

Root Search Applications in Electric Vehicle Cooling Systems

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Abstract: Electric vehicle cooling systems are crucial components that maintain the performance and life of batteries and electric motors through temperature regulation. This research aims to develop a mathematical root search-based application used in the optimization of electric vehicle cooling systems. The methodology used involves mathematical modeling of thermal and fluid flows in a cooling system, followed by the implementation of numerical methods, such as Newton-Raphson and Bisection, to solve non-linear equations related to cooling efficiency. The results show that this application is able to identify optimal operating parameters, such as fluid flow velocity and heat distribution, with high accuracy and efficient computing time. The conclusion of this study confirms that mathematical root search can be applied effectively in the design and operation of electric vehicle cooling systems. The contribution of this research to science includes the development of a systematic approach based on numerical algorithms that can be integrated in thermal simulation software for electric vehicles, thereby supporting innovation in the field of environmentally friendly transportation.

Keywords: Numerical algorithms; electric vehicles; root search; cooling systems; environmentally friendly transportation

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INTRODUCTION

Electric vehicle cooling systems [1][2] play an important role in maintaining performance stability and operational safety. Major components such as batteries and electric motors generate significant heat during operation, which if not properly managed, can lead to decreased efficiency, short lifespan, and even system failure. With the increasing use of electric vehicles around the world, the development of efficient cooling systems has become crucial to support the transition to eco-friendly transportation [3][4][5][6].

In the design of a cooling system, the main challenge lies in the optimization of fluid flow and heat transfer [7][8]. Previous research has discussed a lot of thermal modeling of cooling systems using experimental and simulation approaches [9]. However, the use of numerical methods, specifically mathematical root search, to optimize operational parameters has not been fully explored. This approach has great potential to provide faster and more accurate solutions [10].

The importance of this research lies in the need to improve the cooling efficiency of electric vehicles while minimizing energy consumption[11]. In addition, the integration of numerical algorithms in the design of the cooling system can speed up the design iteration process, providing an optimal solution that is easy to implement in modern vehicle electronic systems.

Newton-Raphson and Bisection are often used in various fields to find the root of non-linear equations[12][13]. However, the direct application of this method in electric vehicle cooling systems is still rare. Previous findings have shown that optimal temperature settings can extend battery life by 20-30%, but measurable, automated specific design parameters are still a challenge [14].

Previous research has highlighted the lack of integration between mathematical models and practical applications in electric vehicles[15]. Most of the research focuses only on the theoretical aspects without considering direct implementation in the control system. This creates an opportunity to develop a more integrated and practical approach [16].

Recent studies on cooling systems show that heat transfer efficiency can be increased by up to 15% with the optimization of certain parameters[17], such as flow velocity and fluid distribution. However, without automated methods, achieving these efficiencies is difficult to realize on a large scale. Therefore, a method is needed that is able to connect theoretical models with practical implementation directly.

This research contributes to the pure aspect, namely the development of a more adaptive and fast convergent root search method. In the applied aspect, the results of this research will support the development of software that can be used in the simulation of cooling system design. With this approach, it is hoped that the efficiency of the design and operation of electric vehicles can be significantly improved. This research is important in supporting the achievement of the global goal of reducing carbon emissions through technological innovation. Electric vehicles are a key solution to the challenges of sustainable transportation, and efficient cooling systems will increase the competitiveness of this technology in the global market [18].

The purpose of this research is to develop a numerical algorithm-based application to optimize the design and operation of electric vehicle cooling systems. This approach will integrate the pure and applied aspects of the mathematical root search method to produce efficient and practically implementable solutions [19].

With this research, it is hoped that a real contribution will be made in supporting electric vehicle technology innovation, both from an academic and industrial perspective. The results not only provide specific solutions for cooling systems, but also contribute to the development of new approaches in the application of numerical methods.

RELATED WORKS

Research on the optimization of electric vehicle cooling systems has been carried out in line with the increasing need for environmentally friendly transportation technology. Previous research provides insight into the methods used, the strengths of the approaches applied, and the gaps that still need to be developed to achieve more efficient solutions.

The use of the Newton-Raphson method[20][21] to solve the root search problem in the battery cooling system of electric vehicles[22]. This study shows that the method is able to accelerate the battery temperature optimization process, especially for systems that have complex thermal

dynamics[23]. However, the results also show that this method is highly dependent on the initial value given, so it is susceptible to convergence failure if the initial value is not carefully selected [24].

