Research on the development status of AGV parking robot based on patent analysis

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Abstract. With the increasing severity of parking problems, intelligent parking garages are gaining popularity. By the application in intelligent parking garages, AGV robot has opened a new application scenario after industrial and logistics fields. Dozens of enterprises have developed related products. Based on patent analysis method, the development trend, key technologies, regional distribution, advanced agencies and technology roadmap of AGV parking robot are clarified, to provide intelligence support for further development of related technologies and products. Research results indicate that AGV parking robot related technologies are booming. China exhibits great R&D enthusiasm towards this field in recent years, and has applied a large number of patents. In terms of vehicle exchange technologies, mechanical arm-based exchange and board based-exchange are key R&D types. In terms of vehicle guidance schemes, laser navigation, magnetic navigation, electromagnetic navigation and visual navigation are mainstream. Moreover, the improvement of driving mechanism, actuating mechanism and positioning mechanism of AGV parking robot, and the integration of AGV parking robot with stereo garage are the development trends of this field. Thus, countermeasures and suggestions are presented for the enterprises to further develop AGV parking robot related technologies.

1. INTRODUCTION
AGV (Automated Guided Vehicle) refers to the transport vehicle equipped with automatic guidance devices, which can autonomously travel along the prescribed guidance path, and has safety protection and various load shifting functions. With the emergence of AGV parking robot, it is expected that the traffic congestion and parking difficulties that have long plagued urban development will be comprehensively alleviated. At present, the most advanced AGV parking robot can dispatch 500 cars at the same time, and can minimize the gap between parking spaces. For the parking lot of the same area, the intelligent system can increase the number of parking spaces by 40%, which can greatly improve the utilization rate of parking space. Dozens of companies around the world have entered this field and developed related AGV parking robot products.

Vehicle exchange and vehicle guidance are the core technologies of AGV parking robot. As shown in figure 1, in terms of vehicle exchange, there are three main technical solutions, including board-based exchange, mechanical arm-based exchange, and comb teeth-based exchange [1-3]. In board-based exchange solution, the vehicle is parked on the board first, then the AGV is drilled under the board to carry the board and the vehicle to the designated parking position. In mechanical arm-based exchange solution, the AGV is drilled directly under the vehicle, and uses the mechanical arm or clamping mechanism to encircle the tires and then transfer and transport the vehicle. In comb teeth-
based exchange solution, the inner comb teeth are fixed, and the outer comb teeth are set on the AGV. The carrier uses the clearance of comb teeth and the lifting of AGV to realize the cross transposition of comb teeth and further the handover of vehicle. In terms of vehicle guidance, technical solutions include magnetic navigation, laser navigation, visual navigation, inertial navigation, etc. [4-5]

Based on the patent analysis method, the development status of AGV parking robot was investigated from the aspects of development trend, key technologies, regional distribution and advantageous institutions, to provide information support for related government departments, companies, universities and research institutes to further develop related industries and technologies.

Figure 1. Different types of vehicle exchange solutions, (a) Board-based exchange, (b) Mechanical arm-based exchange, (c) Comb teeth-based exchange.

2. DATA SOURCES

In this study, patents were retrieved and collected on Derwent patent database with keywords, IPC classification and CPC classification as searching routes, and with time scope from 1962 to Sep. 2018. A total of 233 patent families and 395 patents related to AGV parking robot were obtained. Patent analysis tools such as Derwent Data Analyzer and Derwent Innovation of Clarivate Analytics and PatentStrategy of LexisNexis were comprehensively used.

3. BASIC STATUS OF WORLD PATENT APPLICATIONS FOR AGV PARKING ROBOT

Figure 2. Annual distribution of patent applications for AGV parking robot.

Figure 2 shows the annual patent application trend of the AGV parking robot from 1983 to 2018. According to the trend, the technical development of AGV parking robot can be divided into two stages.

Stage 1 is ferment stage of AGV parking robot technology with time ranging from 2001 to 2014. In this stage, patent applications related to AGV parking robot exhibited small number and low growth rate. No more than 12 patents were applied every year. Main technology source countries were China.
and USA. China had pioneered research and development (R&D) in this area. The total number of patent applicants was only 39. The main applicants were Suzhou Dafang Special Vehicle of China, Unitronics Parking Solutions Ltd of Israel and Boomerang Systems Inc of USA.

