Design and dynamics analysis of intelligent modular cabinet parking device

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Abstract. With the development of economy and the rapid increase of car ownership, as well as the shortage of land resources in the city, it brings an upgrading opportunity to the traditional parking industry, that is, to develop towards the three-dimensional garage direction. Based on this, this paper puts forward a set of intelligent modular cabinet parking device, which is mainly used in urban community. The device adopts a 3×3 modular cabinet type frame structure, which can not only be controlled by wireless connection of mobile phone, but also be controlled by observing dynamic display film keyboard. The control system of the garage can automatically dispatch the vehicles that are about to be stored in the garage, according to the current storage situation of the vehicles in the garage. It can also make free manual selection through the Arduino system.

1. Introduction

In recent years, China's rapid economic development has led to the rapid development of the automobile industry [1]. The number of families with private cars in the city is increasing, which has brought a lot of embarrassment, for example, urban congestion and parking difficulties and other problems. The development of the city has brought about the continuous increase in the number of vehicles, and at the same time the increase in the demand for the number of parking facilities. The relationship between the two is difficult to separate, linked each other, influenced each other [2]. If the number of vehicles and parking facilities is out of balance, it will bring a series of parking problems to the city. The core of the problem of parking difficulty is the parking difficulty of motor vehicles. The number of urban motor vehicles in Our country is increasing rapidly, with an average growth rate of 15-20% in recent years. In contrast, the average growth rate of supporting parking infrastructure is only 2%-3% [3, 4]. Especially in big cities, the gap between the growth rate of the two is even greater. Therefore, we should not turn a blind eye to the problem of parking difficulties [5]. We should face up to the reality and actively look for countermeasures. Three-dimensional parking is an ideal way to solve the above problems.

The structure and control management of the three-dimensional parking lot has been upgraded from the three-dimensional mechanical garage with simple structure to the modern three-dimensional garage with highly intelligent control. These have greatly improved the practicality of the garage and made it more suitable for the urban environment. Therefore, the parking industry has huge potential and...
unprecedented development opportunities. Compared with traditional parking, the market prospect is quite broad. Therefore, the development of three-dimensional parking garages has important economic benefits and social significance.

2. Scheme of intelligent modular cabinet parking device

2.1. Design ideas
The scheme of the intelligent modular cabinet parking device designed in this paper is shown in Fig. 1. The scheme adopts a cabinet-type multi-modular tooth comb structure design. The car is parked on the carrier plate and carried by the carrier device to the corresponding garage. The exchange between the carrier plate and the undertake plate is completed by the tooth comb structure, and the undertake plate transports the vehicle into the garage, and different modular assembly can be completed according to different community patterns, such as $3\times3/3\times5/2\times3$, etc. The relative position of the parking space and the lift way is designed to be more reasonable. The parking spaces are located on both sides of the lift way. The entrance and exit of the vehicle only need the tunnel space of the ordinary elevator size. There is no need to set up a separate traffic lane. It not only makes full use of space and saves space, but also makes the access of vehicles faster and more convenient.

2.2. Workflow
The working process of the intelligent modular cabinet parking device is divided into the parking process and the car retrieval process.

2.2.1. Parking process. When the user parks the car, use the mobile phone to connect to the Bluetooth to choose to park or directly click on the membrane keyboard and observe the operation of the monitor beside the garage. After selecting the corresponding parking garage number, the stepper motor drives the screw to rotate to lower the carrying plate to the road, the vehicle stops on the carrying plate, the carrying plate moves to the above of corresponding garage undertake plate. The rack is driven by the gear rotation to make the bearing plate come out smoothly, the carrier plate descends, and the vehicle is converted between the two mechanisms through the tooth comb structure. After the undertake plate enters the garage, the carrier plate returns to the original point to complete the parking process, as shown in Fig. 2.
2.2.2. Picking car process. When the user picks up the car, can use the mobile phone to connect to the Bluetooth to choose to pick up the car or directly click on the membrane keyboard and observe the operation of the monitor beside the garage. After selecting the corresponding garage number, the stepper motor drives the screw to rotate to move the carrier plate under the corresponding garage undertake plate, the undertake plate comes out steadily, the carrier plate rises, and the tooth comb structure is used to complete the vehicle exchange between the two devices. After the undertake plate enters the garage, the carrier plate drops to the ground and the vehicle drives away to complete the pickup process.

3. Design of intelligent control system

The device can be controlled by mobile phone wireless connection or by observing the dynamic display screen membrane keyboard. The system adopts Arduino intelligent control. Compared with other development boards, Arduino and peripheral products are relatively high-quality and low-cost, and have low learning or creation costs [6, 7, 8]. It is convenient for development and maintenance in daily life. It also has rich interfaces, such as digital I/O ports, analog I/O port, supports SPI, IIC, and UART serial communication at the same time, as shown in Fig. 3.
4. Simulation analysis
In order to simulate the situation where the garage has vehicles parked in all parking spaces, each garage should apply the force of a car. Generally, the average weight of a family car is 1.5 tons. The top surface of each layer of the frame is selected, and each surface is loaded with a force of 15000N in a vertical downward direction. After loading, right-click on Static Structural, select Solve, and start processing simulation information.

