OPTIMIZATION OF MYCELIUM GROWTH USING GENETIC ALGORITHM FOR MULTI-OBJECTIVE FUNCTIONS

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ABSTRACT

Optimization of mycelium growth is a process that are aim to get the optimal value for growing mushroom. Mathematical optimization was typical use for such problem, in which it was supposed to maximizing or minimizing a function. However, for optimizing mycelium growth, there are more than one function that needs to be calculated and solved, making this problem as a multi-objective optimization problem. Multi-objective optimization has become common issues discussed in many fields of study. The traditional method of the optimization requires various degree of understanding and analyzation of multiple things such as the importance of an objective against the other objectives. Trade-off between the objectives, exist for the optimization process. To solve this issues, multi-objective genetic algorithm was chosen as the methodology for this project, specifically using NSGA-ii algorithm. In order to achieve such goal, several research papers related to mycelium and mushroom has been selected as part of the materials for literature review. Several papers related to genetic algorithm and objective optimization were also included. The nitrogen concentration and the mycelium extension rate of are two objectives problem that need to be solved. Through the implementation of selected multi-objective genetic algorithm, NSGA-ii was able to produce pareto front for optimizing both nitrogen concentration and the extension rate of the mycelium. Based on that result, it is concluded that multi-objective optimization problem can be solve using the applied method.

ABSTRAK

Pengoptimuman pertumbuhan miselium adalah proses yang bertujuan untuk mendapatkan nilai optimum untuk menanam cendawan. Pengoptimuman matematik adalah penggunaan biasa untuk masalah seperti tersebut, di mana ianya untuk memaksimumkan atau meminimumkan fungsi. Walau bagaimanapun, untuk mengoptimumkan pertumbuhan miselium, ada lebih daripada satu fungsi dimana ianya perlu dikira dan diselesaikan, menjadikan masalah ini sebagai masalah pengoptimuman pelbagai objektif. Pengoptimuman pelbagai objektif telah menjadi isu biasa yang dibincangkan dalam banyak bidang pengajian. Kaedah pengoptimuman tradisional memerlukan pelbagai tahap pemahaman dan analisa pelbagai perkara seperti kepentingan suatu objektif terhadap objektif lain. Perdagangan antara objektif, wujud untuk proses pengoptimuman. Untuk menyelesaikan masalah ini, algoritma genetik pelbagai objektif dipilih sebagai metodologi untuk projek ini, khusus menggunakan algoritma NSGA-ii. Untuk mencapai matlamat tersebut, beberapa kertas penyelidikan yang berkaitan dengan miselium dan cendawan telah dipilih sebagai sebahagian daripada bahan-bahan untuk semakan kesusasteraan. Beberapa kertas yang berkaitan dengan algoritma genetik dan pengoptimuman objektif juga dimasukkan. Kepekatan nitrogen dan kadar lanjutan mycelium adalah dua masalah objektif yang perlu diselesaikan. Melalui pelaksanaan algoritma genetik pelbagai objektif yang dipilih, NSGA-ii mampu menghasilkan pareto depan untuk mengoptimumkan kepekatan nitrogen dan kadar lanjutan dari miselium. Berdasarkan hasil tersebut, disimpulkan bahawa masalah pengoptimalan multi-objektif dapat diselesaikan dengan menggunakan kaedah yang diterapkan.

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LIST OF ABBREVIATIONS/ACCRONYM USED

GA	Genetic Algorithm
ANN	Artificial Neural Network
EPS	Extracellular Polysaccharide Exopolysaccharide
UMP	*Universiti Malaysia Pahang*
NSGA	Non-Dominated Sorting Genetic Algorithm
GA-ANN	Genetic Algorithm–Coupled Artificial Neural Network

CHAPTER 1

INTRODUCTION

1.1 Introduction

Figure 1 Mycelium of Oyster mushroom (Pleurotus Ostreatus)

Mycelium is a part of fungus or that are consists of long and branching thread-like structures. If large enough, mycelium can be observed with naked eyes. It is used by the fungus to absorb nutrients around its environment. Usually, the larger the mycelium, the large the fungus will be. Industry that commercialize fungus cultivate them in special environment, so that the factor that affect the growth such as temperature and humidity can be controls. In most cases, the factors are controlled so that the mycelium can grow large.

In order to find the best value for the factors, several optimizations have been done toward the growth of the mycelium. Optimization process usually done by analyzing on how the factors affect the mycelium. Using mathematic, mathematical optimization has been implemented into the optimization, where a single function contains a chain of expression that represent the factors. As better optimization process was discovered, mathematical optimization which is a single objective optimization were later then replace with multi-objective optimization.

Through multi-objective optimization, a set of optimum solution can be acquired. There are several methods that can be used for multi-objective optimization. One of it is to convert the objectives into a single algorithms or objective function with a set of weighted sum method. Weighted sum method is effective for single objective optimization problems, and is very effective to be use because the weights in the algorithm or function can be adjusted depending on the priority of the objective, however the method are actually less affective for multi-objective optimization problem.

Another method is by using Genetic Algorithm (GA) as part of the multi-objective function. Genetic Algorithm is a concept that is based on evolution theory that exists to explain the origin of species. In theory, species that are weak and unfit are cease to extinct, while the strongest and fittest will continue to evolve, either through genes mutation or crossover.

1.2 Problem Statement

Optimization of the mycelium growth can be accomplished with the use of genetic algorithm. Implementing the genetic algorithm into the optimization process can be tricky, as no reference or design available to be use directly, therefore understanding how the implementation work can be very useful. Genetic algorithm meant to be use to solve the objectives functions. The solved objectives functions will produce value that should be optimal for mycelium growth. It is not known whether the produced output is optimal or not, so the operation needed to be run multiple times. The output then needed to be analysed first, before it can be confirmed to be optimal.

1.3 Objectives

i) To design a multi-objective optimization using genetic algorithm for mycelium growth

ii) To implement a genetic algorithm for multi-objective optimization for mycelium growth

iii) To validate the optimization of the mycelium growth

1.4 Scope

The scope of this research is to optimize the growth of mycelium growth by implementing genetic algorithm, more specifically by implement NSGA-ii to solve the multi-objectives problem, in which the generated output is only used to create pareto front.

1.5 Thesis Organization

From start to finish this thesis consists five chapters. For chapter 1 discusses about the overall overview of this project. In this chapter, the problem statement was identified and explained. Based on the problem statement, the project objectives were set in this chapter along with the scopes that needs to be cover. The scope was thought carefully to avoid confusion in the future.

Chapter 2 is about literature review. In this chapter we will talk about other research papers that are related to this project's topic. Several research papers will be selected and listed down for review. The purpose of the review is to identify and study the problem statement, methodology that are used and the result of the previously conducted research.

Chapter 3 is about the methodology for this project. Inside this chapter, we will explain about the multi-objective optimization. The flow of the optimization process also be shown here. Later at the end of this chapter, we will discuss about how to verify and test the optimization process.

Chapter 4 is about the implementation. In this chapter, the proposed methodology in chapter 3 are implemented. This chapter will also include some discussion and report on how the implementation are done.

Chapter 5 is about results and discussion. Result that are obtained after the implementation will be presented here. From there, we will discuss about the status of the result, difficulty that are faced during and the future work of this project.