Stage 2 is take-off stage of AGV parking robot technology with time ranging from 2015 to now. In this stage, patent applications related to AGV parking robot exhibited an obvious growth. In contrast to 6 patent applications in 2014, the incomplete number of patent applications was 72 in 2017. Because patents typically take 18 months to be publicly disclosed, the data of patent applications in 2017 and 2018 were still incomplete. China filed much more patents than other countries. The number of patent applicants has increased to more than 80. The main applicants were Shenzhen Yeefung Automation Tech Ltd, Danbach Robot Jiangxi Inc and Guangzhou United Faith Automobile Equipment Mfg Co Ltd of China. Shenzhen Yeefung Automation Tech Ltd launched the world-first AGV parking robot that adopted comb teeth-based exchange and laser navigation solutions and the China-first AGV parking robot that adopted board-based exchange solution in 2015. Hangzhou Hikrobot Technology Co Ltd launched the AGV parking robot that adopted visual and inertial dual navigation solution in 2016. Songling Robot Dongguan Co Ltd launched Buffalo AGV parking robot that adopted mechanical arm-based exchange solution.

4. DEVELOPMENT STATUS OF AGV PARKING ROBOT RELATED TECHNOLOGIES

4.1. Key technologies
Figure 3 is the topographic map of AGV parking robot field. It can be found that AGV parking robot with clamping arm (mechanical arm-based exchange type), AGV parking robot with board lift mechanism (board-based exchange type), AGV parking robot with comb teeth (comb teeth-based exchange type) and navigation technologies are the research focuses of this field.

![Figure 3. Patent topographic map of AGV parking robot.](image-url)

4.2. Vehicle exchange
As shown in figure 4, according to the patent indexing, among the 233 patent families for AGV parking robot, AGV parking robot using mechanical arm-based vehicle exchange technology and AGV parking robot using board-based vehicle exchange technology are the mainstream of R&D, accounting for 54% and 34% patents respectively. AGV parking robot using comb teeth-based vehicle exchange technology, which appears recently, accounts for 7% patents only.
4.3. Vehicle guidance

As shown in figure 5, among the 233 patent families for AGV parking robot, only 65 patent families disclose specific vehicle guidance technologies, including laser navigation, magnetic navigation, electromagnetic navigation, visual navigation, inertial navigation, ultrasonic navigation, RFID location, UWB location and GPS location. Visual navigation solution involves the use of two-dimensional code or bar code.

As shown in figure 6, more than five countries around the world have applied for patents in the field of AGV parking robot, including China, USA, Germany, South Korea and Japan in sequence. China accounts for most patent applications (86%), indicating China is very active in R&D of this field.
Among these source countries, China applied for the first related patent in 2001, leading the development of AGV parking robot technology. Since 2015, annual number of patent applications has been significantly higher than that of other countries. The main applicants of China are Shenzhen Yeefung Automation Tech Ltd, Danbach Robot Jiangxi Inc and Guangzhou United Faith Automobile Equipment Mfg Co Ltd. USA filed the first patent in 2006, and has filed related patents in almost every year since then. The main applicants of USA are Boomerang Systems Inc and Park Plus Inc. In addition, Unitronics Parking Solutions Ltd of Israel filed their patents in USA. The first patent of Germany was filed in 2011, and the main applicants are Serva Transport Systems Gmbh, Bosch Gmbh Robert and Kuka Roboter Gmbh. The first patent of South Korea was filed in 2008, and the main applicants are Korea Electronics and Telecommunications Research Institute (ETRI), Knu Ind Coop Found and Seong-Dae N. Japan started relatively late, and the applicants is Ishikawajima Yusoki KK.

Figure 6. Source countries and districts of AGV parking robot related patents.

6. PATENT ADVANCED AGENCIES OF AGV PARKING ROBOT

6.1. Ranking of applicants
More than 100 organizations and individuals have applied for AGV parking robot related patents worldwide. As shown in table 1, Top 20 applicants are mainly from China, USA and Israel. In addition to Shandong University, other applicants are companies, indicating that the research work in this field is mainly applied research and this field has entered in the industrialization stage.