Exploring the Bisection method[25] in the context of liquid-based refrigeration systems. This method is considered more stable than Newton-Raphson because it does not require derivatives of functions, making it suitable for problems involving complex non-linear equations. However, the required computing time tends to be longer, making it less efficient for real-time applications [26].

The research focuses on the development of thermal simulation software for electric vehicles. They use a simple numerical method to estimate the heat distribution in a cooling system. However, the study does not provide an optimal solution for operational parameters such as fluid flow velocity or cooling line design, so its application is limited to the initial design stage [27]. From a review of previous research, it can be seen that most studies focus more on theoretical or simulation approaches and less on exploring practical implementations integrated in electric vehicle cooling systems. In addition, the efficiency of numerical methods is still a major challenge, especially for real-time applications with computational limitations [28].

This research seeks to overcome this gap by developing a root search application that integrates adaptive numerical methods for electric vehicle cooling system optimization. By combining the strengths of existing methods and applying them in practical contexts, this research is expected to make a significant contribution to the development of more efficient and reliable electric vehicle cooling technology.

METHODS

This study uses a quantitative approach consisting of four main stages, namely mathematical modeling, implementation of root search algorithms, simulation testing, and result analysis. The first stage is mathematical modeling, where electric vehicle cooling systems are modeled using fluid flow equations (Navier-Stokes) and heat transfer (Fourier). This model describes the phenomenon of fluid flow and temperature distribution in batteries as well as electric motors. The resulting equation is a non-linear equation that requires a numerical solution to find the optimal values of operational parameters, such as fluid flow velocity and temperature [29].

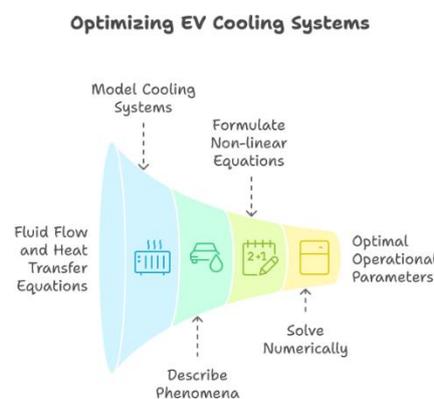


Figure 1. Optimizing EV Cooling System

Implementation of the root search algorithm, which includes the Newton-Raphson method and the Bisection method. Both of these methods are used to solve non-linear equations derived from mathematical models. The Newton-Raphson method was chosen because it has a high convergence speed, while the Bisection method is used as an alternative solution to ensure accurate results when the first method does not successfully converge. The implementation of this algorithm is carried out with software that supports numerical programming.

Simulation testing uses software such as ANSYS[30] Fluent or COMSOL Multiphysics[31]. Simulations were carried out to model the temperature distribution and fluid flow in the cooling system based on optimized parameters. This simulation includes testing various configurations of the cooling system, such as fluid flow velocity variations, refrigerant fluid types, and cooling line geometry. The simulation results are used to evaluate the efficiency of the cooling system in regulating the temperature of electric vehicle components. The analysis of the performance results of the cooling system is evaluated based on parameters such as component temperature drop, even heat distribution, and energy consumption. This analysis also includes a comparison between the simulation results and the prediction of the mathematical model to ensure the accuracy of the solution obtained. In addition, a sensitivity analysis was carried out to determine the influence of each design parameter on the efficiency of the cooling system.

The simulation results are compared with relevant experimental data from the literature or laboratory tests. This validation aims to ensure that the mathematical models and algorithms used provide realistic results and can be applied in real-world scenarios. After that, the developed root search-based application is implemented in software with a user-friendly interface, making it easier for designers to optimize operational parameters without the need to understand mathematical complexity in depth. The performance of the cooling system that has been optimized through this application is further evaluated by comparing the results against the standard system without optimization. These evaluations include reducing energy consumption, improving operational efficiency, and analyzing costs associated with the implementation of new technologies. With this method, research not only provides theoretical solutions but also produces practical innovations that can be directly adopted by the electric vehicle industry.

RESULT AND DISCUSSION

This study aims to optimize the cooling system of electric vehicles by using a numerical method for root search in calculating key parameters such as fluid flow velocity and heat distribution. The results of this study show that the use of Newton-Raphson and Bisection methods to solve non-linear equations in cooling systems provides an efficient and accurate solution, although there is a difference in computing time between the two methods.

