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Comparative Analysis of the Regula Falsi and Secant Methods for Numerically Solving the Roots of Nonlinear Equations

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Abstract: This study aims to analyze and compare the effectiveness of two numerical methods, namely Regula Falsi method and Secant method, in solving the roots of non-linear equations. The non-linear equations used in this study include various types of functions, such as polynomial, trigonometric, exponential, and logarithmic functions. Both methods were tested through numerical simulations using MATLAB software to measure performance based on convergence speed, accuracy of results, and stability of the iteration process. The Regula Falsi method works based on linear interpolation between two points that have different function signs, while the Secant method uses two initial guesses without different sign requirements. The analysis shows that the Regula Falsi method is more stable but has slower convergence, while the Secant method converges faster but is less stable under certain conditions. By considering the advantages and disadvantages of each method, the selection of the optimal method is highly dependent on the characteristics of the function and the given initial conditions. This research contributes to understanding the fundamental differences between the two methods and provides practical guidance for researchers, academics, and practitioners in choosing the right numerical approach to solve various mathematical problems involving non-linear equations.

Keywords: Regula Falsi Method, Secant Method, Root Solving, Non-Linear Equations.

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A. INTRODUCTION

Numerical method is a technique used to obtain solutions to mathematical problems with a computational approach, especially when analytical solutions are difficult to find or too complicated to calculate directly (Purwati & Erawati, 2021). In this method, mathematical problems are solved using approximations, often through iterative procedures that produce solutions close to the desired result. Numerical methods are particularly useful in fields such as engineering, physics, and economics, where many problems involve non-linear equations or systems that are too large to solve analytically (Arfinanti, 2018).The roots of an equation, which are the values of X that make an equation f(x)=0 true, are an important element in many mathematical problems and their applications in various fields of science (Pandia & Sitepu, 2021). In mathematics, root finding is at the core of many models and theories, especially those involving non-linear functions. The roots of these equations are used to determine equilibrium points, optimal solutions, or extreme conditions of a system. In an engineering context, for example, finding the roots of non-linear equations can be used to solve fluid flow problems or analyze material structures (Parida et al., 2024). In physics, roots are used to solve dynamic problems involving non-linear laws of physics, such as in wave theory or quantum mechanics. Similarly, in economics, many economic models involve non-linear equations that describe the relationship between economic variables, such as economic growth, or the calculation of market prices (Pratama et al., 2023). However, despite their importance, many non-linear equations cannot be solved analytically. Therefore, accurate and efficient numerical solutions are needed to find the roots of these equations (Nuzla, 2022).

Numerical methods are very important because many non-linear equations do not have analytical solutions that can be expressed in closed form (Dwiwansyah et al., 2021). When analytic solutions are not available or too complicated to calculate, numerical methods become the main way to obtain solutions. Numerical methods provide an iterative approach that can produce solutions close to the root of the equation with high accuracy in a relatively short time (Azmi et al., 2019). Some numerical methods that are often used to find the roots of non-linear equations include the Regula Falsi, Secant and Bisection methods. Each method has its own characteristics that affect its convergence rate, stability and ease of implementation. The main focus in this research is to compare two popular methods, namely Regula Falsi and Secant, each of which has its advantages and disadvantages in convergence and accuracy of results (Batarius, 2021). Both methods are very useful, especially when other methods such as Newton-Raphson cannot be used due to their dependence on the derivative of the function or the need for an initial guess very close to the root (Endaryono, 2018).

The Regula Falsi method is one of the numerical methods used to find the roots of an equation by linearly interpolating between two points of opposite sign on the function f(x). This method works by selecting two points that have opposite signs on the function and then using a straight line to estimate the root position (Sabaryati & Zulkarnain, 2019). The advantage of the Regula Falsi method is its ability to always ensure convergence to the root as long as the sign of f(x) changes in the chosen interval. However, despite being more stable, it can experience a slower convergence rate, especially when one of the points approaches the root quickly. On the other hand, Secant's method is also used to find the roots of equations by linear approximation, but it only requires two initial guesses and does not require determining the sign of the function on the interval. The main advantage of the Secant method is its higher convergence speed compared to the Regula Falsi method, although it can be more sensitive to the choice of initial guesses and is not always stable. The differences in the working and stability of these two methods will be the main focus in the comparison that will be conducted in this study (Tulandi, 2020).