Chapter 6 is about the conclusion of this project. This chapter will conclude this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For this chapter, several journal, article and research paper has been selected to be study and review. To simplify the findings, the research papers were separated into four (4) categories:

- Optimization of mycelium / mushroom
- Genetic Algorithm Optimization
- Optimization of mycelium / mushroom using Genetic Algorithm
- Multiple optimization using Genetic Algorithm

2.2 Optimization of mushroom / mycelium

In one of reviewed research paper, the parameters that were observed for optimization of mycelium are the culture media, temperature, and carbon & nitrogen source. Through the studies, it's discovered that wheat extract agar was the most ideal culture media for the growth of the mushroom. It is also discovered that for the temperature, the most optimum is at 27.50^{o}C *Pleurotus sajor-caju*, and for *Pleurotus florida* it is at 22.50^{o}C. For carbon source, the research stated that Fructose was the best source *P. florida*, and starch for *P. sajor-caju* (Kumar, Kumar, Chand, Kumar, & Nadeem Akhtar, 2018).

There is also a journal discussed on the growth requirement for *L. tuberregium*. The growth of the mushroom was optimized through different use of amino acids, vitamins, and carbon & nitrogen source. The optimization then followed by the ratio of carbon to nitrogen (C:N). The optimization shown significant increment on the biomass of the mushroom through the amendment of glycine (amino acid), thiamine (vitamin). The studies also shown that the mycelia form effectively at 1:3 and 1:5 ratio of C:N with different rational supplement of dextrose and yeast extract. On top of the studies, the research paper also discussed about the antimicrobial activity of *L. tuberregium*. The activity was observed and evaluated by a series of test, using a method known as well diffusion using bacteria and yeast. The raw extract of the *L. tuberregium* shown relatively high antimicrobial activity (Manjunathan & Kaviyarasan, 2011).

Another journal discussed about the techniques that are used to grow mushroom using locally available materials. The technique was evaluated starting from culturing the mushroom to harvesting the mushroom. It is discovered that the mushroom was able to grown successfully inside a potato dextrose agar. For the substrates, the search used Barley straw, Sinar straw, Wheat straw, waste paper, and Gabi wastes. Gabi is a type of cloth that are made of woven cotton and it is commonly dressed in the Ethiopian. It is discovered that substrates made of waste paper and Gabi wastes, albeit alone or in mixture with some saw dust, was able to yield more oyster when compared to substrates made from Barley straw, Sinar straw and Wheat straw. The substrates then were later reused again, and they discovered that the yield is slower when compared to initial substrates. They later realized that during pasteurization, contamination had occurred.

Aside from the substrates, the effects of the pore size, relative humidity, along with temperature on the growth of mushrooms were also evaluated. What has been discovered is a pore size as big as a pin-hole, with temperature as high as 25^{o}C and humidity that is relatively high is very optimal for the growth of the oyster mushroom. The temperature is also suitable and optimal to be used to spawn the mushroom (Tesfaw, Tadesse, & Kiros, 2015).

2.3 Genetic Algorithm Optimization

Among the selected research paper, one of it discussed about the concept and the design procedure of GA as a tool for optimization. Later in the paper, they explore the methodologies of several literature to uncover the applicability and workability of genetic algorithm to optimize the process control applications. The control parameters that involved in process controller are the direct torque control of induction motor drive, the speed control of DC servo motor and the speed control of gas turbine. Genetic Algorithm were applied to the control parameters through simulations that has been run in Simulink package integrated with MATLAB. The obtained results show better optimization of the hybrid genetic algorithm controllers compared to conventional controllers and fuzzy standalone. (Malhotra, Singh, & Singh, 2011)

Under this topic, there is article discussed about the ability of genetic algorithm in fast searching the optimum parameter for ion-optical systems that has various types of reflective mirrors. The article also brought up the issues of how ineffective or impossible the use of analytical methods and direct programming had become. The article also added how consuming and costly the stochastic search of variants is. Later in the article, it is suggested that genetic algorithm can be a very effective addition to current developer tools and software environments, such as SIMION; an electron and ion/electron optics simulator (Karpov, Sysoev, Poteshin, Chernyshev, & Sysoev, 2015).

The journal discussed about genetic algorithm in general, and how the algorithm can be used to generate a useful set of solutions, that can be used for optimization and search problems. It is also explained on how the algorithm generates solution using methods or techniques that are inspired by natural evolution such as genetic inheritance, genetic mutation, genome selection and crossover (Bajpai & Kumar, 2010).

2.4 Optimization of mushroom / mycelium using Genetic Algorithm

Since genetic algorithm plays a huge role in this project, research papers that related to the topic were also selected. Among the few, one of the articles discussed about the use of artificial neural network (ANN) coupled with genetic algorithm to optimize the condition for extracting adenosine from *Cordyceps gunnii*. Adenosine is a chemical that used in medication to treat certain types of irregular heartbeat, nerve pain, pulmonary hypertension, and surgical pain. By using the extraction rate of adenosine as observation point, the selected factors or parameters for the research are the temperature for extraction, the time for extraction and the ratio of solid-liquid. The article stated that through the application of GA-ANN, the obtained result obtained were more dependable, since the obtained value of the statistical parameters are better. From the research they discovered that the optimum parameter for the extraction are 46.7^{o}C, with the ratio of solid-liquid is 1:53 g·mL-1 and the time of extraction of 2.88h. It is discovered that under this condition, the extraction rate of adenosine may be able to reach the highest value which of 4.93 mg·g-1. (Meng et al., 2013)

The next research paper discussed about the optimization of the production Extracellular Polysaccharide Exopolysaccharide (EPS) by a strain of Shiitake mushroom. The optimization is done through the usage of mutation and through the implementation of Genetic Algorithm–Coupled Artificial Neural Network (GA-ANN). The production of EPS is studied through the effect of treatments using ultraviolet irradiation and acridine orange. The study shows that the use of multistep optimization schemes that uses physical-chemical mutation and medium optimization might be able to potentially be an effective plan to improve the yield of bio-actives compound from mushrooms (Adeeyo, Lateef, & Gueguim-Kana, 2016).

2.5 Multiple objective optimization using Genetic Algorithm

A journal discussed about multi-objective optimization problems in general. The journal begins by stating on how objective vector can be scalarised into a single objective where the yielded objective is highly sensitive to the objective weight vectors, but it required users to have knowledge about the underlying problems. The journal also said that on top of all of that, a set of Pareto-Optimal points in the search space may also be required, instead just a single point. Genetic algorithm works with a set of individual solutions that often referred to as population. For multi-objective optimization problems, it is common to use GA schemes to capture a number of solutions simultaneously. The journal also discussed about technique that has been developed to solve these problems such as VEGA, MOGA, NPGA, NSGA, etc., but all of it has its own problems. At the end of the journal, a new approach to solve the problems has been suggested (Mukta, Islam, & Hasnayen, 2012).

