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Research on Adjustable Storage-Retrieval Device for Bicycle 3D Garages

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Abstract: Against the backdrop of the in-depth promotion of the concepts of sustainable development and green travel, the rapid surge in bicycle ownership has exacerbated the urban parking dilemma. Three-dimensional garages have offered a new solution approach to this problem, yet existing bicycle three-dimensional garages generally suffer from drawbacks such as low space utilization efficiency and poor vehicle compatibility, which has severely hindered their practical implementation and popularization. This study designs an adjustable storage and retrieval device with a comb-shaped interleaved structure. The motion principle is verified via three-dimensional modeling to ensure the safe and stable operation of the mechanisms, and static structural simulation analysis is conducted on the main mechanisms to verify the feasibility and rationality of their structures. This adjustable storage and retrieval device has effectively broken through the specification adaptation limitations of bicycle three-dimensional garages, and provides a reliable technical support for their practical application and large-scale popularization.

1. Introduction

Against the backdrop of the widespread advocacy of global sustainable development and green travel concepts, the bicycle has gained worldwide recognition and favor with its unique advantages [1]. In this context, the rapid surge in bicycle ownership has made the bicycle parking dilemma increasingly prominent [2]. Drawing on the design concepts and technologies of existing three-dimensional car garages, it is particularly imperative to explore an innovative solution that can effectively address the bicycle parking dilemma [3]. Meanwhile, three-dimensional garages, with their prominent advantages of space saving, high efficiency and convenience [4], have provided a new train of thought and approach for solving this problem [5].

Research on bicycle three-dimensional garages has a long history, and scholars at home and abroad have carried out numerous studies in this field [6]. The fast storage and retrieval device for bicycle three-dimensional garages developed by the team led by Zou Jiehui from Guilin University of Electronic Technology [7], and the warehouse-type automatic storage and retrieval three-dimensional garage for bicycles designed by the team led by Chang Qingqing from Nanning

University [8], boast advantages such as horizontal and vertical expandability and realizable multi-row and multi-layer parking, and thus serve as typical representatives among numerous garage designs. However, the storage and retrieval devices of these three-dimensional garages are designed for a specific size, resulting in poor vehicle compatibility. Therefore, this paper designs a bicycle storage and retrieval device compatible with various models and sizes, which adapts to different wheelbases and hub sizes by adjusting the wheel groove spacing.

2. Main Research Contents

The adjustable storage and retrieval device designed in this study is mainly composed of a conveying mechanism and a storage mechanism. The two realize the bicycle storage and retrieval operation through the relative motion mode of interleaved meshing of comb teeth. Meanwhile, the device can adjust the spacing of comb teeth to adapt to bicycles with different wheel diameters and front-rear wheelbases. As shown in Figure 1, the storage and retrieval device also includes a storage and retrieval motion mechanism; the conveying mechanism is mounted on the system-controlled storage and retrieval motion mechanism, thereby completing the processes of bicycle conveying, positioning and storage.

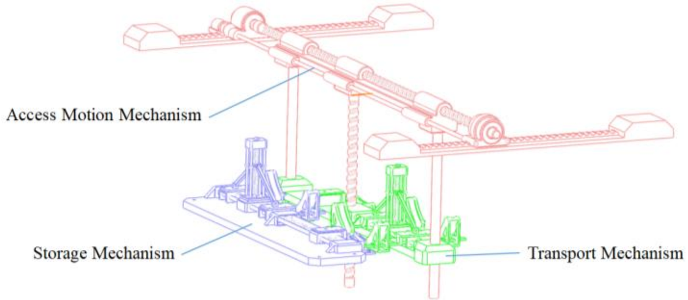

Figure 1: Structural Diagram of Adjustable Storage and Retrieval Device.

2.1. Design of the Transport Mechanism

The conveying mechanism is a key component of the bicycle storage and retrieval device, which is used to transport bicycles back and forth between the user deposit port and the target storage slot. To achieve compatibility with different bicycle models and ensure the safe and stable operation of the conveying mechanism when it moves with a bicycle loaded, the groove group for fixing the front wheel of a bicycle in the conveying mechanism is composed of two sets of lead screw modules, which can adapt to different wheelbases and bicycle sizes, as shown in Figure 2.