This research aims to analyze and compare the effectiveness of Regula Falsi method and Secant method in numerically finding the roots of non-linear equations (Sulistyowati & Ramatulloh, 2022). Using several examples of non-linear equations that have roots that are difficult to find analytically, this study will evaluate the performance of both methods in terms of convergence speed, accuracy of results, and stability. The tested equations will include cases that represent non-linear functions with different properties, such as algebraic, trigonometric, and exponential equations (Sunandar, 2019). By comparing the two methods, this research is expected to provide deeper insight into the conditions under which each method is more effective and what factors affect the selection of the right method (Yose Amelia et al., 2024). The results of this study are also expected to provide recommendations for the application of numerical methods in solving various mathematical and technical problems involving non-linear equations, both in academia and in industrial applications.

B. METHOD

In this section, we will explain in detail about the two methods used to solve the roots of non-linear equations, namely the Regula Falsi Method and the Secant Method. Each method will be explained starting from the basic concept, iterative formula, to its numerical application to solve the roots of non-linear equations" (Burden & Faires, 2011). In this study, researchers compared the solution procedures of the Regula falsi Method and the Secant Method in selecting the roots of non-linear equations. then for the implementation of each formula, researchers used Matlab software. The description of the two methods used is explained below.

1. Regula Falsi Method

The Regula Falsi method (also known as the method of finding roots by line interpolation) is one of the numerical methods used to find the roots of a non-linear equation $f(x) = 0$ iteratively. It relies on linear interpolation between two points of different signs on the function $f(x)$, and uses the intersection of the straight lines as an approximation to the roots of the equation. This method is similar to the bisection method, but replaces the midpoint check with a straight line approximation, which can speed up convergence compared to the simpler bisection method (Tulandi, 2020). The Regula Falsi method works by finding the roots of an equation by interpolating the function values at two points that have opposite signs. From these two points, a straight line is formed, and the intersection point of this straight line with the x-axis is considered as the root approximation. This intersection point is calculated using the linear interpolation formula.

Steps of the Falsi Regula Method:

a. Determine two starting points x_0 and x_1 that have different signs in the function $f(x), i.e. f(x_0) \cdot f(x_1) < 0$. This means that there is a root between these two points based on the Central Value Theorem.

b. Calculate the intersection point x_0 on the line connecting points $(x_0, f(x_0))$ and $(x_1, f(x_1))$ using the linear interpolation formula:

c.

$$x_n = x_k - \frac{f(x_1)(x_1 - x_0)}{f(x_1) - f(x_0)} \quad (1)$$

d. Evaluate the sign of f(x_2):

If $f(x_2) = 0$, then x_2 is the exact root of the equation.

If $f(x_2) \cdot f(x_0) < 0$, then the root lies in the interval $[x_0, x_2]$, so we set $x_1 = x_2$ and repeat step 2.

If $f(x_2) \cdot f(x1) < 0$, then the root lies in the interval $[x_2, x_1]$, so we set $x_0 = x_2$ and repeat step 2.

e. Repeat steps 2-3 until we reach the desired precision, i.e. until $| x_2 - x | \ or \ | f(x_2) |$ is smaller than the tolerance limit specified earlier.

2. Secant Method

The Secant method is a numerical method used to find the roots of the non-linear equation $f(x) = 0$. This method is similar to the Regula Falsi method, but differs in that it does not require the function values on both boundaries of the interval to differ in sign, so it does not require checking the sign of the function. Instead, the Secant method relies only on two initial guesses to estimate the roots and uses the secant line (a line connecting two points on the graph of the function) to find the roots of the equation (Yose Amelia et al., 2024).

This method has the advantage of higher convergence speed compared to the Bisection and Regula Falsi methods because it avoids the slower steps of those methods. However, it cannot guarantee convergence for all types of equations, especially when the initial guess is not close enough to the root or if the root is repetitive.