Next paper discussed about the optimisation strategy for the process of metal reheating. The paper defined optimum reheating processes as “one that produces heated stock to desired discharge temperature and temperature uniformity while consuming minimum amount of fuel energy”. Inside the article, a framework, which is strategic enough to solve the multi-objective optimization problem for a large size reheating furnace has been presented. For the studies, a model-based multi-objective optimisation strategy by using genetic algorithm was used. The purpose of the model is to determine the optimal temperature trajectory of the bloom as well as to minimise the appropriate cost function. With the respect of the trade-offs, several situations have been evaluated. The results have shown that the developed furnace model can provide useful information and understanding on the behaviour of a dynamic heating with the respect to the multi-objective standard. The paper also deduced that current furnace build practice considered the heated product quality more than the energy efficiency (Hu, Tan, Broughton, Roach, & Varga, 2017).

The last research paper discussed about creating the framework for developing job sequencing method based on multi-objective optimization using genetic algorithm. The methods need to take account of multiple resource constraint. The journal also talks about the Drum-Buffer-Rope methodology based on the Theory of Constraints. This methodology has been combined with genetic algorithm to exploit the system constraints. It is stated that the exploitation might affect the time of lead, the throughput and may increase the costs of the inventory holding. The multi-objective optimization using genetic algorithms were introduced to reduce the lead times to minimum, while also reduce total inventory holding cost to the minimum. The process includes encoding of the problem, representation of the chromosome, selection, genetic operators and then followed by fitness measurements. The queuing times and the throughput are used to measures the fitness. The proposed framework was later compared with other optimization approaches. At the end of the paper, the results were then compared to show the improvement of the proposed framework (Riham Khalil David Stockton, 2012).

2.6 Summary

No	Author	Problem	Finding
1	Kumar, Santosh Kumar, Amarendra Chand, Gireesh Kumar, Tribhuwan Nadeem Akhtar, Md	The optimal parameters of the culture media, temperature, and carbon & nitrogen source for the growth of the mushrooms.	Different species has different set of optimal value.
2	Manjunathan, J. Kaviyarasan, V.	The optimal parameters of amino acids, vitamins, and carbon & nitrogen source.	A species could have a parameter that effect another parameter more.
3	Tesfaw, Asmamaw Tadesse, Abebe Kiros, Gebre	The optimal materials as substrates The optimal pore size, relative humidity, and temperature	Different value of parameters could achieve similar effect as the optimal value.
4	Malhotra, Rahul Singh, Narinder Singh, Yaduvir	To prove how GA can be used as an optimization tools by using it to find the optimal value of the direct torque control of induction motor drive, the speed control of DC servo motor and the speed control of gas turbine.	GA was able to provide optimal value of the parameters. It was compared with other methods, but no actual validation has been provided.
5	Karpov, A. V. Sysoev, Alexander A. Poteshin, S. S. Chernyshev, D. M. Sysoev, Alexey A.	To prove the capability of GA of fast searching the optimum value for the parameters of ion-optical that has various reflective mirrors, versus other methods.	GA was able to find the optimum value, proven its capability in reducing the time consume for searching optimum values.

6	Bajpai, Pratibha Kumar, D R Manoj	To prove how GA can be used as a global optimizing tools by generate useful solution using techniques inspired by nature.	Explanation how GA was inspired by nature.
7	Meng, Fan Xin Wu, Li Yan Wang, Yan Zhen Zhao, Xi Yang, Dong Sheng Teng, Li Rong	To use GA-ANN to find the optimal temperature and time for the extraction and the ratio of solid-liquid to extract adenosine from mycelia.	The method that are used were successful in finding the optimum parameter. Multi-criteria instead of multi-objective.
8	Adeeyo, Adeyemi Ojutalayo Lateef, Agbaje Gueguim-Kana, Evariste Bosco	To use GA-ANN to optimize the production value of the Extracellular Polysaccharide from Shiitake mushroom.	The method was able to optimize the production. Single-objective not multi-objective.
9	Mukta, Saddam Hossain Islam, T M Rezwanul Hasnayen, Sadat Maruf	To explain about problems faced by other GA variants such as VEGA, MOGA, NGA, NSGA, etc. and solve the problem by proposing new approach.	Several different methods using GA has exist.
10	Hu, Yukun Tan, C. K. Broughton, Jonathan Roach, Paul Alun Varga, Liz	To develop an optimized furnace model by using GA to find the optimal value of the discharge temperature and the temperature uniformity that consume the least amount of fuel energy for reheating furnace	Using GA for multi-objective can provide several different result that compensate each other.
11	Riham Khalil David Stockton, Parminder Singh Kang	To create a framework for developing job sequence method based on multi-objective	GA can be use for different application. Mainly for is uncomplicated nature as it mimic nature.

	Lawrence Manyonge Mukhongo	optimization using GA as the function.	

Table 1 Selected research titles along with their author, research problem(s) and result.

From literature review we learnt that optimization has become common problem that can be solve. The successfulness of the optimization depends on the manipulation of the selected variables or parameters during the experiment. From first three of the selected studies, the result of the experiment has proven that optimization can be done and can be successful, but the potential for maximize optimization is unknown. Genetic algorithm can be applied to uncover the potentials by finding the optimum parameters, depending on the goal. The next three of the selected studies explain and shows on how GA were can be used to successfully optimized parameters to reach specific objective. The application of GA in mycelia related research has been shown in the next three of the selected studies. The studies have shown the usefulness and success in applying GA to optimize the manipulated parameters. The last three of the selected studies is to understand on how multi-objective optimization can be achieve using GA. Through this selected study, some similar or better steps and technique will be applied for this project.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, we will discuss about the methodology that are used to optimize the growth of the mycelium. As stated inside the scope of this project (subchapter 1.4), we will be using equations from a research paper, in which the equation will be later be used to create functions. The objective of the functions will be discussed more in subchapter 3.2. This chapter will also show the flow of the optimization process will be done, along with the ways to verify and test the optimization result.

3.2 Objective Function

To ease the process, it is decided that we will be using equation from a research paper titled *"Data on modeling mycelium growth in Pleurotus sp. cultivation by using agricultural wastes via two level factorial analysis"* (Dzulkefli & Zainol, 2018) as the objective functions that needs to be solved.

$$M = 0.60 - 0.023A + 0.019B - 0.029C + 0.029D - 0.14E + 0.041BD - 0.034BE - 0.044CE + 0.044DE$$

Figure 2 Equation for calculation mycelium extension rate.

$$N = 352 + 241.5A + 43B - 0.50C + 50.50D + 21.50E + 59.50AB + 41.00AD - 35.50BC + 47.50BE - 33.00CD - 39.00CE + 32.00DE$$

Figure 3 Equation for calculating nitrogen concentration.

Figure 2 and 3 are the equations that were obtained from the research paper. Table 2 describe the expression or variable that are used in the equations.

Variable Name	Description
M	Mycelium extension rate (cm/day)
N	Nitrogen concentration (mg/L)
A	Type of substrate
B	Size of substrate
C	Mass ratio of spawn to substrate (SP/SS)
D	Temperature
E	Pre-treatment of substrate

Table 2 Variables from the equations and their descriptions.

The purpose of the function is to use it together with an optimizing algorithm, such as genetic algorithm. A function usually consists of a chain of factors that uniquely different than each other, and the factors is the observable and manipulated value that affect the growth of the mycelium. Generating such function is not easy, because each of the parameter need to be converted into a variable so that it can be use inside the objective function.