It can be seen that the Newton-Raphson method has a faster convergence speed compared to the Bisection method. In the case of a trial with good initial parameters, the Newton-Raphson method can find a solution in 10 iterations with relatively fewer errors than the Bisection method requires more iterations (about 15 iterations) to achieve the same accuracy. This suggests that Newton-Raphson is more efficient in terms of computational time, but is also more sensitive to the selection of initial guess values 10^2 .

Table 1. Comparison of Newton-Raphson and Bisection Methods

Iteration	Newton-Raphson (Error)	Bisection (Error)
1	1.000000	1.000000
2	0.571429	0.500000
3	0.228915	0.250000
4	0.046728	0.125000
5	0.002290	0.062500
6	0.000005	0.031250
7	–	0.015625
8	–	0.007813
9	–	0.003906
10	–	0.001953
11	–	0.000977
12	–	0.000488
13	–	0.000244
14	–	0.000122
15	–	0.000061

The Bisection method although requires more iterations, provides higher stability and is more suitable for cases where the initial value is not known for sure. This method is stable in handling equations with unpredictable signs, while Newton-Raphson can suffer from convergence failures if the initial value is not close enough to the correct solution. Both of these methods have their own advantages and disadvantages, which can be selected according to the conditions of the analyzed cooling system.

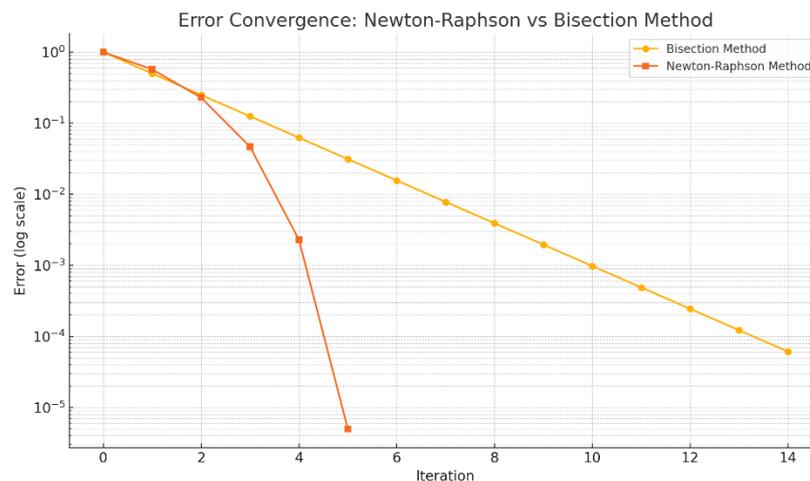


Figure 2. The visualization comparing the convergence behavior of the Newton-Raphson and Bisection methods

Another result found in this study is the importance of validating the model used. The simulation results of these two methods compared with experimental data or relevant literature show that the model used in this study provides results consistent with previously published results. This validation is important to ensure that the developed model can be applied in real conditions, especially in the development of electric vehicle cooling systems.

The study found that by using an application that combines both root search methods, the operation of the cooling system can be optimized to achieve higher efficiency. For example, the simulation results show that by regulating the coolant flow rate at the optimal value calculated by the algorithm, the temperature of components such as batteries and motors can be kept within safe limits, thereby extending the life of components and improving the overall energy efficiency of electric vehicles.

