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Development of Fast and Power Efficient Elevator

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Abstract

The rapid urbanization and vertical expansion of cities have led to a surge in the construction of high-rise buildings, creating a growing demand for elevator systems that are not only fast but also energy efficient. As population density in metropolitan areas increases, the pressure on vertical transportation systems intensifies, highlighting the need for solutions that can handle high passenger traffic without compromising performance or sustainability. This study presents the development of a fast and power-efficient elevator system designed to meet the dual challenges of minimizing travel time and reducing energy consumption in modern buildings. The proposed system incorporates advanced scheduling algorithms, such as the nearest neighbor algorithm (NNA), to optimize elevator path planning and reduce idle movement. Additionally, the integration of intelligent sensors and load detection mechanisms allows the system to dynamically adjust operations based on real-time demand, ensuring efficient energy usage. Regenerative braking technology and power-saving drive units further enhance the system's overall energy performance. The system is designed not only to improve the speed and efficiency of passenger movement but also to contribute to long-term energy conservation goals. Experimental simulations and comparative analysis with traditional elevator scheduling methods demonstrate significant improvements in both response time and energy usage. Additionally, the system employs a microcontroller-based control unit to optimize acceleration, deceleration, and door operations, thereby minimizing idle energy loss. Simulation and experimental analyses demonstrate that the improved system achieves significant reductions in power consumption compared to conventional models, along with enhanced response time and smoother ride quality. The results indicate that this approach offers a sustainable and cost-effective solution for next-generation vertical transportation systems, contributing to overall building energy efficiency and operational performance.

Keywords: Fast elevator system, energy efficiency, intelligent control algorithms, high-rise structures, genetic algorithm

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INTRODUCTION

An elevator is an object that travels in a vertical shaft to convey people or goods between floors of a building with several stories. Electric motors drive the majority of contemporary elevators using a network of wires and sheaves (pulleys), assisted by a counterweight. The elevator had a pivotal role in establishing the distinctive urban geography of many contemporary cities, particularly in the United States, by providing access to taller structures. It is expected to play an essential role in the development of cities in the future. The fast rate of urbanization and the increasing reliance on vertical living and working spaces have underscored the critical role of elevators in modern infrastructure. For all types of homes, businesses, and business buildings to have effective and dependable vertical conveyance, elevators are necessary. However, as the demand for high-rise structures grows, traditional elevator systems face significant challenges in terms of speed, energy consumption, and operational efficiency.

In light of this, development of quick and quiet elevators has become necessary. A high-speed elevator minimizes travel time, improving convenience for users and enhancing the functionality of buildings. Simultaneously, reducing the energy consumption of these systems contributes to environmental sustainability and cost savings, aligning with global efforts to promote energy-efficient technologies. This study explores innovative approaches to elevator design, focusing on optimizing performance while minimizing energy usage. The proposed system incorporates advanced technologies, such as intelligent control mechanisms, energy regeneration techniques, lightweight materials, and IoT-enabled maintenance. These advancements aim to address the dual objectives of speed and energy efficiency without compromising safety or reliability [1].

SMART ELEVATOR DESIGN

Smart elevator systems integrate advanced technologies and innovative components to achieve efficiency, speed, and sustainability (Figure 1). The major components of a smart elevator are outlined below along with an explanation of how they work and their importance:

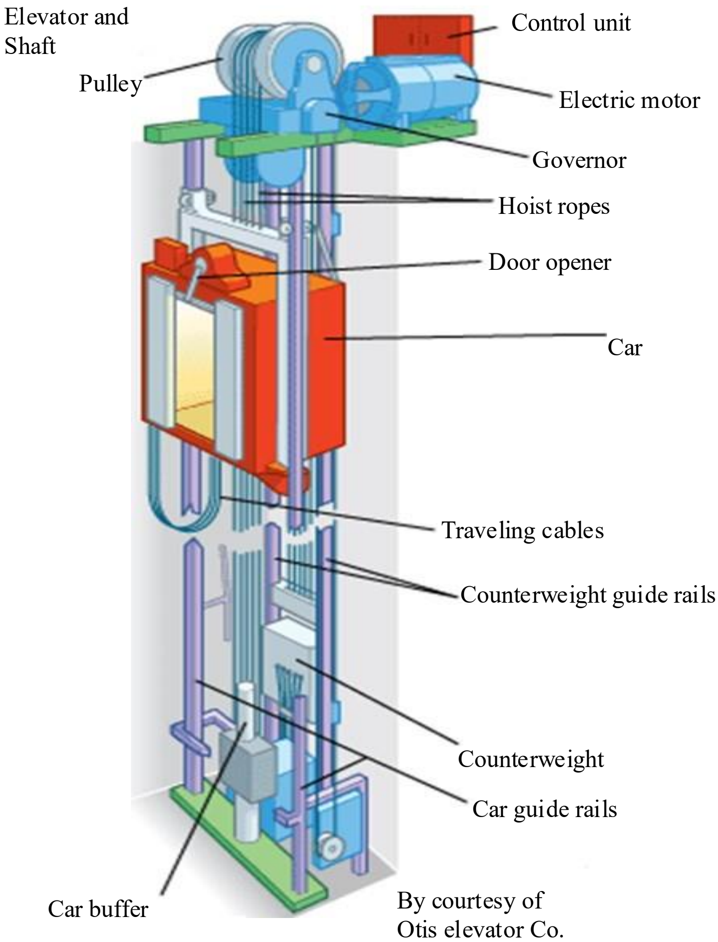

Figure 1. Elevator design.

Advanced Elevator Drive System

The main part in charge of governing the elevator's motion is the drive system. Variable Frequency Drives (VFDs), which offer exact control of motor speed and torque, have been employed in smart elevators. VFDs enable smooth acceleration and deceleration, improving ride comfort and energy efficiency while reducing mechanical wear on components.

Regenerative Braking System

A regenerative braking system captures the energy generated when the elevator slows down or descends under specific load conditions. This energy is converted into electricity and fed back into the building's power grid or used to power other systems. This feature significantly reduces energy consumption, making the elevator more sustainable and cost-effective [2, 3].

IoT-Enabled Sensors and Control Systems

Sensors from the World Wide Internet of Things (IoT) are vital for gathering and analyzing data in continuous time. These sensors monitor parameters such as cabin load, usage frequency, and component health. The data is transmitted to a central system for predictive maintenance, ensuring uninterrupted operation by addressing potential issues before they occur.

Smart Destination Control System (DCS)

The destination control system optimizes passenger flow by grouping individuals based on their destinations. Instead of pressing floor buttons inside the cabin, users input their desired floors on an external panel. The system assigns the most efficient elevator to minimize waiting and travel times, enhancing user experience and reducing energy usage [4].

Lightweight and Durable Materials

The use of advanced materials, such as carbon fiber and aluminium alloys, reduces the weight of the elevator cabin without compromising durability. A lighter cabin requires less energy for movement, contributing to power efficiency. Additionally, these materials are resistant to wear and corrosion, extending the lifespan of the elevator.

Energy-Efficient LED Lighting

LED lighting, that utilizes a lot less energy than ordinary fluorescent or incandescent lighting, has been fitted in smart elevators. Additionally, LEDs have a longer lifespan, which reduces maintenance costs and minimizes the need for frequent replacements.

Integrated Backup Power System

To ensure passenger safety during power outages, smart elevators include an integrated backup power system. This system enables the elevator to reach the nearest floor and open its doors, preventing passengers from being trapped and ensuring safe evacuation.

Artificial Intelligence (AI)-Powered Algorithms

AI algorithms analyze usage patterns and optimize elevator scheduling and movement. By predicting peak usage times and adjusting operations accordingly, AI minimizes energy waste and improves overall system performance.

Touchless Access and Security Features

Smart elevators incorporate touchless technologies, such as RFID cards, smartphone apps, or biometric systems, for secure and hygienic access. These features promote security and convenience, which renders them especially helpful in sensitive or hectic settings.

Real-Time Monitoring and Remote Management

Operators can keep an eye on elevator operational efficiency in real time thanks to cloud-based solutions. Software revisions, problem detection, and troubleshooting are made easier by remote management solutions, which eliminate the need for on-site service. This capability improves maintenance efficiency and reduces downtime [5].