Steps of Secant Method:

Here are the steps to apply the Secant method in finding the roots of a non-linear equation $f(x) = 0$:

a. Determine two initial guesses x_0 and x_1 that are close to the root of the equation. These two guesses do not have to have different signs (unlike the Regula Falsi method).

b. Calculate the secant intersection point x_2 using the formula:

$$x_2 = x_1 - \frac{f(x_1)(x_1 - x_0)}{f(x_1) - f(x_0)} \tag{2}$$

This formula connects two points $(x_0, f(x_0))$ and $(x_1, f(x_1))$ and finds the intersection point of the secant line connecting them. This intersection point is considered as the approximate root

c. Check the accuracy of the solution:
If $|\, x_2 - x \,|$ *or* $|\, f(x_2) \,|$ is smaller than the specified tolerance limit, then x_2 is considered as the root of the equation.

d. Update the guess:
Replace x_0 with x_1 and x_1 with x_2, then repeat steps 2 and 3 until convergence is achieved (i.e., $|\, x_2 - x \,|$ or $|\, f(x_2) \,|$ is small enough).

Both methods are then used to solve the problem of non-linear equations. The non-linear equations used involve polynomial, trigonometric, exponential, and logarithmic non-linear equations. Furthermore, the problem used for the simulation consists of:

a. Polynomial Problem: $f(x) = 2x^3 + 5x - 11$
b. Trigonometric Problem: $f(x) = 2x^2 \sin(3x + 11)$
c. Exponential Problem: $f(x) = 2xe^{-4x} + 11$
d. logarithmic Problem: $f(x) = 2x \log(2^{x+1} + 11)$

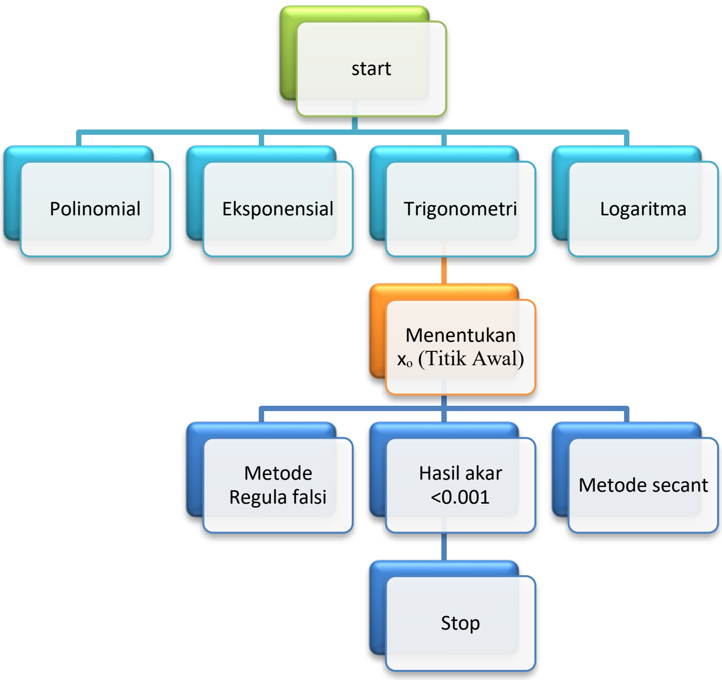


Figure 1. Shows The Flow Of Research Conducted

The flowchart in Figure 1 illustrates the process of solving the roots of non-linear equations using numerical methods. The process starts with the initial step or start, then the user chooses the type of function to be solved, whether it is a polynomial function, exponential, trigonometric, or logarithmic function. After selecting the type of function, the next step is to determine the initial value x0x_0x0 as the starting point to find the root. Based on this starting point, the user can choose an appropriate numerical method, such as the method, such as the Regula Falsi method or the Secant method. Next, the iteration process is carried out until a root result is obtained that has an error rate is less than 0.001. If the result has met criteria, then the process is stopped. This diagram as a whole overall shows the systematic steps in solving the roots of function using the numerical approach.

C. RESULTS AND DISCUSSION

Researchers used four non-linear equation problems consisting of trigonometric, polynomial, exponential, and logarithmic equations. according to the steps that have been taken, the graphs resulting from each synchronous equation are Figure 2, Figure 3, Figure 4, and Figure 5.