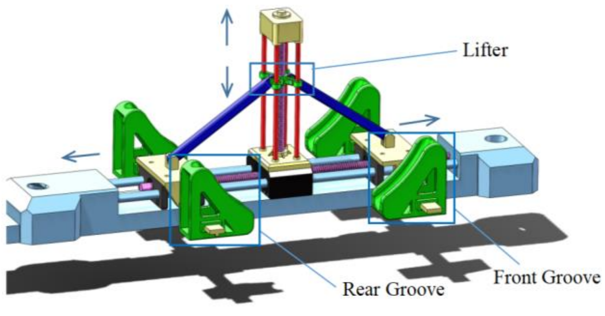

Figure 2: Adjustable structure of the wheel groove

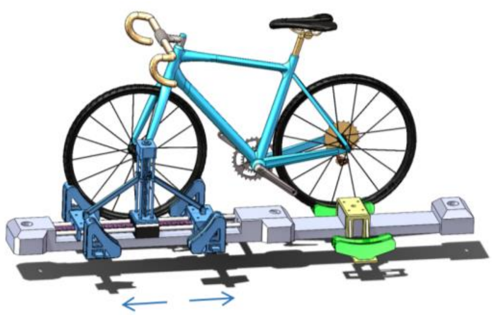

Figure 3: Wheel groove movement

The lead screw lifting module is driven by a motor to rotate the lead screw, which in turn drives the lifter to move up and down. The lifter adjusts the spacing between the front and rear grooves of the front wheel groove group through two push rods, so as to accommodate the wheel hub sizes of different bicycles. This lead screw lifting module is mounted on a horizontal lead screw linear motion platform, which can drive the front wheel groove group to move forward and backward, as shown in Figure 3. The rear wheel groove is fixed at the other end of the transport base plate; the movement of the front wheel groove relative to the rear wheel groove enables adaptation to the wheelbases of different bicycles.

2.2. Design of the Storage Mechanism

The storage mechanism is also a key component of the access device in the three-dimensional bicycle garage. Depending on its installation position, the storage mechanism varies in the number of available parking spaces: the one mounted on the side wall of the three-dimensional bicycle garage is as shown in Figure 4, while the one installed inside the three-dimensional bicycle garage is as shown in Figure 5.

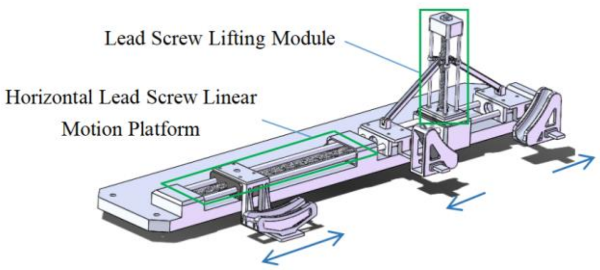

Figure 4: Side wall storage mechanism

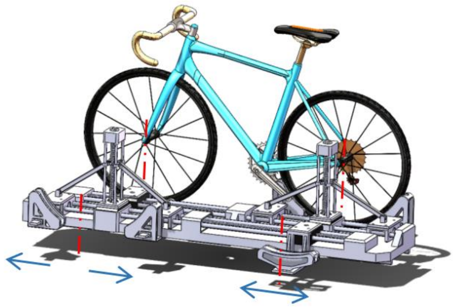
Figure 5: Internal storage mechanism

The storage mechanism is used for storing bicycles. Similarly to the transport mechanism, its lead screw lifting module enables the front and rear grooves to accommodate different wheel widths. The difference lies in that the lead screw lifting module and the horizontal lead screw linear motion platform module of the storage mechanism correspond to the front wheel groove and the rear wheel groove respectively. Specifically, the lead screw lifting module is fixed at the rear wheel position of the storage mechanism, which only allows the front and rear grooves of the rear wheel groove group to move while the lead screw lifting module (i.e., the center of symmetry of the front and rear grooves) remains fixed. The horizontal lead screw linear motion platform module is used to adjust the centerline spacing between the front wheel groove and the rear wheel groove, thereby adapting to the wheelbases of different bicycles.