Most of the factors has their own constant value, or weight that determine how much does it affect the function, so all of it must also be separated from one another. The purpose of separating these factors, is so that we can properly identify what affecting the function the most, and which affect the least.

3.3 Using Genetic Algorithm for Objective Functions

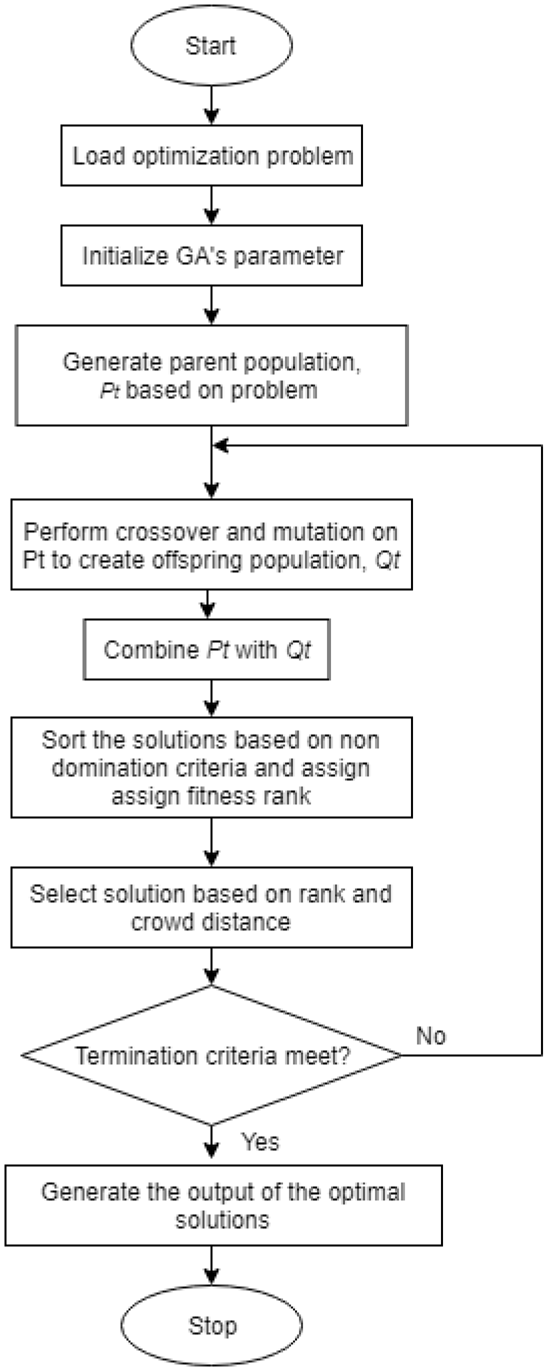

Figure 4 Flowchart of the optimization process.

This chapter will only explain the optimization process in theoretical manners. There will be slight difference between the explanation in this chapter with the actual implementation. The detailed explanation of the actual optimization process will be documented in chapter 4. Below is the rough explanation of the involved steps as shown in figure 4.

1. Firstly, the optimization problem will be loaded into the project. The problem contains the objectives and factors that will be used to create solutions.

2. Initialize the parameter of the Genetic Algorithm such as the index and the probability for the genetic crossover and mutation.
    a. Genetic Crossover is to simulate the interchange of genetic(s) between two chromosomes.
    b. Mutation is to simulate the alteration of genetic(s) of a chromosome after crossover.

3. Generate a parent population, Pt with solution based on loaded problem.
    a. This parent population will be used to generate an offspring population (step 4) through crossover and mutation.
    b. This parent population will also be used to create new population together with the child population (step 5).

4. Perform crossover and mutation to the population.

5. Combine the parent population with offspring population.

6. Sort the population and assign ranking.
    a. Sorting method is non-dominate sorting.
    b. Solution that are the best will be given higher rank.

7. Selection of the best solutions as the new parent population based on rank and crowd distance.
    a. If best solutions with similar rank exceed the population limit, then the solutions will be selected using crowd distance to fit into the limit.

8. Check if termination criteria meet.
    a. If yes, repeat the process starting at step 4 with new parent population obtained in step 7.
    b. If no, continue to step 9.

9. Generate the output of the optimal M and N.

The optimization process actually used the NSGA-ii algorithm from a Java-Based framework called jMetal. NSGA-ii is a very famous algorithm to use to solve multi-objective optimization problems. The algorithm with slightly be modified so it can be used for this project.

3.4 Validating the results

Validating the result can be done by plotting the generated data sets into a scatter graph of M and N. The purpose of the graph is to observe the distribution of the between the objectives. If the scatters are widely spread, then the results are wrong. But if the result has a distinct pattern such as like an arch, then the result could possibly be correct. The graph will be plotted inside Microsoft Excel 2016.

For further validating the objective functions will run through the genetic algorithm multiple times, with at least 5 different values of combined parameters. The involved parameters and its value will be discussed more during the implementation in chapter 4. The pattern of the generated result should be same with slight differences in distribution, even though 5 different values of parameters are used.

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3.5 Hardware and Software

For this project several hardware and software are use. Table below show the list of hardware and software used in this project.

Hardware	Quantity	Specification	Purpose
Personal Computer A	1	Intel Core i7 4710HQ 2.50GHz 8 GB RAM Windows 10 Pro 64-bit Operating System	A Laptop. To write and document this project.
Personal Computer B	1	Intel Core i5 6500 3.20GHz 16 GB RAM Windows 10 Pro 64-bit Operating System	A Desktop. To execute the algorithm for the optimization. Feeding the algorithm with huge data could potentially causes the PC to be temporary unusable.

Table 3 Hardware description used for this project.

Table 5 shows the list of hardware used in this project. The hardware were available since the beginning of this project.

Software	**Description**	**Purpose**
Java Development Kit	Software development environment that is used to develop Java applications.	To use provide runtime environment, interpreter/loader and compiler for the algorithm for the optimization process.

Software	Description	Purpose
Eclipse	Eclipse is an integrated development environment. It is one of the commonly used Java IDE.	To use, design, modify and execute the algorithm and coding for this project.
jMetal	Metaheuristic Algorithms written in Java language, and it is an object-oriented Java-based framework for multi-objective optimization.	Provide framework that contains NSGA-ii algorithm. This framework also contains the reference for pareto front.

Table 4 Software description used for this project

Table 6 shows the description and the purposes of the software used for this project.

3.6 Gantt Chart

Since this project will be done during the final year of my study, this project will be break into two parts. Part 1 will be done in *Projek Sarjana Muda 1* (PSM 1), which requires me to complete chapter 1 until chapter 3. Part 2 will be done in *Projek Sarjana Muda 2* (PSM 2), in which it requires me to complete the last two chapter along with my thesis.

With this I attach the Gantt chart for this project. (REFER APPENDIX A).

CHAPTER 4

IMPLEMENTATION

4.1 Introduction

This chapter discussed about process that happened during implementation of this project. Methodology that are propose in previous chapter will be used during this stage.