LIFT PATH OPTIMIZATION

The optimization of lift paths plays a crucial role in improving the efficiency, speed, and energy consumption of elevator systems, especially in high-rise buildings where multiple lifts operate simultaneously. Lift path optimization involves designing algorithms and control systems to reduce travel time, minimize waiting time for passengers, and optimize energy usage. This section discusses the strategies and techniques used for effective lift path optimization [6].

Scheduling Algorithms

First-Come, First-Served (FCFS)

This is the simplest scheduling algorithm where elevators respond to requests in the order they are received.

Nearest Car (Best Fit)

This algorithm directs the nearest available elevator to respond to a request.

Group Control System

This system manages a group of elevators together rather than individually. It uses algorithms to determine which elevator should respond to requests based on various criteria.

Dynamic Scheduling (Adaptive Algorithms)

These algorithms adjust elevator responses based on real-time demand and current traffic conditions. They use data from past usage patterns to predict future demand.

Multi-Objective Optimization (MOO)

This algorithm uses multi-objective optimization techniques to balance various competing objectives in elevator scheduling, such as minimizing wait time, travel time, and energy consumption.

Heuristic Algorithms

Heuristic algorithms use problem-solving techniques that find satisfactory solutions to complex scheduling problems through experience-based approaches rather than guaranteed optimal solutions [7].

Nearest Neighbor algorithm

It is a simple and intuitive machine learning algorithm commonly used for classification and regression tasks. The basic idea behind this algorithm is that similar data points are likely to be near each other in feature space. Here is how it works.

IMPLEMENTATION OF ALGORITHM

Nearest Neighbor Algorithm

The Nearest Neighbor Algorithm (NNA) is a widely used heuristic approach for solving optimization problems where proximity or shortest path is a critical factor. In the context of lift path optimization, this algorithm is employed to determine the most efficient sequence of stops for an elevator by minimizing the travel distance or time.

Concept

Nearest Neighbor operates on the idea that data points that are close together share similar characteristics. It is based on the principle of "finding neighbors", where the similarity (or closeness) between data points is calculated using a distance metric, like Euclidean distance, Manhattan distance, or Hamming distance.

Types of Nearest Neighbor Algorithms

- *K-Nearest Neighbors (KNN):* This is the most popular version, where “K” represents the number

of nearest neighbors considered to make a prediction. For example, if K=3K=3K=3, then the algorithm looks at the 3 closest data points.
- *1-Nearest Neighbor:* This is a special case where K=1K=1K=1, meaning the algorithm looks for the closest data point to classify or predict the target value of a new data point.

How It Works

The Nearest Neighbor Algorithm follows a step-by-step process to determine the optimal path for an elevator:
- *Initialization:* The algorithm begins with the elevator's current position as the starting point.
- *Calculate Proximity:* All pending floor requests are evaluated based on their "distance" from the current position. The distance can be defined as the number of floors between the current and requested floors.
- *Select Nearest Floor:* The algorithm identifies the nearest pending floor request and selects it as the next destination [8].
- *Serve Request and Update:* The elevator moves to the selected floor, fulfills the request (e.g., picking up or dropping off passengers), and updates its current position.
- *Dynamic Recalculation:* The algorithm recalculates the next nearest floor based on the updated position, taking into account any new requests that may have arrived.
- *Repeat Until All Requests Are Served:* The process continues until all floor requests are addressed (Figure 2).

Example Scenario

To illustrate how the nearest neighbor algorithm optimizes lift paths, consider an elevator system in a 10-floor building with the following requests (Table 1 and Figure 3).

Table 1. Passenger data.

Starting floor	Destination floor	Passenger floors
1	15	3, 7, 12
2	10	4, 5, 9
3	20	6, 11, 17, 18
5	25	8, 13, 14, 21
1	12	2, 4, 6, 10
6	18	7, 9, 14, 16
3	15	5, 8, 10, 11
2	12	4, 5, 7, 9
4	14	6, 9, 13
1	10	2, 3, 5, 6
7	20	8, 10, 15, 18
5	15	6, 9, 12, 14
8	22	10, 13, 16, 21
4	19	5, 7, 10, 17
2	17	6, 11, 13, 15
5	14	7, 8, 9, 13
3	11	4, 5, 6, 10
1	16	3, 8, 10, 12
4	18	7, 10, 15
2	14	6, 8, 11, 13

Initial Position: Floor 5
Pending Requests: Floors 3, 7, 1, and 9.