2.3. Working Principle

2.3.1. Bicycle Storage and Retrieval Process

As shown in Figure 6, during bicycle storage, after the user places the bicycle on the adjusted transport mechanism, the transport mechanism transmits information such as the bicycle's wheel size and wheelbase to the target parking space. The target storage mechanism adjusts the spacing of the front and rear grooves as well as the wheel spacing based on this information to prepare for storage. Subsequently, the storage and retrieval motion mechanism transports the transport mechanism to above the target parking space, and the two complete the handover through staggered clearance cooperation of the grooves, finishing the storage process.

During bicycle retrieval, the transport mechanism first obtains information such as the wheel size and wheelbase of the bicycle in the target parking space, adjusts itself to adapt to the target bicycle, and makes preparations for lifting. After the storage and retrieval motion mechanism transports the transport mechanism to the position below the target parking space, the two complete the handover through staggered clearance cooperation of the grooves, finishing the retrieval process.

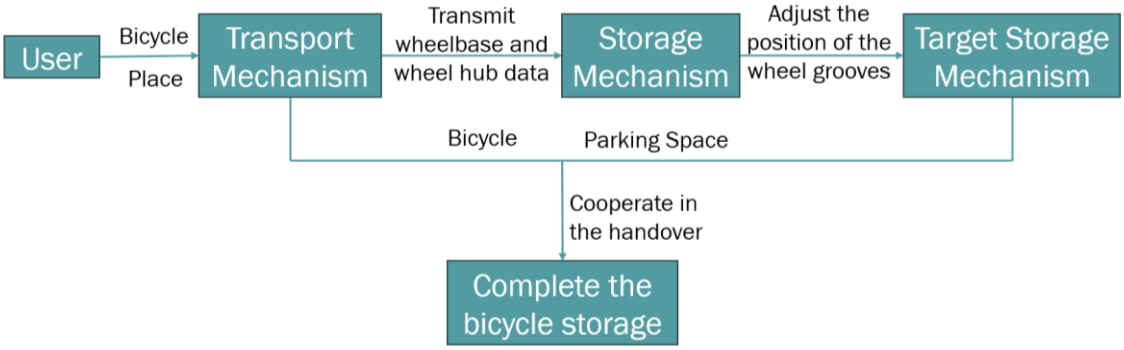

Figure 6: Bicycle storage flow chart

2.3.2. Transport Mechanism Adjustment

As shown in Figure 7, the user first locks the rear wheel of the bicycle into the rear wheel groove of the transport mechanism, then controls the front wheel groove group to move to accurately align with the center position of the front wheel according to the bicycle wheelbase parameter L. Subsequently, the user adjusts the opening and closing range of the front and rear grooves to adapt to the front wheel dimension parameter D, thus completing the positioning and placement of the bicycle on the transport mechanism.

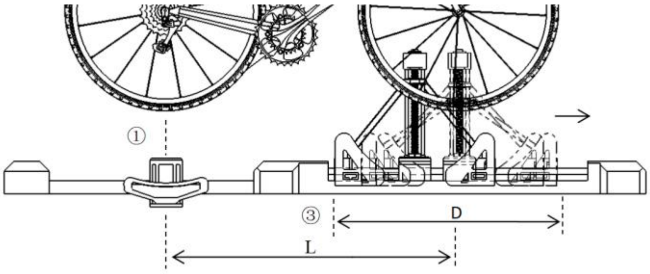

Figure 7: Adjustment process of the transport mechanism

2.3.3. Storage Mechanism Adjustment

When the transport mechanism is transporting the bicycle, it will transmit the information of the bicycle wheel size D and wheelbase L to the target parking space for the parking space to adjust and adapt accordingly. The front wheel groove of the target parking space moves according to the wheelbase L, while the rear wheel groove is adjusted according to the wheel size D, as shown in Figure 8.