4.2 Using Objective Function

The objectives functions designed in chapter 3 will be used for implementation in this chapter. These objective functions will be written inside a Java file. The framework refers the file as a problem, a problem that has objective functions that needs to be evaluate and solve.

```java
/** Evaluate() method */
public void evaluate(DoubleSolution solution) {
  double[] f = new double[getNumberOfObjectives()];
  double M = this.evalM(solution);
  double N = this.evalN(solution);

  f[0] = M;
  f[1] = N;

  solution.setObjective(0, f[0]);
  solution.setObjective(1, f[1]);
}
```

Figure 5 Function to call for evaluating the objective functions

Figure 5 shows the function for that are used to call other function for evaluating M and N. Inside this function, an array for storing double type value are declared with the array size being the number of objectives. Since optimization of mycelium growth has two objectives, the function getNumberOfObjectives() will return the value 2. After declaring arrays, the function will call for other functions to evaluate M and N. The evaluation process will be explained later in this subchapter. At the end of the evaluation process, the value was then stored inside the solution set.

```
    //Mycelium Extension rate (cm/day)
    private double evalM(DoubleSolution solution) {
    double m = 0.0;
    double A,B,C,D,E;

    A = solution.getVariableValue(0);
    B = solution.getVariableValue(1);
    C = solution.getVariableValue(2);
    D = solution.getVariableValue(3);
    E = solution.getVariableValue(4);

    m = 0.60 - (0.023*A) + (0.019*B) - (0.029*C) + (0.029*D) - (0.14*E)
        + (0.041*B*D) - (0.036*B*E) - (0.044*C*E) + (0.044*D*E);

    return m;
  }
```

Figure 6 Objective function for Mycelium Extension Rate

```
    //Nitrogen Concentration (mg/L)
    public double evalN(DoubleSolution solution) {
    double n= 0.0;
    double A,B,C,D,E;

    A = solution.getVariableValue(0);
    B = solution.getVariableValue(1);
    C = solution.getVariableValue(2);
    D = solution.getVariableValue(3);
    E = solution.getVariableValue(4);

    n  = 352 + (241.5*A) + (43*B) - (0.50*C) + (50.50*D) + (21.50*E)
             + (59.50*A*B) + (41.00*A*D) - (35.50*B*C) + (47.50*B*E)
             - (33.00*C*D) - (39.00*C*E) + (32.00*D*E);

    return n;
  }
```

Figure 7 Objective function for Nitrogen Concentration

The function EvalM() and EvalN() has similar structure in it. Inside the function, there are five variables that represent five factors that affect the growth of mycelium. The function getVariableValue(*n*) will return a random value. The different *n* value is to make sure that getVariableValue() return different value, because the variable can't have a value that equal to other variable. The function getVariableValue() is hardcoded into the framework, making modification for custom range of value almost difficult.

4.3 Implementing Genetic Algorithm

The algorithm for NSGA-ii is already available in the framework. Figures 8 shows snippet of the algorithm.

```
problem = ProblemUtils.<DoubleSolution> loadProblem(problemName);

double crossoverProbability = 0.7 ;
double crossoverDistributionIndex = 20.0 ;
crossover = new SBXCrossover(crossoverProbability, crossoverDistributionIndex) ;

double mutationProbability = 0.3 / problem.getNumberOfVariables() ;
double mutationDistributionIndex = 20.0 ;
mutation = new PolynomialMutation(mutationProbability, mutationDistributionIndex) ;

selection = new BinaryTournamentSelection<DoubleSolution>(
    new RankingAndCrowdingDistanceComparator<DoubleSolution>());

algorithm = new NSGAIIBuilder<DoubleSolution>(problem, crossover, mutation)
    .setSelectionOperator(selection)
    .setMaxEvaluations(10000)
    .setPopulationSize(100)
    .build() ;

AlgorithmRunner algorithmRunner = new AlgorithmRunner.Executor(algorithm)
    .execute() ;
```

Figure 8 Snippet of coding for using NSGA-ii

The algorithm first read the problem that needed to be solve. Subchapter 4.2 had discussed about creating the problem file. The variable “problemName” contains the path to the problem file. The algorithm was run for 5 times. Each execution has different parameters values. The purpose for it and the parameters value for each of the run are further discussed later in subchapter 4.4.

4.4 Genetics Algorithm's Parameter

The parameter of the genetic algorithm needed to be set first. Below are the determined parameters of the genetic algorithm and its value.

Population	Max Evaluation	Crossover Probability	Mutation Probability
100	1000	0.5	0.1
100	1000	0.7	0.1
100	1000	0.5	0.2
100	1000	0.7	0.2
100	1000	0.7	0.3

Table 5 Parameters Value of the Genetic Algorithm

As previously mention and presented in the table, the algorithm will run 5 times with different combination of crossover and mutation probability. The purpose of this is to observe the distribution of the generated result and to compare if there were any significant differences between the generated data set. At the end of each run, there will be two data set; one of it contains the answer of the objective functions, and the other contains value for the factors that are used to solve the objective functions. The data set that contains the answer will be use as a reference point to achieve desired optimal mycelium growth. This reference point is also known as pareto front.

For easier observation and better understanding, the pareto fronts are presented in form of graphs. The graphs are presented in chapter 5.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter will discuss about the result from the implementation. This chapter will also include some discussion regarding problems encountered during this project.

5.2 Generated Data Set

Data sets that are generated, especially the answer to the objective answer are usually hard to read. For better understanding and easier readability, the data sets are plotted into scatter graphs.

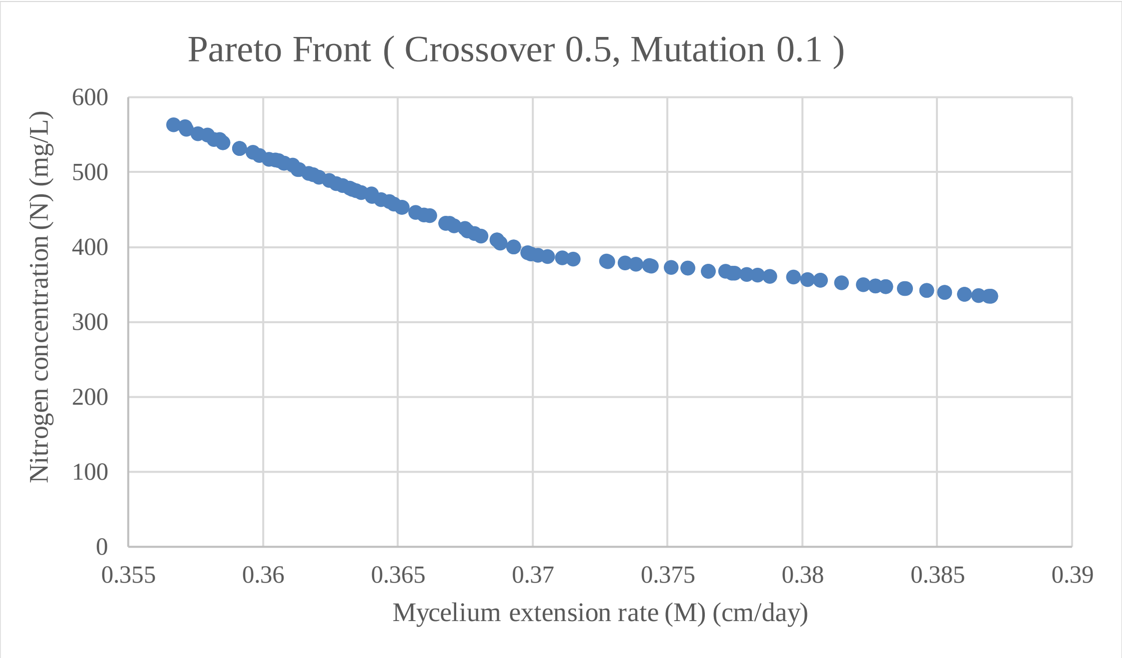

Figure 9 Generated result with crossover probability of 0.5 and mutation probability of 0.1

Figure 9 shows that the highest value of nitrogen concertation is 563.50 mg/L with the lowest value of mycelium extension rate 0.357 cm/day.