Step-by-Step Execution

Step 1: Start at Floor 5

Calculate distances:
Floor 3: |5–3|=2
Floor 7: |5–7|=2
Floor 1: |5–1|=4
Floor 9: |5–9|=4
Floors 3 and 7 are equidistant. For simplicity, the algorithm selects Floor 3.

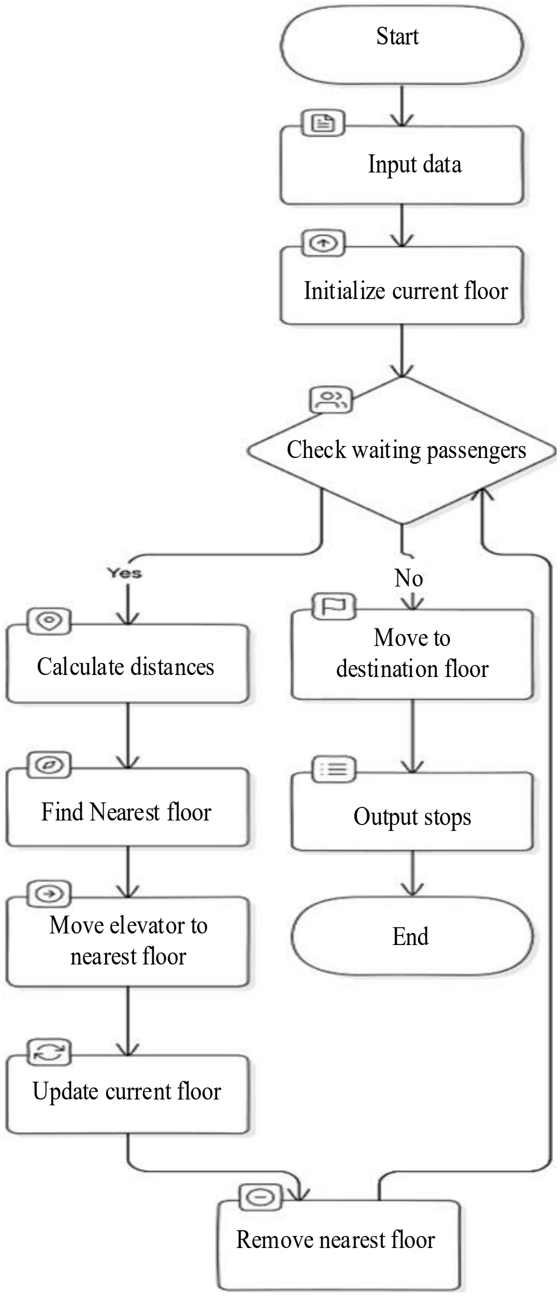

Figure 2. Flowchart NNA algorithm.

Step 2: Move to Floor 3

Serve the request at Floor 3.
Recalculate distances:
Floor 7: $|3-7|=4$
Floor 1: $|3-1|=2$
Floor 9: $|3-9|=6$
The nearest floor is Floor 1.

Step 3: Move to Floor 1

Serve the request at Floor 1.
Recalculate distances:
Floor 7: $|1-7|=6$
Floor 9: $|1-9|=8$
The nearest floor is Floor 7.

```
# Load data from the Excel file
excel_file = 'requests.xlsx'
data = pd.read_excel(excel_file)

# Extract the starting floor, destination floor, and passenger floors from the DataFrame
starting_floor = int(data['Starting Floor'][0])  # Convert to standard Python int
destination_floor = int(data['Destination Floor'][0])  # Convert to standard Python int
# Convert the passenger floors from a comma-separated string to a list of integers
passenger_floors = list(map(int, data['Passenger Floors'][0].split(',')))

# Get the elevator stops sequence
stops_sequence = nearest_neighbor_elevator_schedule(starting_floor, destination_floor, passenger_floors)

# Print the sequence of stops
print("Elevator stops in the following order:", stops_sequence)

import pandas as pd

def nearest_neighbor_elevator_schedule(starting_floor, destination_floor, passenger_floors):
    # Initialize the elevator's position and the stops list
    current_floor = starting_floor
    stops = []

    # While there are floors with waiting passengers
    while passenger_floors:
        # Find the nearest floor with a waiting passenger
        nearest_floor = min(passenger_floors, key=lambda x: abs(x - current_floor))

        # Move the elevator to the nearest floor
        stops.append(nearest_floor)
        current_floor = nearest_floor

        # Remove the floor from the passenger list (indicating pickup)
        passenger_floors.remove(nearest_floor)

    # After all passengers are picked up, move to the destination floor
    stops.append(int(destination_floor))  # Convert to standard Python int
```