China occupies the leading position in the field of AGV parking robot. In TOP 20 applicants, 17 applicants are from China, including Shenzhen Yeefung Automation Tech, Danbach Robot Jiangxi, Guangzhou United Faith Automobile Equipment, Hangzhou Jimu Tech, Suzhou Dafang Special Vehicle, etc. Among them, Shenzhen Yeefung Automation Tech has relatively longer active years, and patent applications in recent five years account for 93.3%, indicating the company starts early and are keeping R&D investment in this field. Suzhou Dafang Special Vehicle starts the earliest, but the patent application activity only lasts for one year and the average patent age is 6, indicating a possible shift in the company’s R&D focus. The patent application periods of companies such as Danbach Robot Jiangxi, Hangzhou Jimu Tech, Dongguan Songshan Lake Int Robot Res Inst, Shanghai Hictrl Automation Tech and Foshan Zhenrui Intelligent Tech are relatively short, and the average patent ages are relatively small, indicating that these companies have only invested in the R&D and patent application of AGV parking robot in the past three years.
In addition, among Top 20 applicants, Park Plus of USA and Unitronics Parking of Israel are keeping the investment in R&D of this field, while Boomerang Systems of USA only filed one patent in the past five years.

Table 1. Patent index of main applicants of AGV parking robot.

| No. | Applicant                   | Patent applications | Active years | Average patent age |
|-----|-----------------------------|---------------------|--------------|--------------------|
| 1   | Shenzhen Yeefung, China     | 30                  | 4            | 2.6                |
| 2   | Danbach Robot, China        | 12                  | 1            | 1.0                |
| 3   | Guangzhou United Faith, China | 9                   | 1            | 3.0                |
| 4   | Unitronics Parking, Israel  | 8                   | 6            | 4.9                |
| 5   | Hangzhou Jimu, China        | 7                   | 1            | 1.0                |
| 6   | Suzhou Dafang, China        | 7                   | 1            | 6.0                |
| 7   | Boomerang Systems, USA      | 6                   | 4            | 6.5                |
| 8   | Dongguan Songshan Lake, China | 6               | 1            | 1.0                |
| 9   | Shenyang General Robot, China | 6               | 1            | 2.0                |
| 10  | Nanjing Zhuanlu, China      | 5                   | 1            | 2.0                |
| 11  | Shanghai Hictrl, China      | 5                   | 2            | 1.4                |
| 12  | Foshan Zhenrui, China       | 4                   | 1            | 0.0                |
| 13  | Guangzhou Machine Tool, China | 4                 | 1            | 2.0                |
| 14  | Guoxin Robot, China         | 4                   | 1            | 0.0                |
| 15  | Park Plus, USA              | 4                   | 3            | 4.0                |
| 16  | Yunnan Ksec, China          | 4                   | 2            | 0.5                |
| 17  | Hangzhou Hikrobot, China    | 3                   | 1            | 2.0                |
| 18  | Hangzhou Xizi-Iuk, China    | 3                   | 2            | 1.7                |
| 19  | Shaanxi Longxiang, China    | 3                   | 1            | 1.0                |
| 20  | Shandong University, China  | 3                   | 1            | 1.0                |

6.2. Distribution of disclosed vehicle exchange solutions of main applicants

Figure 7 shows the patent applications of TOP 20 patent applicants towards various types of vehicle exchange solutions, from which the R&D priority of each applicant can be found out. Danbach Robot, Guangzhou United Faith, Unitronics Parking, Hangzhou Jimu, Suzhou Dafang, Shenyang General Robot, Nanjing Zhuanlu and Guoxin Robot all focus on R&D of AGV parking robot that adopt mechanical arm-based vehicle exchange technology. Boomerang Systems, Foshan Zhenrui, Guangzhou Machine Tool, Park Plus, Yunnan Ksec, Hangzhou Hikrobot and Shaanxi Longxiang all focus on R&D of AGV parking robot that adopt board-based vehicle exchange technology. Other applicants have more balanced R&D layouts. For example, Shenzhen Yeefung has R&D investment and patent application for all the three types of vehicle exchange technologies.
6.3. Distribution of disclosed vehicle guidance solutions of main applicants

Shenzhen Yeefung has the most comprehensive patent layout towards vehicle guidance technologies of AGV parking robot, involving laser navigation, magnetic navigation, electromagnetic navigation, visual navigation and inertial navigation. The patents of Hangzhou Jimu disclose vehicle guidance solutions based on laser navigation, visual navigation, inertial navigation, ultrasonic navigation and UWB location. The patents of Shanghai Hictrl disclose vehicle guidance solutions based on laser navigation, visual navigation, RFID location and GPS location.

6.4. Patent application strategies of main applicants

Figure 7. Distribution of disclosed vehicle exchange solutions of TOP 20 applicants.