The highest mycelium extension rate is 0.387 cm/day, with the lowest nitrogen concentration at 334.05 mg/L.

If the goal is to get the best out of both of it, then from the data set we can get 385.57 mg/L of nitrogen concertation and 0.371 cm/day of mycelium growth.

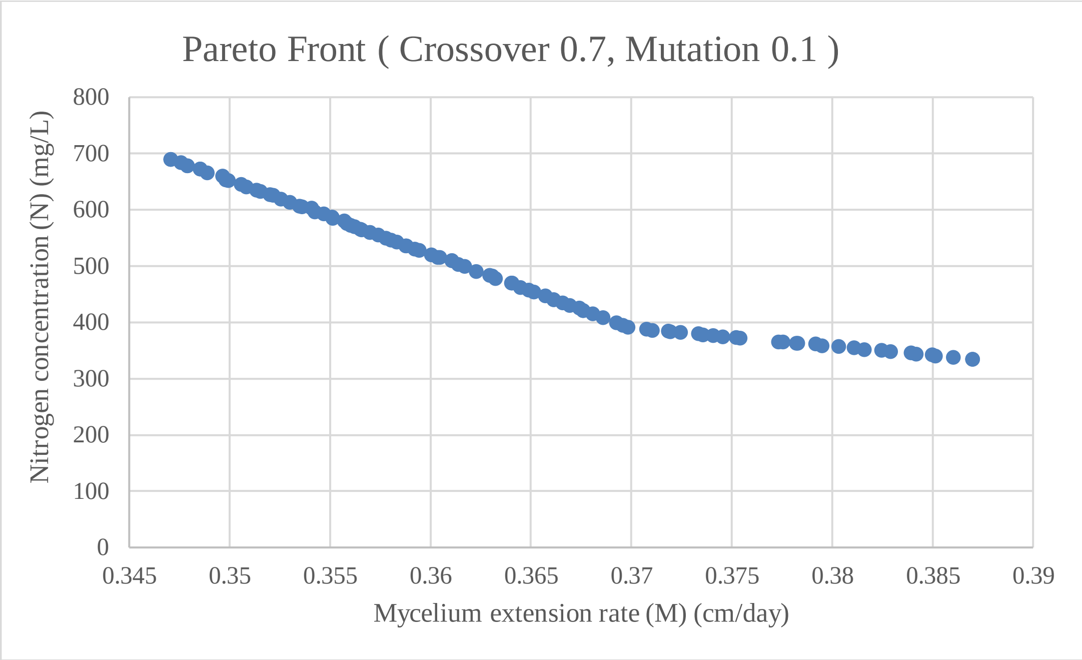

Figure 10 Generated result with crossover probability of 0.7 and mutation probability of 0.1

Figure 10 shows that the highest value of nitrogen concertation is 689.93 mg/L with the lowest value of mycelium extension rate 0.347 cm/day.

The highest mycelium extension rate is 0.387 cm/day, with the lowest nitrogen concentration at 334.13 mg/L.

If the goal is to get the best out of both of it, then from the data set we can get 387.38 mg/L of nitrogen concertation and 0.371 cm/day of mycelium growth.

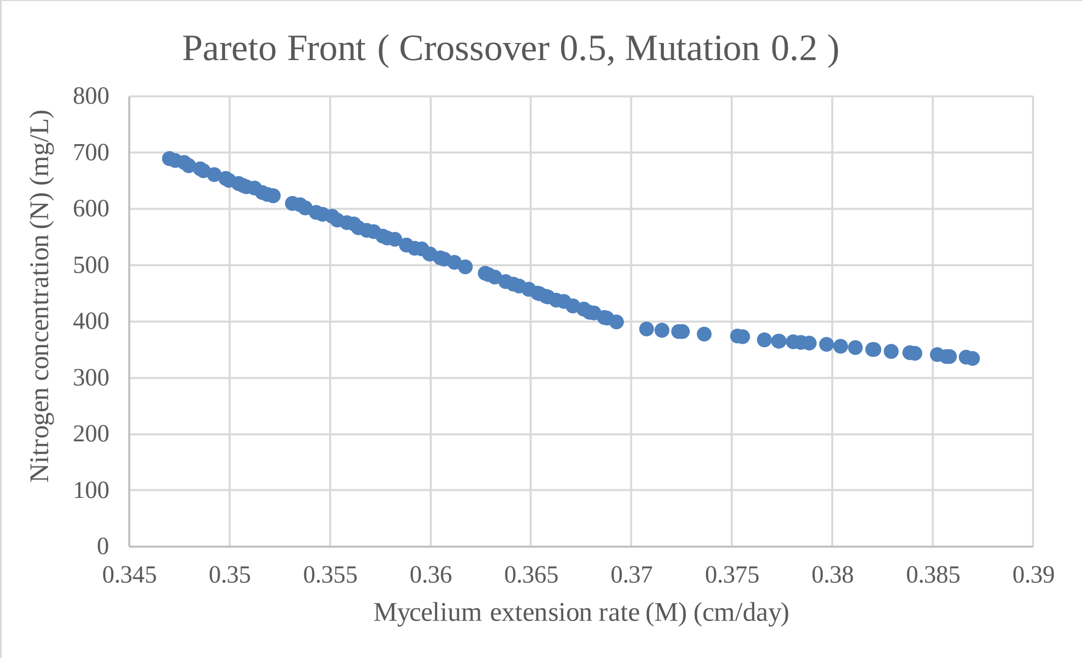

Figure 11 Generated result with crossover probability of 0.5 and mutation probability of 0.2

Figure 11 shows that the highest value of nitrogen concertation is 689.79 mg/L with the lowest value of mycelium extension rate 0.347 cm/day.

The highest mycelium extension rate is 0.387 cm/day, with the lowest nitrogen concentration at 334.06 mg/L.

If the goal is to get the best out of both of it, then from the data set we can get 398.77 mg/L of nitrogen concertation and 0.369 cm/day of mycelium growth.