Figure 3. Code of NNA.

Step 4: Move to Floor 7

Serve the request at Floor 7.
Recalculate distance:
Floor 9: |7–9|=2
The nearest floor is Floor 9.

Step 5: Move to Floor 9

Serve the request at Floor 9.
Final Sequence of Stops: Floors 3 → 1 → 7 → 9

RESULT

Output

The nearest neighbor algorithm offers a straightforward and efficient approach for optimizing elevator paths in single-elevator systems. By prioritizing proximity, it minimizes travel distance and improves passenger satisfaction. However, its limitations in achieving global optimization and handling complex traffic patterns necessitate enhancements for broader applicability. Integrating NNA with advanced algorithms and predictive models can further enhance its performance, making it a valuable tool for modern elevator systems (Figure 4).

```
PROBLEMS    OUTPUT    DEBUG CONSOLE    TERMINAL    PORTS    COMMENTS

PS D:\BE robotics\MVS_34\Practical_2\Code\python code> & C:/Users/RUSH/
2/Code/python code/elevator.py"
Elevator stops in the following order: [5, 1, 9, 15, 20, 20]
PS D:\BE robotics\MVS_34\Practical_2\Code\python code>
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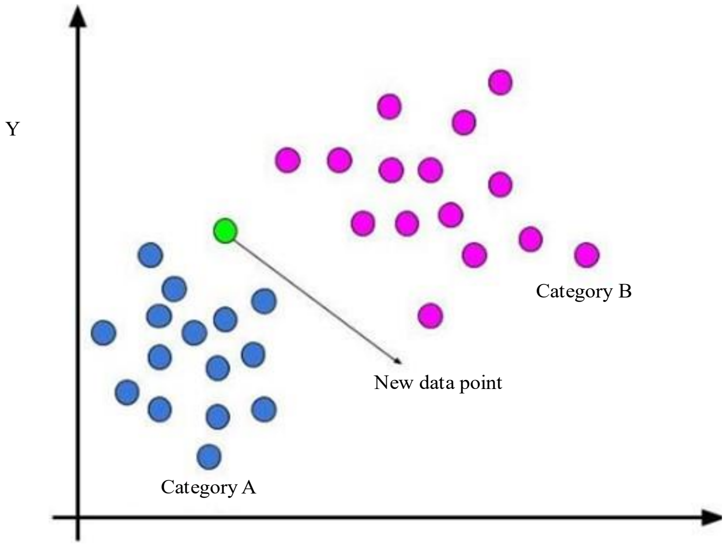

Figure 4. Graph of NNA.

SECOND APPROACH

Genetic Algorithm

Genetic Algorithm (GA) is an evolutionary optimization technique inspired by natural selection. It is highly effective for solving complex, multi-objective problems, such as lift path optimization, by finding near-global solutions. In lift systems, GA is used to determine the optimal sequence of floor stops, minimizing travel time, energy consumption, and passenger waiting time. The algorithm begins by encoding potential solutions (sequences of floor stops) as chromosomes and initializing a population of these sequences. Through iterative processes of selection, crossover, and mutation, GA generates improved solutions over successive generations. A fitness function evaluates each chromosome based on key objectives like minimizing energy use and response time, guiding the algorithm toward the best path [9, 10].

For instance, in a scenario with multiple floor requests, GA evaluates various sequences and identifies the one that optimally balances objectives. Unlike traditional algorithms such as Nearest Neighbor, which prioritize local optimization, GA explores a broader solution space to achieve near-global optimization. While computationally intensive, its ability to adapt to dynamic, real-time traffic patterns makes it ideal for multi-elevator systems in high-rise buildings. By incorporating real-time data and fine-tuning parameters, GA enhances elevator efficiency, reducing delays and energy costs, thereby contributing to smarter and more sustainable vertical transportation (Figure 5).