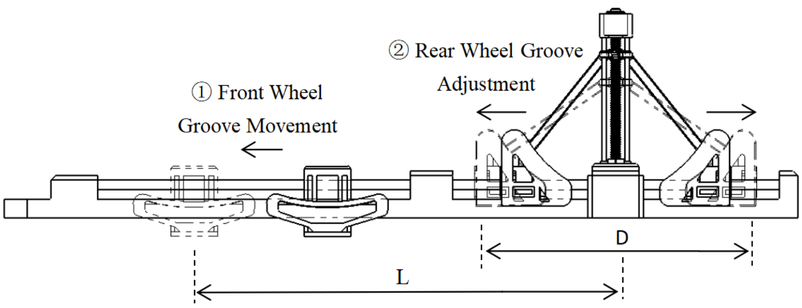

Figure 8: Adjustment process of the storage mechanism

2.3.4. Handover Between the Transport Mechanism and the Storage Mechanism

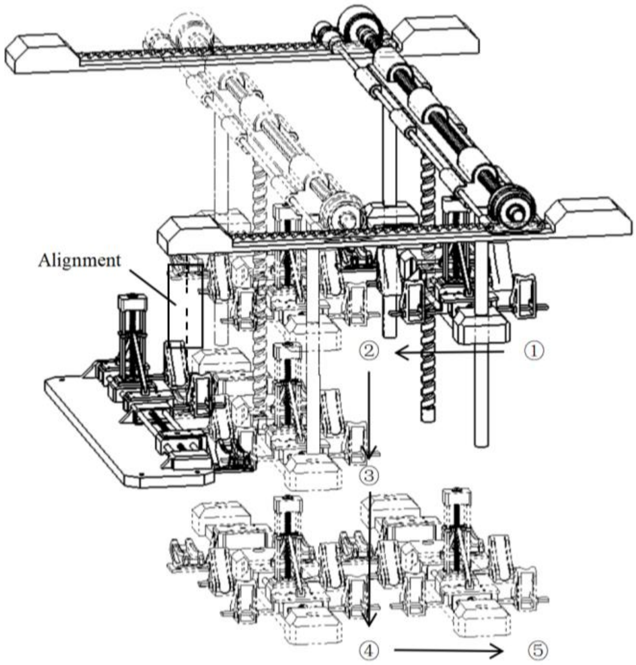

Figure 9: Bicycle handover process

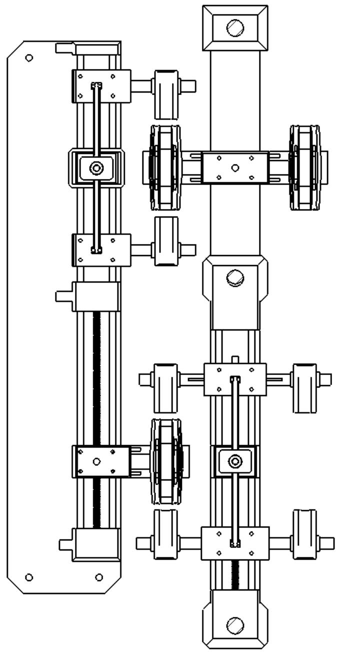

Figure 10: Staggered clearance handover of grooves

The transport mechanism first transports the bicycle to the position above and in front of the target parking space (marked as Position ① in Figure 9), and then moves to the position directly above the target parking space (Position ②) to complete docking. In this process, the center of the rear wheel groove of the transport mechanism begins to align with that of the target parking space, as shown in Figure 10. After reaching the position directly above, the transport mechanism moves downward to Position ③, the target parking space, to complete the bicycle handover, and then moves downward to depart immediately.

3. Statics Analysis

3.1. Statics Analysis of the Transport Mechanism

The wheel groove support frames of both the transport mechanism and the storage mechanism are made of ordinary carbon steel, and their mechanical property parameters are shown in Table 1.

Table 1: Mechanical property parameters of ordinary carbon steel.

Density (kg/m^3)	Elastic Modulus	Poisson's Ratio	Tensile Strength	Yield Strength
7850	206GPa	0.3	＞375MPa	＞235MPa

As described in the working principle, the transport mechanism is always adjusted under no-load condition, and all adjustment mechanisms are locked and stationary when carrying a bicycle, which allows static analysis to be performed on each load-bearing structure. In the static state, the weight of the carried bicycle is set to 25 kg, and the gravitational acceleration is calculated as 10 m/s^2. Static analysis is carried out on one side of the structure, as shown in Figure 11. The finite element analysis is performed using Simulation, the simulation plug-in in SolidWorks, and the stress nephogram and static force diagram are generated, as shown in Figures 12 and 13.