Figure 2. Trigonometric Graphs

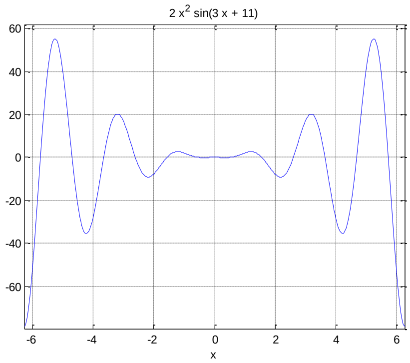


Figure 3. Polynomial Graph

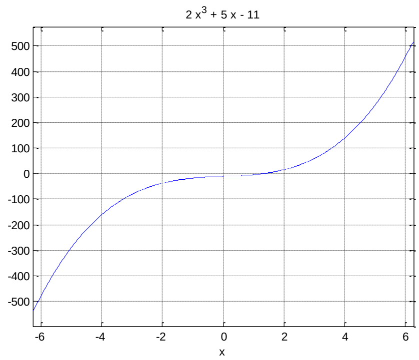


Figure 4. Exponential Graph

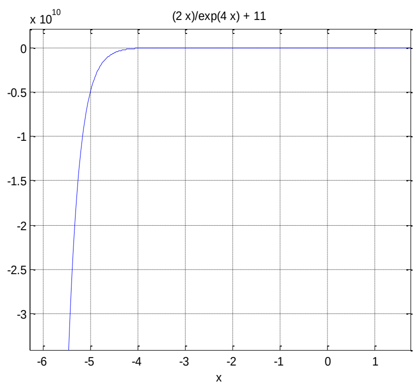
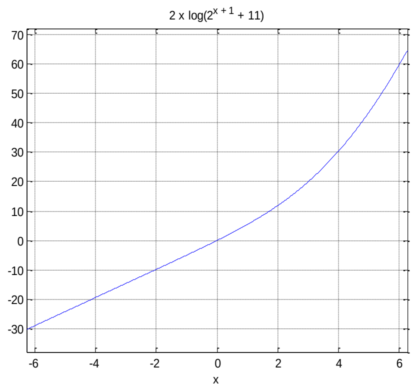


Figure 5. Logarithm Grap



According to Figure 2 above, it can be seen that the roots of the equation are in the interval $[-6,6]$. In this case, the crew point $x_0 = [-5]$ is obtained to be the starting point for finding the roots of the trigonometric equation, Figure 3 above can be seen that the roots of the equation are in the interval $[-6,5]$. In this case, the starting point $x_0 = [3]$ is used as the starting point to find the roots of the polynomial equation, then in Figure 4 above it can be seen that the roots of the equation are in the interval $[-6,1]$. In this case, the crew point $x_0 = [-4]$ becomes the starting point for finding the roots of the exponential equation, and in Figure 5 above it can be observed that the roots of the equation are in the interval $[-6,6]$. In this case, the crew point $x_0 = [1]$ becomes the starting point to find the roots of the logarithm equation.

Table 1. Script Every Method

Method — **script**

Regulafalsi

```
clear; clc;
disp('-------------------------------')
disp('program   : Metode Regula Falsi')
disp('programer : dwi suryo putro  ')
disp('-------------------------------')
f=input ('f(x) = ');
x1=input('x1 = ');
x2=input('x2 = ');
imax=input('Iterasi = ');
galat1=input('Error = ');
iter=0;
fprintf('\n    Iterasi     Akar         f(Akar)          Galat\n');
for k=1:imax
iter=iter+1;
%Rumus Regula Falsi
x3=x1-((x2-x1)*feval(f,x1)/(feval(f,x2)-feval(f,x1)));
galat=abs((x3-x2)/x3);
x2=x3;
y=feval(f,x2);
fprintf('%10.0f     %6.10f      %6.10f      %6.10f\n',[iter;x2;y;galat])
if (galat<galat1 || (iter>imax)),break,end
end
fprintf('Akarnya adalah = %6.10f\n',x3)
```