The application of Genetic Algorithms (GA) for lift path optimization provides a robust and efficient approach to addressing the complexities of modern elevator systems. By leveraging the principles of natural selection, GA explores a wide range of possible solutions to find the optimal sequence of floor stops. This ensures significant improvements in minimizing travel time, reducing energy consumption, and enhancing passenger satisfaction. Unlike traditional algorithms that focus on local optimization, GA achieves near-global optimization, making it particularly effective for high-traffic, multi-elevator systems.

While the computational demands of GA can pose challenges, advancements in processing power and real-time data integration have made it increasingly viable for practical deployment. The ability of GA to adapt dynamically to changing traffic patterns and prioritize multiple objectives simultaneously positions it as a powerful tool for creating smart and sustainable elevator systems. With further research and refinement, GA has the potential to revolutionize vertical transportation, meeting the growing demands of urban infrastructure efficiently and effectively.

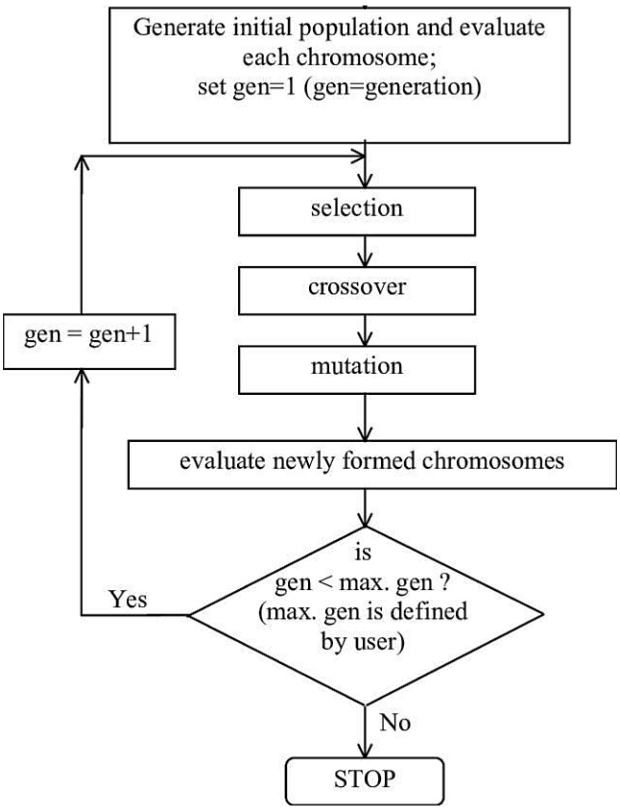

Figure 5. Flowchart of genetic algorithm.

CONCLUSION

The development of fast and power-efficient elevators is a crucial innovation in addressing the demands of modern urbanization, where high-rise buildings have become the norm. The integration of advanced technologies, such as intelligent algorithms, energy-efficient components, and real-time control systems, has revolutionized elevator systems by enhancing speed, optimizing energy consumption, and improving user satisfaction. Key advancements, including lift path optimization techniques like the Nearest Neighbor Algorithm and Genetic Algorithms, enable elevators to dynamically adapt to traffic patterns, minimize waiting times, and reduce unnecessary travel distances. These improvements not only ensure faster vertical transportation but also significantly lower energy costs, contributing to environmental sustainability and operational efficiency.

Despite the progress made, challenges remain, such as the need for scalability in multi-elevator systems and the integration of renewable energy sources to further reduce environmental impact. Future advancements could involve the application of artificial intelligence and machine learning to predict traffic patterns and optimize operations in real-time. Additionally, combining advanced materials for lighter and stronger components with regenerative braking systems could further improve energy efficiency. The development of fast and power-efficient elevators is a step toward smarter, greener cities, aligning with the global goal of sustainable urbanization while ensuring comfort and convenience for building occupants. This research emphasizes the importance of continued innovation and interdisciplinary collaboration to meet the growing demands of modern infrastructure.

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