Automated Car Parking Facilities in the Age of Autonomous and Connected Vehicles

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Abstract: **The automated car parking facilities can give an environmental-friendly and time-friendly solution for parking problems in busy European old town centers. But the the fear of the dependency of automation and operating failure of active actuating systems prevent its spreading over the world. Although the fear and the complexity of these systems, we may to apply these facilities to provide parking opportunities in city centrals. But is this demand changed by the newly appeared electrical and/or autonomous and/or connected vehicles, which can park themselves? Can they co-operate to create more favorable semi-automated facilities? How can we utilize the smart mobile devices to get a better parking experience? The article collects the solution options for smart cities to utilize the nowadays available automated car parking technologies.**

Keywords**: Smart cities, Parking facilities, Parking experience, Semi-automated car parking facilities, Autonomous cars, Connected cars**

I. INTRODUCTION

Nowadays, the automated, mechanized car parking system have got a good challenger in the field of comfortable car parking solutions. One of the biggest benefits of robotic car parking facilities is that the driver needs only to locate a free receiving cabin nearest to the destination, drive in and can immediately leave the car, and the system take care about the load, storage and retrieval of the parked car.

The autonomous, self-driving cars can challenge this feature, because we do not need to locate and drive into a parking facility, but we can stop with the car at the destination, jump out – which is not so difficult in jammed city traffic – and order the autonomous car to find a parking place somewhere nearest.

In Europe, this feature of autonomous cars is disabled because of the European highway code does not allow an autonomous car to run without a responsible driver. But we can utilize this self-driving ability to establish a cheaper automated, mechanized car parking facilities, which use the self-driving car motion ability to replace one horizontal motion axis in the 3-dimensional car storage system.

Figure 1. Generic cuboid types of multi-storey robotic car parking facilities

For this, the paper analyzes the generic type of multy-storey robotic car parking facilities, optimization tasks, cost-functions and related general control strategies and develop optimal solutions for system simplification by controlling self-driving car in parking facilities. At last, but not least, some general security and social issues will be discussed related to remote control ability of self-driving or semi-self-driving cars with distance holding and lane assist.

II. OVERVIEW OF GENERIC TYPES OF MULTY-STOREY ROBOTIC PARKING FACILITIES

Generic multi-storey robotic parking systems are 3-dimensional cuboid or cylindrical storage systems served by 3-axis transport system. This paper deals primarily with cuboid shaped systems, where the transportation can be performed by high-rack loading and retrieval machines or elevators and some type of horizontal transport system in a distributed service model.

a) Standard aisle type high-rack shelf storage with automated loading and retrieval machine

In these systems the car storage is performed by high load capacity shelf storage racking system in aisle layout. Cars are placed onto car storage pallets or are "grabbed" at the tyres by self-adjusted roller arms. Automated high-rack loading and retrieval machines are carrying the pallet or type grabber units in each aisle (storage corridors).

b) Multi-storey Robotic Parking Facilities with Aisle Type Distributed Machinery

In this type of robotic parking facilities, vertical and horizontal machinery can operate separately. Elevators lift the cars on pallets or standalone to the right floor, then satellite cars transport horizontally and place the car or the pallet into the right storage place. Satellite cars can be equipped with "pallet-grabber" or "tire-grabber".

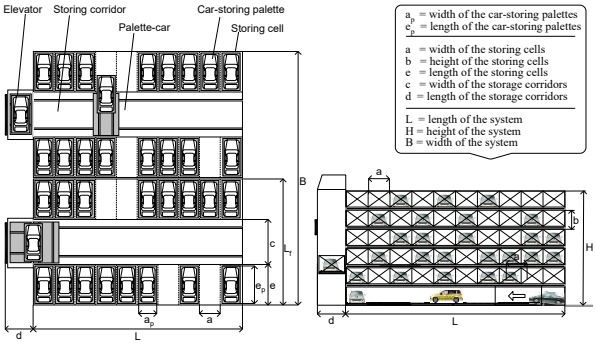

Figure 2. Multi-storey robotic parking facilities with aisle type distributed machinery: vertical elevators and horizontal satellite cars [2]