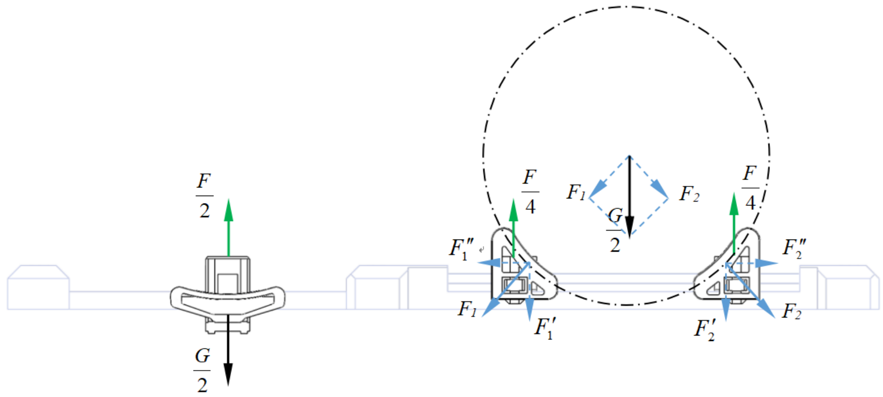

Figure 11: Statics analysis diagram of one side of the transport mechanism

In the statics analysis diagram, G represents the gravity of the bicycle, G/2 is the pressure exerted by the bicycle wheels on the front and rear wheel grooves, and F represents the supporting force exerted by the transport platform on the wheel groove support frames.

In the force analysis of the front wheel groove group:

$$\left(\frac{G}{2}\right)^2 = F_1^{\ 2} + F_2^{\ 2} \tag{1}$$

$$F_1^{\ 2} = F_1'^{\ 2} + F_1''^{\ 2} \tag{2}$$

$$F_2^{\ 2} = F_2'^{\ 2} + F_2''^{\ 2} \tag{3}$$

$$\frac{G}{2} = F_1' + F_2' \tag{4}$$

Since the center of the wheel groove group is aligned with the center of the bicycle wheel when carrying a bicycle, and the pressure G/2 bisects the included angle between F1 and F2, hence:

$$F_1 = F_2 \tag{5}$$

$$F_1' = F_2' = \frac{G}{4} \tag{6}$$

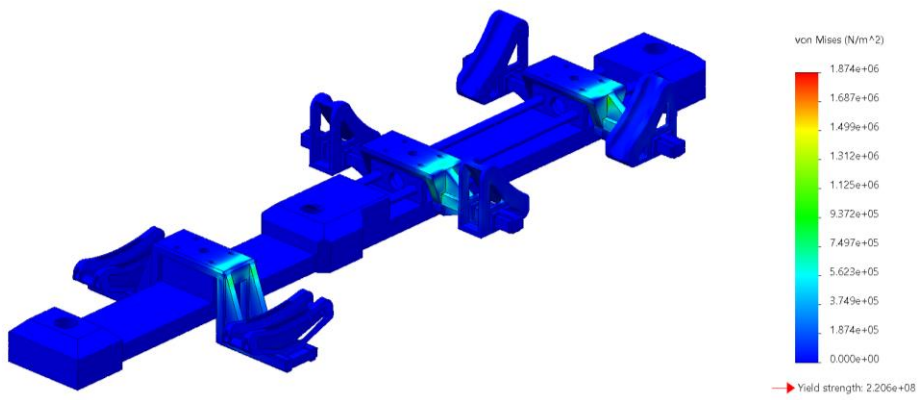

Figure 12: Stress diagram of the parking space on one side of the transport mechanism

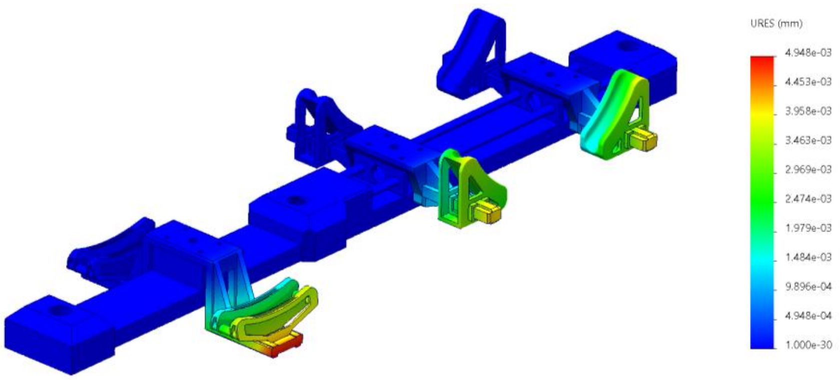

Figure 13: Displacement diagram of the parking space on one side of the transport mechanism