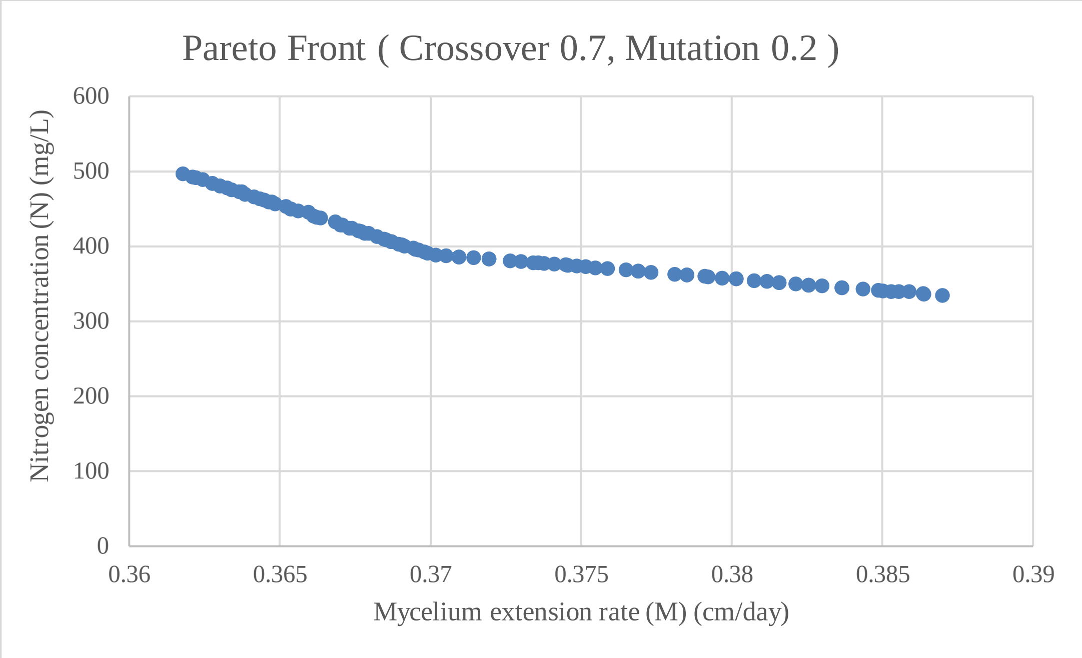

Figure 12 Generated result with crossover probability of 0.7 and mutation probability of 0.2

Figure 12 shows that the highest value of nitrogen concertation is 496.87 mg/L with the lowest value of mycelium extension rate 0.362 cm/day.

The highest mycelium extension rate is 0.387 cm/day, with the lowest nitrogen concentration at 334.02 mg/L.

If the goal is to get the best out of both of it, then from the data set we can get 388.45 mg/L of nitrogen concertation and 0.370 cm/day of mycelium growth.

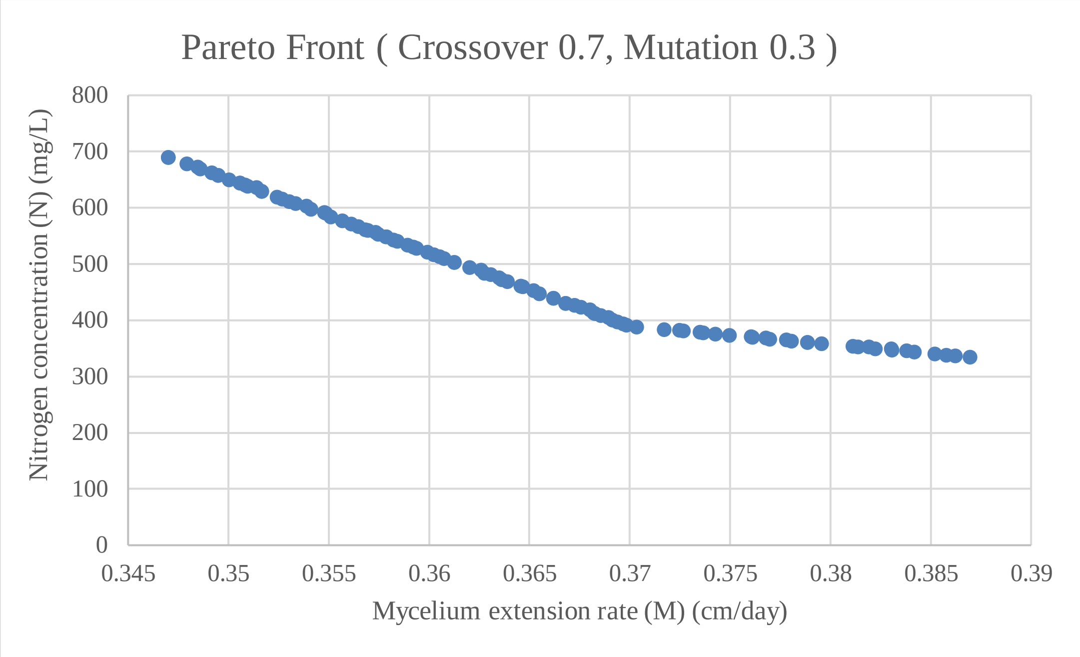

Figure 13 Generated result with crossover probability of 0.7 and mutation probability of 0.3

Figure 13 shows that the highest value of nitrogen concertation is 689.98mg/L with the lowest value of mycelium extension rate 0.347 cm/day.

The highest mycelium extension rate is 0.387 cm/day, with the lowest nitrogen concentration at 334.05 mg/L.

If the goal is to get the best out of both of it, then from the data set we can get 387.93 mg/L of nitrogen concertation and 0.370 cm/day of mycelium growth.

As observed on the plotted graphs, the distribution pattern looks quite similar, having a sharp curve in the somewhere in middle. The maximum mycelium extension rate for all data set is similar, with the value of 0.387 cm/day. However, the maximum nitrogen concentration for all data set is different. From figure 12, with parameter value for crossover probability equal 0.7 and mutation probability equal 0.2, the lowest maximum nitrogen concentration is 496.87 mg/L. In figure 13 we can see that with parameter value for crossover probability equal 0.7 and mutation probability equal 0.3, the highest nitrogen concentration among the 5 generated datasets is 689.98 mg/L.

CHAPTER 6

CONCLUSION

6.1 Expected Result

This project is about optimizing the growth of mycelium through the implementation of genetic algorithm to solve the objective functions. Proposed methodology in chapter 3, has been successful implemented, allowing this project to reach its objective. Via the implementation, mycelium growth can be optimized greatly by using the obtained result as a reference point for desired goal. The trade-off between two objectives, which is between the Nitrogen concentration (N) (mg/L) and the Mycelium extension rate (M) (cm/day) can be analysed easily by looking at the graph. We can choose either to maximised one of the objectives, or balance both of it.

6.2 Difficulty using jMetal

The Java based framework contains many algorithms for different variant of genetic algorithm, and just for NSGA-ii. For example, jMetal also contains the algorithm for GDE3, PESA2, SMPSO. Each of this algorithm required different method of implementing. Even though example were given in the framework, it is still challenging to understand how the algorithm in the framework interact with other packages. The documentation for jMetal can be obtained on the official webpage, but even the explanations in the documentation are difficult to be understood.

During this project, the implementation has failed several times before successful. For example, during the implementation of NSGA-ii, it is initially planned to set the parameter of population equal to 30 and the number of generations to 100, however as seeing in figure 8 there are no parameter of adjusting the number of generations, instead there is parameter to adjust MaxEvaluation. Adjusting these two parameters will affect the number of data generated in the data set.

6.3 Future Work Recommendations

Optimization of mycelium growth can be also be done by using other variant of genetic algorithms, such as SPEA2. Replacing or implementing NSGA-ii with other variant of genetic algorithm can produce different but better result.