Secant

```
clear; clc;
disp('-------------------------------')
disp('program   : Metode Secant')
disp('programer : dwi suryo putro ')
disp('-------------------------------')
f=input ('f(x) = ');
x1=input('x1 = ');
x2=input('x2 = ');
imax=input('Iterasi = ');
galat1=input('Error = ');
iter=0;
fprintf('\n    Iterasi     Akar         f(Akar)          Galat\n');
for k=1:imax
iter=iter+1;
%Rumus Secant
x3=x2-((x2-x1)*feval(f,x2)/(feval(f,x2)-feval(f,x1)));
galat=abs((x3-x1)/x3);
x1=x3;
y=feval(f,x1);
fprintf('%10.0f     %6.10f      %6.10f      %6.10f\n',[iter;x1;y;galat])
if (galat<galat1 || (iter>imax)),break,end
end
fprintf('Akarnya adalah = %6.10f\n',x1)
```

Scripts of Regula Falsi method and Secant method are given above in order to find the roots of non-linear equations. Furthermore, from the above scripts, 8 trials will be conducted to find the iteration of the roots of the roots of the equations; Trigonometric, polynomial, exponential, and logarithmic

Table 2. Root Results Of The Two Methods

No	**Method**	Problem	**Non-linear equation**	**Equation X**	Iterations
1.	Regulafalsi	Polynomial	$2x^3 + 5x - 11$	1	7
	Method	Trigonometric	$2x^2 \sin(3x + 11)$	2	4
		Exponential	$2xe^{-4x} + 11$	-2	1
		Logarithm	$2x \log(2^{x+1} + 11)$	-1	7
2.	Secant	Polynomial	$2x^3 + 5x - 11$	0.3752	58
	method	Trigonometric	$2x^2 \sin(3x + 11)$	-1.4392	100
		Exponential	$2xe^{-4x} + 11$	-0.8941	100
		Logarithm	$2x \log(2^{x+1} + 11)$	0	1

According to the results of the above computations using the Regula Falsi method for case 1 it is known that the value of x so that $f(x) < 0.001$ is $x = 1$, the value was obtained after computing up to 7 iterations. for case 2 it is known that the value of x so that $f(x) < 0.001\ is\ x = 2$, the value was obtained after computing up to 4 iterations. for case 3 it is known that the value of x as a result $f(x) < 0.001$ means $x = -2$, the value was obtained after computing up to 4 iterations. for case 3 it is known that the value of x such that $f(x) < 0.001\ is\ x = -2$, the value was obtained after computing up to 1 iteration. for case 4 it is known that the value of x such that $f(x) < 0.001\ is\ x = -1$, the value was obtained after computing up to 7 iterations.

By using the Secant method, for case 1 it is known that the value of x such that $f(x) < 0.0001\ is\ x = 0.3752$, the value was obtained after computing up to 58 iterations. for problem 2 it is known that the value of x such that $f(x) < 0.0001\ is\ x = -1.4392$, the value was obtained after computing up to 100 iterations. For case 3 it is known that the value of x such that $f(x) < 0.0001\ is\ x = -0.8941$, the value was obtained after computing up to 100 iterations. For problem 4 it is known that the value of x such that $f(x) < 0.0001\ is\ x = 0$ the value was obtained after computing up to 1 iteration.

Falsi regularization shows faster convergence in some cases (especially when the function is quite simple or the initial conditions are close to the root). Secant often requires more iterations to achieve accurate results, especially in more complex cases. Falsi regularization often reaches convergence in fewer iterations than Secant (e.g. in Case 1 and Case 2). Secant is slower in some cases, such as in Case 1 (58 iterations) and Case 2 (100 iterations), although Secant can give more precise results in the first iteration in some cases (Case 4). Both methods are able to give highly accurate results, with Secant being more sensitive to accuracy in more complex cases, despite requiring more iterations. Falsi's regularization is often faster in achieving values very close to the root sought with fewer iterations.

D. CONCLUSIONS AND SUGGESTIONS

This study concludes that the Regula Falsi and Secant methods each have advantages and disadvantages in solving non-linear equations numerically. The Regula Falsi method is more stable but has a slower convergence speed. In contrast, the Secant method offers faster convergence but is less stable under certain conditions. The selection of the optimal method depends on the characteristics of the equation at hand, such as the type of function and its complexity. These findings provide important guidance for researchers and practitioners in choosing a suitable numerical method for solving non-linear equations, both for academic purposes and industrial applications.

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