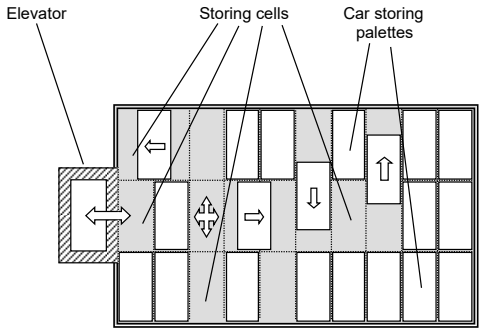

Figure 3. Multi-storey robotic parking facilities with block-storage type motion-store matrix machinery

In case of using pallets, empty pallet-handling should be performed.

c) Robotic Parking Facilities with block storage multi-storey machinery

In the block storage robotic parking systems, cars are placed onto car storage palettes. These palettes are elevated with the car up to the right floor, then is loaded out from the elevator to the storage floor. On the storage floor "transport&store" cells are installed in more rows and columns side by side near to each other. Each "transport&store" cell is mounted with a 2-axis driving mechanism, which can transport the palettes in longitudinal and transverse direction.

The advantage of this storage system is, that nearly 100% of utilization can be reached and only a few free cells are required to the movements.

Disadvantages, all the cells should be mechanized, which results higher installation and operating costs and the control of this system is much complex.

III. Required Optimum Criteria in Operating Robotic Car Parking Facilities

In operating car parking systems, the key performance indicator is the waiting time of the driver for park-in and park-out or in other words drive-in and drive-out. The immediate drive-in requires only the availability of free receiving cabin. The occupation depends on the time duration of park-in process by the driver. After the driver left the cabin, the machinery must free up the receiving cabin by transport the car into the storage system. On the other hand, the procedure of the retrieval in case of park-out request is longer, because the car should be retrieved

Figure 4. Receiving cabin in robotic car parking facility using car storage pallet

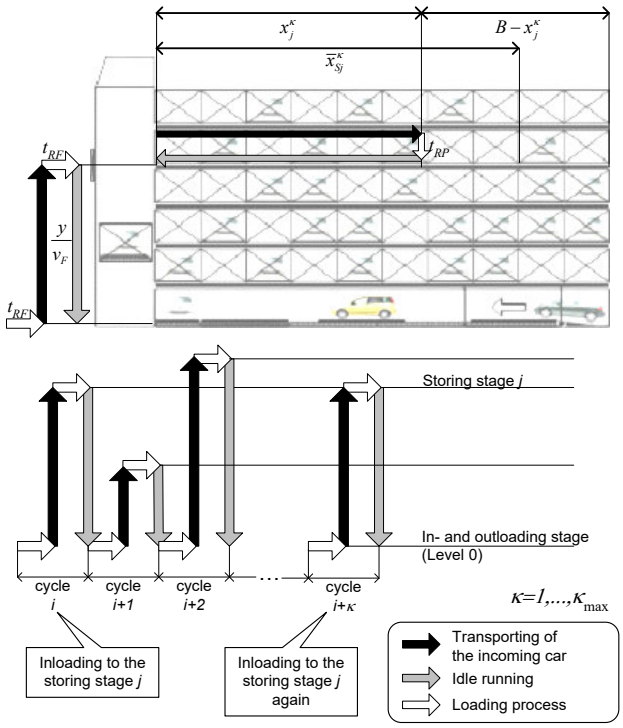

Figure 5. Periodical transport cycle in multi-storey robotic car parking facilities served by distributed machinery

from the storage system. So, the driver must wait. Therefore, the mayor task is to minimize the driver's average waiting and service time by the right service strategy. On the other hand, the operating costs of the entire facility should be at an adequate level. Related to this, the right balance of utilization of the driving units should be performed regarding to the planned maintenance cycles [4].

IV. Operating Strategies and Optimization Tasks

Based on the optimum criteria, the operating strategies should support the waiting queue optimization, the transportation of the incoming cars and the retrieval of the outgoing cars.

Basic strategy is to free up the receiving cabin as soon as the machinery can arrive to catch the incoming car from the receiving cabin.