Since the end-goal of this project is to produce pareto front, in the future the pareto front can be used to implement into a system to get more optimized result.

REFERENCES

Adeeyo, A. O., Lateef, A., & Gueguim-Kana, E. B. (2016). Optimization of the Production of Extracellular Polysaccharide from the Shiitake Medicinal Mushroom Lentinus edodes (Agaricomycetes) Using Mutation and a Genetic Algorithm-Coupled Artificial Neural Network (GA-ANN). *International Journal of Medicinal Mushrooms*, *18*(7), 571–581. https://doi.org/10.1615/IntJMedMushrooms.v18.i7.20

Bajpai, P., & Kumar, D. R. M. (2010). Genetic Algorithm - an Approach to Solve Global Optimization Problems. *Indian Journal of Computer Science and Engineering*, *1*(3), 199–206. https://doi.org/10.1016/s0378-7753(96)02556-6

Dzulkefli, N. A., & Zainol, N. (2018). Data on modeling mycelium growth in Pleurotus sp. cultivation by using agricultural wastes via two level factorial analysis. *Data in Brief*, *20*, 1710–1720. https://doi.org/10.1016/j.dib.2018.09.008

Hu, Y., Tan, C. K., Broughton, J., Roach, P. A., & Varga, L. (2017). Model-based multi-objective optimisation of reheating furnace operations using genetic algorithm. *Energy Procedia*, *142*, 2143–2151. https://doi.org/10.1016/j.egypro.2017.12.619

Karpov, A. V., Sysoev, A. A., Poteshin, S. S., Chernyshev, D. M., & Sysoev, A. A. (2015). Genetic algorithm for voltage optimization of gridless ion mirror. *Physics Procedia*, *72*, 236–240. https://doi.org/10.1016/j.phpro.2015.09.070

Kumar, S., Kumar, A., Chand, G., Kumar, T., & Nadeem Akhtar, M. (2018). Optimization of Mycelia Growth Parameters for Pleurotus florida and Pleurotus sajor-caju, (7), 4818–4823.

Malhotra, R., Singh, N., & Singh, Y. (2011). Genetic Algorithms : Concepts , Design for Optimization of Process Controllers. *Computer and Information Science*, *4*(2), 39–54. https://doi.org/10.5539/cis.v4n2p39

Manjunathan, J., & Kaviyarasan, V. (2011). Optimization of mycelia growth and antimicrobial activity of new edible mushroom, Lentinus tuberregium (Fr.). Tamil Nadu., India. *International Journal of PharmTech Research*, *3*(1), 497–504.

Meng, F. X., Wu, L. Y., Wang, Y. Z., Zhao, X., Yang, D. S., & Teng, L. R. (2013). Optimizing the conditions for adenosine extraction from mycelia of Cordyceps gunnii using genetic algorithm. *Journal of Chemical and Pharmaceutical Research*, *5*(12), 376–379.

Mukta, S. H., Islam, T. M. R., & Hasnayen, S. M. (2012). Multiobjective Optimization Using Genetic Algorithm, *1*(3).

Riham Khalil David Stockton, P. S. K. L. M. M. (2012). A Multi-Objective Optimization Approach Using Genetic Algorithms for Quick Response to Effects of Variability in Flow Manufacturing. *International Journal of Advanced Computer Science and Applications(IJACSA)*, *3*(9), 12–17. https://doi.org/10.14569/IJACSA.2012.030902

Tesfaw, A., Tadesse, A., & Kiros, G. (2015). Optimization of oyster (Pleurotus ostreatus) mushroom cultivation using locally available substrates and materials in Debre Berhan, Ethiopia. *Journal of Applied Biology & Biotechnology*, *3*(01), 15–20. https://doi.org/10.7324/JABB.2015.3103

APPENDIX A: GANTT CHART

	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		**Multi-Objective Optimization**	**159 days**	**Mon 10/9/18**	**Thu 18/4/19**	
2		**Research Planning**	**12 days**	**Mon 10/9/18**	**Tue 25/9/18**	
3		Meeting With SV	1 day	Mon 10/9/18	Mon 10/9/18	
4		Research Current Situation	4 days	Tue 11/9/18	Fri 14/9/18	3
5		Determine the problem	2 days	Mon 17/9/18	Tue 18/9/18	4
6		Determine the objective	1 day	Wed 19/9/18	Wed 19/9/18	5
7		Determine the scope and thesis organization	1 day	Thu 20/9/18	Thu 20/9/18	6
8		Write report for the planning	3 days	Fri 21/9/18	Tue 25/9/18	7
9		**Literature Review**	**13 days**	**Wed 26/9/18**	**Fri 12/10/18**	**2**
10		Select research paper	2 days	Wed 26/9/18	Thu 27/9/18	6
11		Conduct review	4 days	Fri 28/9/18	Wed 3/10/18	10
12		Meeting With SV	1 day	Mon 1/10/18	Mon 1/10/18	
13		Summarise finding	2 days	Thu 4/10/18	Fri 5/10/18	11
14		Submit Chapter 1 of PSM report	1 day	Tue 9/10/18	Tue 9/10/18	8
15		Write report for literature review	4 days	Mon 8/10/18	Thu 11/10/18	13
16		Submit Chapter 2 of PSM report	1 day	Fri 12/10/18	Fri 12/10/18	15
17		**Research Methodology**	**38 days**	**Mon 15/10/18**	**Wed 5/12/18**	**9**
18		Meeting With SV	1 day	Mon 15/10/18	Mon 15/10/18	16
19		Find suitable method to achieve objective	3 days	Tue 16/10/18	Thu 18/10/18	18
20		Write report for methodology	3 days	Wed 24/10/18	Fri 26/10/18	19
21		Submit Chapter 3 of PSM report	1 day	Mon 29/10/18	Mon 29/10/18	20
22		Meeting With SV	1 day	Tue 30/10/18	Tue 30/10/18	21
23		Correction of Chapter 1,2,3	25 days	Wed 31/10/18	Tue 4/12/18	22
24		Submit PSM 1 Proposal	1 day	Wed 5/12/18	Wed 5/12/18	23
25		**Implementation**	**78 days**	**Tue 1/1/19**	**Thu 18/4/19**	**17**
26		Obtain and setup the software	7 days	Thu 6/12/18	Fri 14/12/18	24
27		Execute the algorithm	7 days	Tue 1/1/19	Wed 9/1/19	26
28		Feed data	9 days	Thu 10/1/19	Tue 22/1/19	27
29		Run Optimization Process	11 days	Wed 23/1/19	Wed 6/2/19	28
30		Meeting With SV	2 days	Thu 7/2/19	Fri 8/2/19	29
31		Write report for implementation	14 days	Mon 11/2/19	Thu 28/2/19	30
32		Conclude research	5 days	Fri 1/3/19	Thu 7/3/19	31
33		Submit Chapter 4 of PSM report	2 days	Fri 8/3/19	Mon 11/3/19	32
34		Submit Chapter 5 of PSM report	2 days	Tue 12/3/19	Wed 13/3/19	33
35		Submit PSM 2 Thesis	2 days	Thu 14/3/19	Fri 15/3/19	34