It can be seen from Figure 12 that the maximum stress occurs at the bent part of the wheel groove support frame, with a value of 1.874×10^{6} N/m ²(i.e., 1.874 MPa), which is much lower than the yield strength of ordinary carbon steel. It can be seen from Figure 13 that the maximum deformation area is located in the upper part of the front wheel groove group, with a maximum displacement of 4.949×10^{-3} mm (approximately 0.005 mm), which meets the maximum deformation requirements of the material and the design specifications.

3.2. Statics Analysis of the Transport Mechanism

Similarly to the transport mechanism, all wheel groove support frames of the storage mechanism are made of ordinary carbon steel, and the static analysis of each of its load-bearing structures is basically consistent with that in Figure 11. The finite element analysis is also performed using Simulation, the simulation plug-in in SolidWorks, and the stress nephograms and static force diagrams are plotted as shown in Figures 14 and 15.

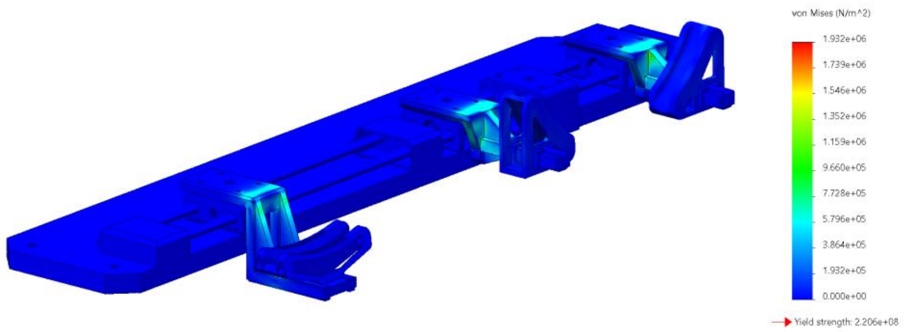

Figure 14: Stress diagram of the parking space on one side of the storage mechanism

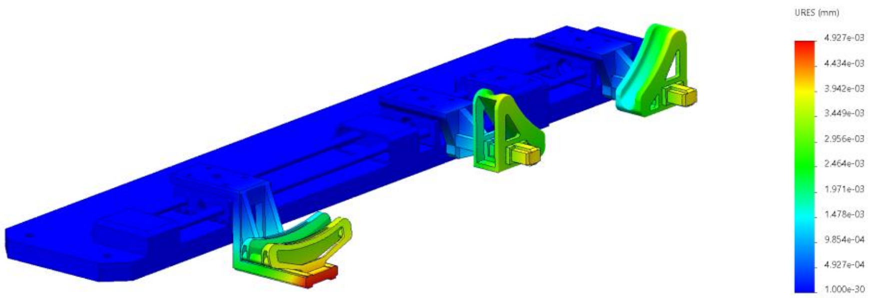

Figure 15: Displacement diagram of the parking space on one side of the storage mechanism

It can be seen from Figure 14 that the maximum stress also occurs at the bent part of the wheel groove support frame, with a value of 1.932×10^6 N/m^2 (i.e., 1.932 MPa), which is much lower than 235 MPa, the yield strength of ordinary carbon steel. It can be seen from Figure 15 that the maximum deformation area is located in the upper part of the rear wheel groove group, with a maximum displacement of 4.927×10^{-3} mm (approximately 0.005 mm), which meets the design requirements for the material and the mechanism.

4. Conclusion

This paper presents an adjustable self-service bicycle storage and retrieval device. The device adopts a comb-shaped interleaved structure, and by adjusting the spacing of the grooves, it is adaptable to bicycles with different wheel sizes and front-rear wheelbases. This device features strong vehicle compatibility and high storage and retrieval efficiency. This paper also conducts a static finite element analysis on the load-bearing structures of the transport mechanism and the storage mechanism. The simulation results verify the feasibility of this three-dimensional garage device, effectively address the problem of low compatibility in existing bicycle three-dimensional garages, improve the practicability and adaptability of self-service bicycle storage and retrieval, and provide a reliable technical support for its application and popularization.

Acknowledgments

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