Research on a lift car collision avoidance strategy for a circulatory multipath elevator based on digital twins

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Abstract. To reduce the lateral movement time of elevator passengers in large-span high-rise buildings, a circulatory multipath elevator design scheme is proposed. To reduce the complexity of the circulatory multipath elevator control process due to the increase in the number of lift cars, a circulatory multipath elevator control system framework is established based on digital twin technology. To ensure the safe operation of the elevator, a lift car following model is established, and a circulatory multipath elevator collision avoidance strategy is designed. The lift car collision avoidance strategy can effectively reduce collision accidents in the process of multi lift car operation and ensure the safety of elevator passengers.

1. Introduction

After establishing the same physical model as an entity and fully collecting sensor data, the digital twin of the entity uses these data to simulate the state of the physical entity in a real-time environment on a computer and ultimately improves the performance of the physical entity by means of interaction, fusion and analysis [1]. Digital twin technology can be combined with computer, material, mechanical and other disciplines. Currently, digital twin technology is widely used in manufacturing, design, equipment management and other fields [2].

With the rapid development of urbanization, the rapid growth of the urban population has brought great challenges to urban infrastructure such as buildings [3]. Due to the pressure of a shortage of land resources caused by the rapid growth of the urban population, the scale of buildings has gradually expanded [4]. In high-rise buildings with large spans, an elevator cannot achieve automatic transportation in the lateral direction, resulting in a low efficiency of passenger movement and poor passenger mobility [5].

Therefore, this paper proposes a circulatory multipath elevator design scheme to solve the problem that an elevator cannot efficiently run laterally and to save the time used by elevator passengers in lateral movement. Focusing on a circulatory multipath elevator structure, an elevator control framework based on digital twins is proposed to achieve the overall control of a circulatory multipath elevator system, and a lift car collision avoidance strategy is studied to control the lift car running speed and improve the safety of the elevator.
2. Circulatory multipath elevator
The circulatory multipath elevator is an improvement on the structure of the circulatory multicar elevator [6-8], which combines two long-distance circulatory multicar elevators through four lateral moving channels. The structure of the circulatory multipath elevator is shown in figure 1. The circulatory multipath elevator has four vertical shafts and four lateral moving channels. The four vertical shafts are the No. 1, No. 2, No. 3 and No. 4 vertical shafts. The four lateral moving channels are the No. 1, No. 2, and No. 3 and the No. 4 lateral moving channel. To enable the diversion of passengers with different mobile demands, passengers are divided into vertical moving passengers and lateral moving passengers. The vertical moving passengers are the passengers moving vertically in the current vertical shaft, and the lateral moving passengers are the passengers who need to move to the other side of the vertical shaft before reaching the target layer. Therefore, according to the type of lift carrying the passengers, the lift cars are divided into vertical lift cars and transverse lift cars. A vertical lift car is responsible for carrying vertical moving passengers, and a transverse lift car is responsible for carrying lateral moving passengers.

Figure 1. Structure of circulatory multipath elevator
To avoid operational conflicts among different types of lift cars, four cycle paths are planned for the lift cars. Cycle path A is the cycle path of a vertical lift car between the No. 1 vertical shaft, No. 2 lateral moving channel, No. 2 vertical shaft and No. 3 lateral moving channel. Cycle path B is the cycle path of a vertical lift car between the No. 3 vertical shaft, No. 2 lateral moving channel, No. 4 vertical shaft and No. 3 lateral moving channel. Cycle path C is the cycle path of a transverse lift car between the No. 1 vertical shaft, No. 1 lateral moving channel, No. 4 vertical shaft and No. 4 lateral moving channel. Cycle path D is the cycle path of a transverse lift car between the No. 2 vertical shaft, No. 3 lateral moving channel, No. 3 vertical shaft and No. 2 lateral moving channel. A lift car of a circulatory multipath elevator is driven by a linear motor. To enable the operation of the lift car between different vertical shafts and lateral channels, a reversing device is installed at the connection of the vertical shaft and the lateral moving channel to change the moving direction of the lift car. Therefore, the elevator has 12 reversing devices.