Additional strategy is the right sorting order in the storage system to make the loading and retrieval time shorter. And at last, but not least, equipment utilization and usage optimization should be performed for the right maintenance processes. At this point, there are different strategies for loading and retrieval machine, for multi-elevator systems and multi-satellite car systems and for block storage floors.

V. Simplified Robotic Solutions for Car Parking Automation

There can be found simplified robotic solutions, where classic Ramp Access Garages (RAG) are equipped with remote controlled Autonomous Guided Vehicle (AVG) running on concrete surface altogether with other driver-controlled cars. This option is a cost-efficient enhancement

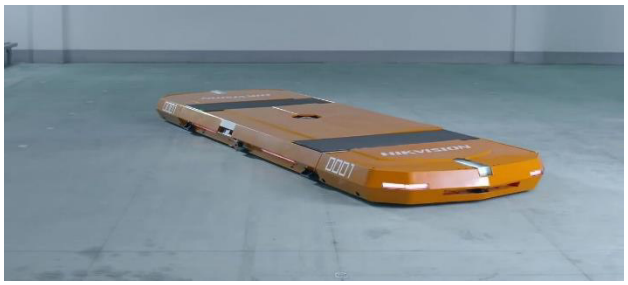

Figure 6. Remote controlled car lifter Autonomous Guided Vehicle (AGV) working on classic Ramp Access Garage (RAG) concrete surface

of parking facility giving a hybrid solution both for drive-in parking and a comfortable luxury parking.

The system is very scalable, because the number of the car lifter AGV can be adjusted to the demand for automated park-in-park-out.

Disadvantages are that the volume utilization optimization is not available, and the lifting method of the car is not gentle with the car chassis.

VI. Role of Self-Driving Cars in Parking Facility Automatization

The role of autonomous, self-driving cars is that it can replace one motion axis and the required drive system in the robotic parking system. For this, remote control performed by the robotic parking system.

In non-automated parking systems, this motion axis can be utilized to reach block storage in row format, which can raise the volume utilization up to 25% in first approach. Disadvantages are the high sorting demand.

In semi-automated parking systems, where the drive-in ramps are replaced by elevators, this utilization growth can be extended by additional 25% in first approach.

In fully automated systems one motion axis can be replaced, therefore pallet installation, pallet or tire grabber unit and tire grabber or pallet handling operations can be left, which factors result a much simpler system with less installation and operation costs.

But it requires the self- or semi-self-driving ability of the car, and the availability to control the car by the facility control system. On other hand, the complexity and requirements for right operation and reliability of control system is much higher, and industrial standards required to reach the car manufacturers.

Figure 7. Loading cars by tire-grabber in robotic parking system (without applying car storage pallet) [5]

VII. Optimal Solutions

Optimal solutions are the standard high-rack shelf storage with automated loading and retrieval machine, block storage with elevators, and multi-storey parking systems served by Elevators/Loading-Retrieval Machine and Satellite cars.

At all solutions, the self-driving ability is applied to enter and leave the lifting or transport unit of the machinery, so the car can roll on or roll off the surface of lifting unit loading and retrieval machine or the satellite car. On any error, car transporter AGV must called to place the stuck self-driving car and driver must be notified.

This easy operation takes only approximately 5-6 meters at up to maximum 1 m/s speed controlled directly by the car onboard self- or semi-self-driving capability.

Steering by the car is not necessary because of the linear motion, therefore semi-self-driving capability is enough using distance sensor and lane-assistant, like e.g. Toyota Auris Safety Package.

VIII. Issues to be Solved

Externally controlled parking mode should be developed using standardized protocols and interfaces. This standard should contain the specification of the external command process and protocol.

The externally controlled movement should be enabled by the driver at leaving the car. If the eternally controlled movement is started it should be reported to the driver and to the owner in real-time by the car itself. For this, wireless coverage should be provided, which is not easy in steel racking system.

