimization (PSO)

The basic PSO algorithm can be described as follows:

1. Initialize the population of particles with random positions and velocities

2. Evaluate the fitness (Objective function) of each particle position using a fitness function

3. Update the particle's velocity using the current position, the particle's best position, and the global best position of the swarm. Which is given by

$$v_i(t + \Delta t) = wv_i(t) + c_1 r_1 \left(P_{B_i} - x_i(t)\right) + c_2 r_2 (G_{B_i} - x_i(t))$$

where w is the inertial weight, c_1 are c_2 are cognitive and social parameters, r_1 and r_2 are random values between 0 and 1. P_{B_i} is the personal best position of particle i and G_{B_i} is the global best position of the swarm

Particle Swarm Optimization (PSO)

The basic PSO algorithm can be described as follows:

4. Update the particle's position using the new velocity by

$$x_i(t + \Delta t) = x_i(t) + \Delta t v_i(t + \Delta t)$$

5. If the stopping criterion is met, stop. Otherwise, return to step 2.

Validation of ANN-GA/PSO

Validation of ANN-GA/PSO Approach for Mathematical Functions

Validity of the ANN-GA/PSO Approach is checked with two variable functions:

$$f(x,y) = xy - x^2 - y^2 - 2x - 2y + 4$$

$$g(x,y) = (4x - x^2)\cos y$$

Results are as follows:

Function	Model	Optimization	True Optimal Point	True Optimal Value	Predicted Optima Point	Predicted Optimal Value	
	ANN	GA	(-2, -2)	8	(-1.97,-1.99)	7.598332	
		PSO			(-2.32,-1.66)	7.438	
	ANN	GA	(-5, 3)	45	(-4.89, 3.11)	46.5717	
		PSO			(-5.12, 2.98)	44.89	

APPLICATION OF ANN-GA/PSO IN LACTIC ACID

Application of ANN-GA/PSO in Lactic Acid

We use the real dataset generated from the KU-Biotech laboratory to train the ANN model and optimize the output using GA and PSO. Table below is sample taken from the dataset we used.

	pH	Temperature	MgSO4	MnSO4	K2HPO4	CaCO3	Tween80	Glycerol	Yeast Extract	(NH4)2SO4	Response
0	4.0	40.0	0.1	1.0	5.0	4.0	1.0	0.1	1.0	30.0	1.753890
1	7.0	40.0	1.0	0.1	0.2	4.0	1.0	0.1	10.0	30.0	0.961810
2	4.0	40.0	1.0	1.0	5.0	0.0	0.1	4.0	10.0	5.0	1.852900
3	4.0	30.0	1.0	1.0	0.2	4.0	1.0	0.1	1.0	5.0	1.074965
4	7.0	30.0	0.1	1.0	5.0	0.0	1.0	4.0	1.0	5.0	1.859972

The input for our ANN is (PH, Temperature, $MnSO_4$, $MgSO_4$, K_2HPO_4, $CaCO_3$, Tween80, Glycerol, Yeast Extract, $(NH_4)_2SO_4$) and the output is Response. We trained the neural network model using the above dataset and the predicted set of values is optimized using the Genetics Algorithm(GA) and Particle Swarm Optimization (PSO) algorithm.

RESULTS & DISCUSSION

Results

Results From training ANN model with the above dataset **Root mean square error(RMSE) = 0.378** Based on the optimized medium value shown on Table we got a yield (Optimal Yield) of **3.08 from GA** and **yield of 3.1 from PSO**.

Optimal medium values are estimated by GA and PSO

Medium	Predicted Optimal Value	
	From GA	From PSO
pH	5.22	5.36
Temperature	45.12	46.01
MgSO4	0.73	0.71
MnSO4	0.27	0.29
K2HPO4	2.70	2.68
CaCO3	2.46	2.53
Tween80	0.05	0.05
Glycerol	2.89	2.76
Yeast Extract	13.58	13.39
(NH4)2SO4	7.67	7.78

CONCLUSIONS

Conclusions

- We concluded that a multivariate mathematical function can be represented by a simple ANN model if trained properly with enough datasets
- Meta-heuristic algorithms such as genetics algorithm(GA) and particle swarm optimization(PSO) algorithm can be used to find the optimal solution to an multivariate functions
- The main finding of this research work is that we can use the real-time dataset generated from the lab to train an ANN model and find the optimal solution for maximizing lactic acid production
- We have used the lactic acid production dataset from the KU-Biotech Lab, trained the ANN model using the dataset, and found the optimal requirements of various chemicals for maximizing the lactic acid production
- This method helps to save a lot of time and energy used in multiple hit-and-trial experiments in the lab

THANK YOU