A lift car of a circulatory multipath elevator runs in the same direction in the cycle path to transport vertical and lateral moving passengers. Due to the increase in the number of lift cars in the elevator system, the complexity of the elevator control process and the risk of collision between the lift cars are also increased. Therefore, it is necessary to design an elevator control system to meet the control requirements of a circulatory multipath elevator.
3. Circulatory multipath elevator control system based on digital twin

To establish a circulatory multipath elevator control system, first, the elevator entities that the control system needs to control are studied, and the existing data and functions of the entities are explored. Through these data, the control entities can be described to obtain the status of the entities and control them. In a circulatory multipath elevator, the control system obtains the passenger's call command information through the call panel and then assigns the elevator to transport the passengers to the destination floor. The lift car is responsible for carrying passengers and has properties that include location, speed and the number of people in the lift car. The landing door is used to close the elevator shaft and plays the role of ensuring safety, and its data primarily include the opening and closing state data. The lift car door is used to close the lift car and ensure the safety of passengers in the lift car, and its data primarily include the door switch status data. The reversing device is used to change the running direction of the lift car, and its data include the rotation angle, occupancy status and other data. A safety device is used to prevent falling, overspeed and other accidents of lift cars, and its data include its action state data.

The physical entities of circulatory multipath elevators mainly include passengers, elevator action entities and sensors. The elevator action entities usually include a traverse lift car, vertical lift car, lift car door and landing door. Through the installation of sensors, the control system can obtain the elevator position, passenger command, passenger number and other key data in real time to perform lift car scheduling.

The twin model layer consists of twin data and a digital model. The twin data are collected in real time by sensors installed on each part of the elevator, and the digital model is a simulation model of each action entity of the elevator. The twin data are obtained from the data collected by the sensor installed on the elevator entity. The position, displacement and speed information of the elevator entity are obtained by storing, mining, converting and calculating the data. The digital model maps each action entity in the elevator through the twin data, thus constructing a twin model of the circulatory multipath elevator entity.

Through the data interaction with the twin model, the function layer can control and monitor the operation of the circulatory multipath elevator in real time. Through the analysis and learning of elevator fault data, the function layer gives early warnings of elevator faults, guides the elevator maintenance work, and improves the utilization rate and service life of the elevator. Through artificial intelligence and machine learning methods, the historical passenger flow data stored in the twin data are analyzed and learned in order to achieve elevator passenger flow prediction and passenger flow pattern recognition. Through the analysis and statistics of twin data, and using various intelligent optimization algorithms combined with the prediction of the elevator passenger flow and traffic mode, the optimization decision of the elevator scheduling process is obtained. The control of the digital model is carried out based on data interaction. Through the real-time mapping of the digital model and action entities, optimal elevator dispatching and lift car number optimization are ultimately realized. The real-time mapping of elevator action entities is the basis of the integration of the virtual and the real in the process of elevator control, and it is also the key factor in achieving the precise control of the lift car by the elevator control system. As passengers are the senders of the elevator control commands and the receivers of the elevator lift carrying actions, the accurate identification of passengers plays an important role in elevator operation scheduling. Due to the complexity of the passenger movement demand of the circulatory multipath elevator, it is difficult to identify the passengers, and the increase in the number of lift cars also increases the complexity of monitoring the passengers taking the elevator.

To fully mine the passenger data to guide the operation of the elevator control system and reduce the complexity of the elevator ride process, the elevator control panel is divided into four areas: the call button area, layer selection button area, elevator guidance area and operation status area. The call button area is responsible for collecting the passenger's movement direction (vertical or lateral movement) and the passenger's call time. The layer selection button area is responsible for collecting the target layer of passengers. The elevator guidance area is responsible for prompting passengers to enter the designated lift car to take the elevator. The operation status area is responsible for displaying the lift car type, arrival
time and other operation data. The control system extracts the data of the passenger movement type, waiting number, calling time, boarding time, passenger flow density and lateral movement density by collecting and mining passenger input instructions to provide rich reference data for the control system and improve the accuracy of elevator dispatching.

4. Lift car collision avoidance strategy

In 1981, Gipps proposed a safety distance model to control the speed of a vehicle. When the front vehicle performs emergency braking, the rear vehicle can adjust its speed to maintain the distance between the two vehicles to avoid collision [9]. The safety distance model simplifies the calibration of model parameters and reduces the complexity of the simulation process. It is widely used in the field of traffic simulation and is a classic model in the field of micro-traffic flow [10]. A circulatory multipath elevator is composed of multiple cycle paths and different types of lift cars. There is a possibility of multiple lift cars running in the same cycle path, and the lift car stops in real-time response to passenger instructions during the operation process. Therefore, to avoid collisions in the process of multilift car operation, a lift car following model is established based on the safety distance. The model can adjust the running speed of the lift car to ensure the safe and stable operation of the lift car and avoid collision accidents. The safety distance model proposed by Gipps includes two parts: the speed $v_1$ for obstacle-free travel and the speed $v_2$ when there is an obstacle in front of the vehicle and emergency braking is required [17]. The operation process of the circulatory multipath elevator also includes the lift car stopping action, that is, the process of moving to the designated floor to stop smoothly. According to the safety distance model proposed by Gipps, the calculation formula for the lift car stopping speed $v_3$ is derived. Finally, the lift car following model of the circulatory multipath elevator is established, as shown in equation (1):