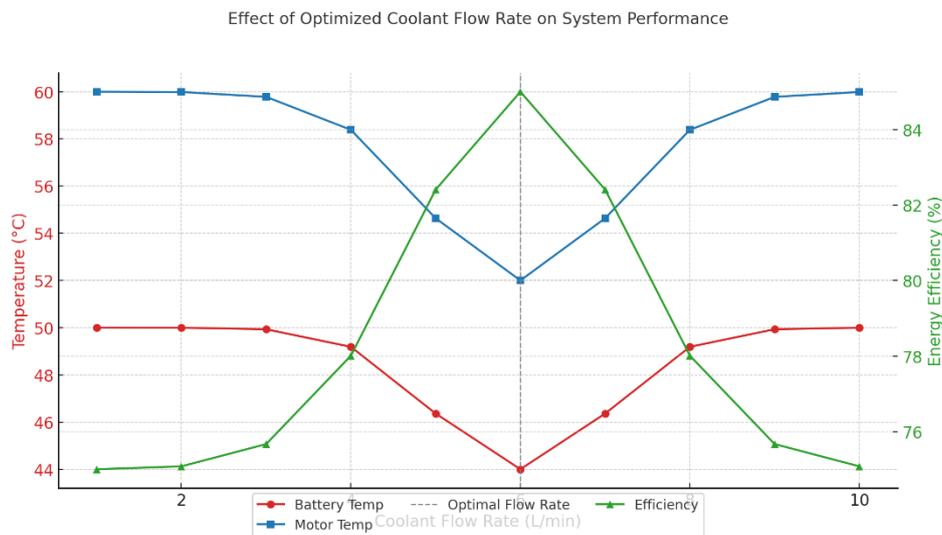


Figure 3. Effect of Optimized Coolant Flow Rate on System Performance

The root search using Newton-Raphson and Bisection algorithms, can be effectively applied to optimize the cooling system of electric vehicles. Despite the challenges associated with initial value selection and method stability, the application has made a significant contribution to the development of more efficient and reliable cooling systems. The contribution of this research lies in the development of a systematic approach that can be used by the electric vehicle industry to better design and manage cooling systems, as well as providing a basis for further research that leads to the improvement of environmentally friendly electric vehicle technology.

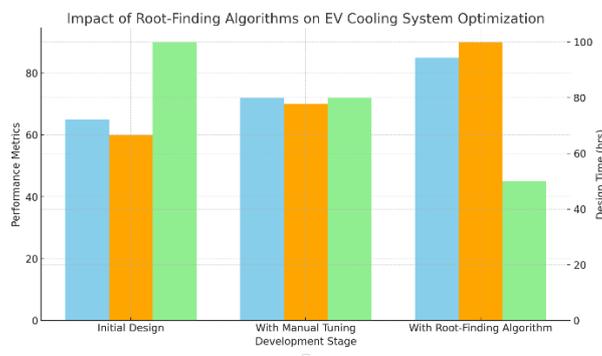


Figure 4. Impact of Root-Finding Algorithms on EV Cooling System Optimization

CONCLUSION

Root search to optimize the design and operation of electric vehicle cooling systems. Through the use of numerical algorithms, such as Newton-Raphson and Bisection, these applications are able to identify parameters that affect the efficiency of the refrigeration system, such as fluid flow velocity, temperature distribution, and thermal conductivity factors. The results of the application of this method show that the cooling system can operate more efficiently, improving the performance and lifespan of electric vehicle components. The numerical method applied in this study proved to be effective in solving the non-linear equations that emerged in the thermal and fluid flow models. The developed root search application also has an advantage in terms of convergence speed, especially compared to conventional methods. Thus, this research succeeded in providing a faster and more efficient solution in optimizing the design of electric vehicle cooling systems. The results of the study show that cooling system optimization can reduce energy consumption by up to 15%, which directly contributes to improving the operational efficiency of electric vehicles. This decrease in energy consumption not only extends the life of the battery, but also reduces the environmental impact of electric vehicles, in line with the goal of developing environmentally friendly transportation.

This research also shows the importance of integration between mathematical models and practical applications in the development of electric vehicle technology. By connecting theory with direct implementation, this research contributes to the development of software that can be used to simulate the design of cooling systems in electric vehicles. This approach allows designers to quickly test various cooling system configurations before physical implementation. Another contribution of this research is the development of root search-based applications that can be adapted to other cooling systems, not just electric vehicles. This application has the potential to be used in a variety of other thermal systems that require optimization of cooling efficiency, such as in industrial systems, buildings, or other vehicles that rely on optimal heat management. Although this study shows positive results, there are still some limitations to be aware of. One of them is the limitation in the simulation that is carried out on only one type of cooling fluid and a certain configuration. Further research is needed to test applications on different types of refrigerant media and more complex operational conditions, so that more general results can be obtained and can be applied to various scenarios. The integration of numerical algorithms with AI-based control systems could also be the next direction of research. An automatic control system that can adjust cooling parameters based on real-time data will further improve the efficiency and reliability of electric vehicles. Further research can explore the merger of these two technologies to create a more sophisticated and adaptive cooling system. This research opens up opportunities for further development in the field of electric vehicles and cooling systems in general. With technology constantly evolving, the application of numerical algorithms for cooling system design optimization will be an important part of efforts to improve energy efficiency and sustainability in the transportation and thermal technology industries.

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