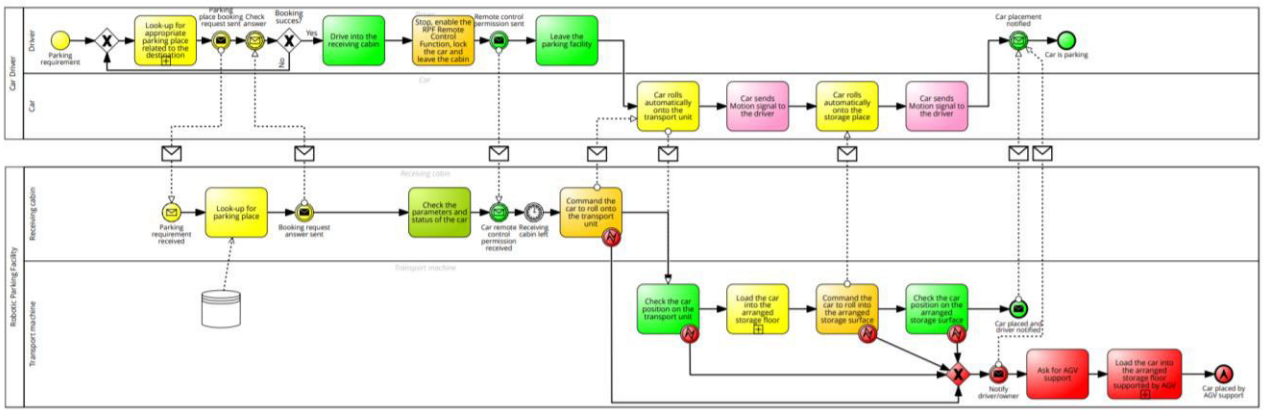

Figure 8. Drive-in and loading process in collaborative robotic parking facilities

Token-based check signal should be applied to check the car's real position. If the signal lost, an automatic call of police should be triggered.

Because of the European highway code does not allow driverless drive of cars, exception for robotic facilities with unmanned storage area should be legalized.

IX. SUMMARY

The article presents a solution for automated, mechanized car parking facilities utilizing the self-driving ability of autonomous cars, which use the self-driving car motion ability to replace one horizontal motion axis in the 3-dimensional automated car storage system. The research overviews the generic types of robotic parking facilities and the basic control strategies and optimization tasks, selection of optimal system solutions by controlling self-driving car in parking facilities, and several security and owner issues to be solved. Optimal roll-on-roll-off solutions are:

- standard high-rack shelf storage system with automated loading and retrieval machine in each aisle,
- multi-storey car storage systems served vertically by elevators or loading-retrieval machine and horizontally by satellite cars,

Further benefit is that this function can avoid the entire system from overload in case of high utilization by splitting the motion requirement between the parking system and the car driving system. And it decreases the facility installation costs by replacing one motion axis and its drive system.

On the other hand, a lot of related issues should be solved such as legal, social safety and property safety issues. The further research needs to solve the industrial standardizing of the communication and regulation solutions and additionally, trust of driver and owner society should be gained by reliable, useful pilot projects.

REFERENCES

[1] D. Monahan (2015) „De-Mystifying Automated Parking Structures", Walker Parking Consultants

[2] L. Rádai, J. Cselényi, B. Illés (2006) "Models and Methods for Determining the Inloading Performance in Small and Medium Size Automated Car Park Systems Served by Elevators and Palette-cars", *MicroCAD 2006 International Scientific Conference*, University of Miskolc, Hungary, 2006

[3] "No need to put in a garage by the driver, a system will automatically carry the robot to the parking space fully automatically", in: *Gigazine*, 28th January, 2018.

[4] K. Széll, G. Manhertz (2016). "Development of a web-based training module in robotics", *International Symposium on Small-scale Intelligent Manufacturing Systems (SIMS2016)*, Narvik, Norvégia, 21-24.06.2016, pp. 1-6., ISBN:978-1-5090-3074-3, 2016.

[5] "Multiparker solutions", Otto Wöhr Autoparksysteme GmbH, 2014

[6] K. Széll, A. Czmerk, P. Korondi (2014). "Friction with Hysteresis Loop Modeled by Tensor Product", *AUTOMATIKA 55* (4) pp. 463-473., 2014.