Figure 8. Patent application strategies of main applicants.
Figure 8 shows the patent application strategies of main applicants. Shenzhen Yeefung and Danbach Robot are superior in terms of patent layout breadth and depth. Shenzhen Yeefung has not only applied for patents about all the three kinds of vehicle exchange technologies and related clamping arm, vehicle carrying board, comb teeth frame and carrier vehicle frame, but also applied for patents about stereo garage that utilizes AGV parking robot and the equipment used in combination with the stereo garage, such as vehicle carrying board stacking machine and turnover machine. Danbach Robot has applied for patents from the perspective of product functions, involving AGV parking robot with self-charging, multi-axis distance adjustable, high buffer, anti-collision or high safety function. Unitronics Parking of Israel has applied for patents about automated vehicle positioning system and automated vehicle centering system for use with AGV parking robot.

7. TECHNOLOGY ROADMAP OF AGV PARKING ROBOT

Figure 9. Technology roadmap of AGV parking robot.

Based on relevant core patents, the technical roadmap of AGV parking robot is drawn. As shown in figure 9, except for two individuals and one research institution, most applicants of these core patents are companies that have mature products, like Shenzhen Yeefung, Unitronics Parking and Boomerang Systems, indicating the companies lead the development of AGV parking robot. In addition, the evolution of technology direction is analyzed along the time axis. It can be found that AGV parking robot using board-based vehicle exchange solution first appeared, followed by the AGV parking robot using mechanical arm-based vehicle exchange solution, and finally the AGV parking robot using comb teeth-based vehicle exchange solution. Meanwhile, two features are emerged in the development AGV parking robot related technologies. The first feature is continuous improvement of transmission mechanism, actuator and positioning mechanism to further enhance the performance of AGV parking robot.
robot. The second feature is the integration with the development of stereo garage and continuous adaptation to meet the requirements of stereo garage.

8. CONCLUSIONS
As can be seen from the above analysis results, AGV parking robot field entered the technology take-off period around 2015 with overall significant increase in the number of patent applicants and patents. China leads the field, accounting for most patent filings and is more active in R&D. Mechanical arm-based exchange and board based-exchange are the key R&D types of vehicle exchange technologies. Laser navigation, magnetic navigation, electromagnetic navigation and visual navigation are mainstream of vehicle guidance technologies. The improvement of internal mechanisms of AGV parking robot and the integration of AGV parking robot with stereo garage are the development trends of this field.

For related companies, the technical innovation of AGV parking robot can be promoted from the following aspects. Firstly, the R&D of the technical difficulties of board-based vehicle exchange technology such as collaboration solution with stereo garage and board rectifying mechanism and the layout R&D of other vehicle exchange technologies should be strengthened. Secondly, in consideration of factors like cost, precision and demand, the integrated R&D of various vehicle guidance schemes should be strengthened. Thirdly, the forward-looking R&D of potential new hotspots should be strengthened, such as safety device of AGV parking robot, suspension device with spring characteristics, stereo garage that utilizes AGV parking robot, the related mechanisms (positioning mechanism, lifting mechanism, regulating mechanism, protecting mechanism and controlling mechanism) of vehicle carrying board devices used with AGV parking robot. Fourthly, the breadth and depth of patent layout should be improved. For example, a series of peripheral patent about the internal mechanisms for AGV parking robot of board-based vehicle exchange type and about the stereo garage and related equipment used in combination with AGV parking robot can be applied to form patent portfolios to strengthen protection. Fifthly, in order to make full use of basic research capabilities and talents, the cooperation with universities and research institutes should be strengthened, such as Pohang University of Science and Technology, Shandong University, Shanghai University, Xi'an Jiaotong University, Dalian University of Technology and Harbin Institute of Technology.

9. REFERENCES
[1] Sun X Y, Zhao Y K, Shen S H, Wang K F, Zheng X J and Shi Y J 2018 Proc. Int. Conf. on Computer Supported Cooperative Work in Design (Nanjing: China/IEEE) p 57–62
[2] Shi Y J, Pan Y H, Sun X Y, Xie R, Chen W and Shen S H 2018 Proc. Int. Conf. on Computer Supported Cooperative Work in Design (Nanjing: China/IEEE) p 496–500
[3] Wang D P, Ye J W and Guo C C 2019 Proc. Int. Conf. on Intelligent Transportation, Big Data and Smart City (Changsha: China/IEEE) p 134–137
[4] Zhu D J and Lian Z T 2017 J. Intell. Fuzzy Syst. 33 3087–94
[5] Ye C B, Chen G, Qu S Q, Yang Q Y, Chen K, Du J T and Hu R E 2018 Int. Conf. on Robotics and Biomimetics (Malaysia: Kuala Lumpur/IEEE) p 1987–92

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