$$
\begin{align*}
  v_1(t + \tau) &= v_n(t) + 2.5a_n \tau \left(1 - \frac{v_n(t)}{V_n}\right) \sqrt{0.025 + \frac{v_n(t)}{V_n}} \\
  v_2(t + \tau) &= -b_n \left(\frac{\tau}{2} + \theta\right) + \sqrt{b_n^2 \left(\frac{\tau}{2} + \theta\right)^2 + b_n \left\{2[L_n - S_{n-1}] - \tau v_n(t) + \frac{v_{n-1}^2}{b_{n-1}}\right\}} \\
  v_3(t + \tau) &= -b_n \left(\frac{\tau}{2} + \theta\right) + \sqrt{b_n^2 \left(\frac{\tau}{2} + \theta\right)^2 + b_n \left\{2[L_n - S_{n-1}] - \tau v_n(t)\right\}} 
\end{align*}
$$

In the formula, $a_n$ is the maximum acceleration of lift car $n$; $b_n$ is the maximum deceleration of lift car $n$; $V_n$ is the maximum driving speed of lift car $n$; $\tau$ is the reaction time of the control system; $v_{n-1}$ is the maximum driving speed of lift car $n - 1$ in front of lift car $n$; $b_{n-1}$ is the maximum deceleration of lift car $n - 1$; $\theta$ is the action time of the braking device; $L_n$ is the distance between the lift car and the landing point; $x_n$ is the position of lift car $n$; $x_{n-1}$ is the position of lift car $n - 1$; and $S_n$ is the minimum safety distance that lift car $n$ should maintain while driving.

The final speed of the lift car is the minimum value between the speed $v_1$ when the lift car is free from obstacles, the speed $v_2$ when there is an obstacle and the speed $v_3$ when the lift car stops, as shown in equation (2):

$$
v_n(t + \tau) = \min (v_1, v_2, v_3)
$$

In the vehicle following process, the safety distance $S_n$ includes the front vehicle length $L$ and the safety distance $m$. The running directions of the lift car include vertical and lateral directions. In the process of vertical operation, the safety distance of the lift car is the sum of the height of the lift car and the distance between the lift cars. In the lateral operation of the lift car, the safety distance of the lift car
is the sum of the lift car width and the lift car spacing. Therefore, the safety distance of the lift car changes with the running direction of the lift car. The comparison of the lift car following process between the running directions is shown in figure 2.

Figure 2. The comparison of the lift car following process between the running directions

In the process of lift car following, there is a space reversing device between the front and rear lift cars, as shown in figure 3. To improve the operational efficiency of the elevator and reduce the impact of the lift car reversing process on the passenger arrival time, if the reversing device crosses between the rear lift car and the front lift car, the safety distance is adjusted to the interval distance between the reversing device nearest to the rear lift car and the front lift car, as shown in figure 4.

Figure 3. The situation of the spacing reversing device between the front and rear lift car

Figure 4. Schematic diagram of safety distance adjustment

In the operation of a circulatory multipath elevator, lift cars of different cycle paths may arrive at the same reversing device and enter the same vertical shaft at the same time. To avoid collision accidents involving the lift cars, the operation priority is set for the lift cars according to the cycle path of each lift car to ensure the orderly operation of the lift cars, as shown in figure 5. A lift car with low operation priority stops in front of the reversing device, waiting for the lift cars with higher operation priority to pass through the reversing device before entering the steering device.

Figure 5. Priority of lift car operation
Through the circulatory multipath elevator control system based on a digital twin, the lift car operation data, including the number of lift cars running, the running speed of each lift car, the location, the maximum acceleration, the maximum deceleration, the operation priority and the landing floor, are obtained. The running speed of each lift car is calculated through the lift car following model of the circulatory multipath elevator.

5. Conclusions
The circulatory multipath elevator lift car collision avoidance strategy based on digital twin technology can accurately control the lift car free running speed, braking speed and parking speed and can be used with a lift car operation priority system. A lift car with low priority can be controlled to avoid lift cars with high priority, thus avoiding lift car collisions. The collision avoidance strategy can control the lift car running speed to slow down smoothly and reach the designated landing position accurately. By controlling the running speed of the rear lift car, the minimum safety distance from the front lift car is maintained. Through digital twin technology, the circulatory multipath elevator collision avoidance strategy can obtain rich elevator operation data, thus achieving real-time control of the lift car speed, reducing the complexity of the circulatory multipath elevator control process, and improving the safety of the multipath elevator system.

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