Insert Equivalent Stress, Total Deformation, and Linearized Stress in Solution, click Solve to display the simulation results of equivalent stress, total deformation, and path stress. The simulation result of equivalent stress is shown in Fig. 4, and the result data is shown in Table 1.

![Figure 4. Simulation results of equivalent stress](image)

It can be seen from Fig. 4 that the equivalent stresses are mainly distributed in the left and right garages. The equivalent stress distribution of the middle garage is less, and there is no obvious stress concentration. The equivalent stress appears from the garage on both sides of the frame and gradually becomes smaller toward the middle garage. Since there are vertical columns nearby that cause the shape
to change sharply, the stress is mainly concentrated in these locations. It can be seen from Table 1 that the maximum stress is 0.14041 MPa, the minimum stress is 2.0402e-17 MPa, and the allowable stress of the garage frame structural steel at room temperature is 235 MPa, indicating that the strength of the material meets the design expectations.

| Results          | Minimum Value Over Time | Maximum Value Over Time |
|------------------|-------------------------|-------------------------|
|                  | Min (MPa)               | Max (MPa)               |
| Min (MPa)        | Max (MPa)               | Min (MPa)               | Max (MPa)               |
| 2.0402e-17       | 0.14041                 | 2.0402e-17              | 0.14041                 |

The path stress simulation result is shown in Fig. 5, and the path stress curve is shown in Fig. 6. The path stress is represented by the third layer garage, and the front end of the third layer garage is selected as the path. The stress it bears can be approximated as the stress distribution of the third-story garage. Since the three layers of the garage have the same structure, it can be equivalent to the stress distribution of each floor. It can be seen from Fig. 5 that the maximum stress value is 0.11771 MPa, and the minimum stress value is 0.0019038 MPa. The color is gradually deepened from two ends to the middle, which shows that the stress distribution is also gradually decreasing from the two ends to the middle. It can be seen from the figure that the stress reaches larger values at about 1225mm, 1633mm, 5308mm, 14292mm and 18375mm, and the location of the larger values tends to be symmetrical, with the maximum value at about 14292mm. Combined with the two figures, it is concluded that there are vertical frame columns on both sides of the position where the larger stress value appears, and the stress concentration points appear at these positions because of the sharp changes in the cross-sectional dimensions of these places. Although there are several points where the stress is relatively concentrated, these stress values are all less than the allowable stress, so the frame strength meets the requirements.
It can be seen from Fig. 7 that the deformation of the frame is mainly concentrated in the middle parking space. The deformation of the left and right columns increases from the outside to the inside, and there is no deformation on the outermost side and the frame base. The position where deformation begins to occur is basically the same as the position where the equivalent stress is relatively concentrated, and the position where the intermediate stress is the least concentrated reaches the largest amount of deformation but gradually becomes gentle. The stress and the strain become a linear proportional relationship, so although the stress concentration at both ends has a small deformation, the tendency of the deformation to increase is the sharpest. The results of the total deformation data are shown in Table 2.

As shown in Fig. 8, the maximum deformation occurs at about 9800mm, the maximum deformation is \(3.3795 \times 10^{-2}\)mm, and the allowable deformation of structural steel is 0.4mm, so the total deformation of the frame meets the requirements. Therefore, this device meets the requirements regardless of local or overall deformation. The prototype model of the intelligent cabinet parking device designed in this paper is shown in Fig. 9.

**Table 2.** Total deformation data

| Results          | Minimum (mm) | Maximum (mm) | Minimum Value Over Time (mm) | Maximum Value Over Time (mm) |
|------------------|--------------|--------------|------------------------------|------------------------------|
|                  | 0            | 3.3795e-2    | 0                            | 3.3795e-2                    |

5. Conclusion

In this work, we have developed a set of intelligent modular cabinet parking devices, the main results are as follows:

(1) The structure of intelligent modular cabinet parking device is relatively simple, the garage institutions are independent of each other, easy to maintain, almost no damage to the community floor, construction and maintenance costs are low.
(2) The intelligent modular cabinet parking device can be controlled by wireless connection of a mobile phone, or by observing the dynamic display screen membrane keyboard.

(3) Perform statics analysis on the frame of the intelligent modular cabinet parking device, including equivalent stress analysis, path stress analysis and total deformation simulation. Equivalent stress maximum stress value is 0.14041MPa, minimum stress value is 2.0402e-17MPa, path stress maximum stress value is 0.0366MPa, minimum value is 0.0014388MPa, the allowable stress of garage frame structure steel at room temperature is 235MPa, indicating the strength of the material It meets the design expected requirements. The maximum deformation is 3.3795e-2mm, and the allowable deformation of structural steel is 0.4mm, so the total deformation of the frame meets the requirements.

Figure 9. Prototype of intelligent modular cabinet parking device

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