A proposal of parking location determination method to realize high time-efficient exit operations in automated valet parking using automatic pallets

Shinichi Funase, Toshihiko Shimauchi, Haruhiko Kimura, Hidetaka Nambo

Abstract— **Multi-storey car parking systems were invented to increase capacity of car park buildings. However, it is pointed out that the systems have problems such as accidents (in-park movement, theft), searching for parking spaces, boarding/deboarding at narrow designated places, and difficulty in using for beginners and elderly people. To solve these issues, many research have been conducted. One of them is a proposal to introduce automatic and electric pallets for transporting vehicles and realize automated valet parking that automates procedures for entrance and exit. In the existing proposed method, the examinations of the capacity rate of the parking lot and the time efficiency of exit procedure were not sufficient. Therefore, in this paper, we propose a new parking location determination method that will lead to further improvements in parking lot profitability, as well as a reduction in the waiting time for users when exiting the parking lot. By adding running wheels and sensors to the automatic pallets, their mobility and operability have been improved. Algorithms for determining the parking position when entering the parking lot and for changing the parking position during the parking period have shortened the waiting time for users when leaving the parking lot.**

Index Terms— **time efficient exit operations, parking location determination method, auto valet parking, automatic pallet, automated driving**

I. Introduction

Cars are used for movement and transportation and are indispensable products for modern and convenient life. Cars require parking lots at two places: the starting point (home, etc.) and the destination (outside). A parking lot at the destination is mainly shared by an unspecified number of users, and it is difficult to design a parking lot that satisfies all users.

Land prices are particularly high in business districts and downtown areas, making it difficult to construct profitable parking lots. In such places, from the viewpoint of profitability, a multi-storey parking lot with larger capacity is often built. It is possible to increase the number of parking spaces per unit area of the site by increasing the number of floors. However, because the cost of installing vehicle elevators and floor-to-floor ramps increases, maximizing the number of parking spaces per floor is an important factor.

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The expansion of scale that realizes the improvement in profitability of multi-storey parking lots could worsen user experiences. For example, problems such as accidents (intra-park movement, theft), searching for parking spaces, boarding/deboarding at narrow designated places, and difficulties in use for beginners and elderly people arise. If these issues are not resolved, even if the accommodation rate improves, the utilization rate will decline, leading to a deterioration in profitability.

Therefore, in this research, we focus on automated valet parking, and propose to improve the accommodation rate and prevent the deterioration of convenience. Previous studies have pointed out that the accuracy of research on automated driving is still insufficient [1]–[8]. Reasons for low accuracy include the fact that the vehicles that use the parking lot are diverse and differ in performance and appearance, and that entrance/exit procedures by automated driving based on instructions from mobile phones have not yet reached the stage of practical use.

To improve accuracy, Funase et al. made a proposal to realize automated valet parking system with high-precision automated driving by limiting the target of automated driving to automatic pallets for transporting vehicles [3]. In this research, we will improve this system in the following two points.

[1] We propose improvement on automatic pallet mobility and operability to increase the number of parking spaces per floor.

[2] We propose a time-efficient parking location determination method for automated valet parking to improve the time-efficiency of exit procedure.

The reasons for this research to improve the time-efficiency for exit procedure are as follows. In entrance procedure, after the user gets out of the car in the drop-off area and completes the driver's facial recognition registration, the car is loaded on an automatic pallet and moved to the parking location determined by the automated valet parking system. For the user, the entry procedure is completed simply by getting out of the car and registering the face, so the time required for entrance procedure is almost zero. Even if it takes an enormous amount of time for the automatic pallet to move to the parking location in the multi-storey car park, the user does not have to wait because the operation is automatic. The time efficiency of automated valet parking, which is a problem for users, is the waiting time required from the time a user orders his/her car to be delivered until the vehicle is actually delivered.

The outline of the parking location determination method proposed in this paper is as follows. Parking locations closer to the exit are assigned in the order of entrance. When an order is issued to carry a car to the exit, the automatic pallet on which the requested car is loaded is guided to the exit. Then, the pallet with next larger exit distance is moves to this vacant space. The vacant space created by this step is then occupied by the pallet with exit distance larger than the second guided pallet. This series of operations is repeated for all automatic pallets on the same floor until the target pallet ceases to exist. The parking space improvement operations move the pallets several times and move them closer to the exit while the cars are parked. This shortens the time necessary for exit procedure, which is the biggest time cost for the user.

II .Multi-storey car parking

The parking has multiple floors from 1st basement floor to the m^{th} floor and uses automatic pallets on which cars are parked. The surfaces of each floor are treated so that pallet wheels do not slip. Two elevators are installed for pallets transport, each connected to the floor entrance and exit. Every automatic pallet is assigned with unique serial numbers, with which entrance and exit procedures are managed. A unit space is a space slightly larger than an automatic pallet and can accommodate one automatic pallet. Each unit space is also given a unique serial number. Each floor is divided into these unit spaces. A unit space that the automatic pallet can access directly from the passage is called a basic unit space (No.*j*). A unit space whose four sides do not face the passage is called a complex unit space (No.*k*). By configuring layout of unit spaces and passages as shown in Figure 1, even if all the basic unit spaces neighboring a complex unit are occupied by the pallets with cars on them, two movements of any of the occupied pallets allow the passage to be created from the complex unit space.

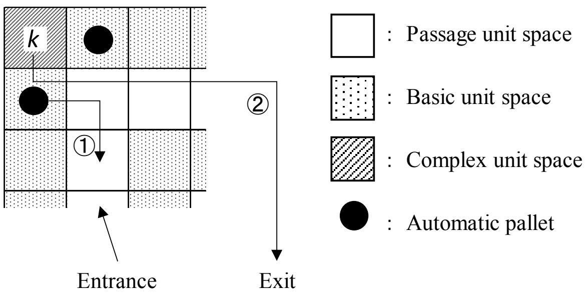
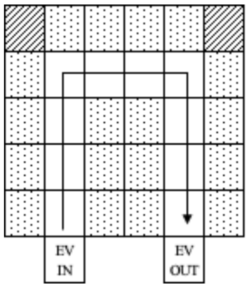
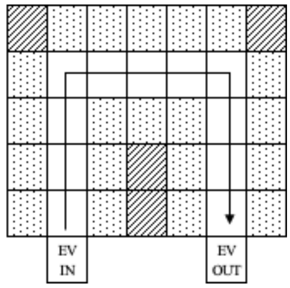


Figure 1 Procedure for creating a passage from a complex unit space (No.k) to the exit

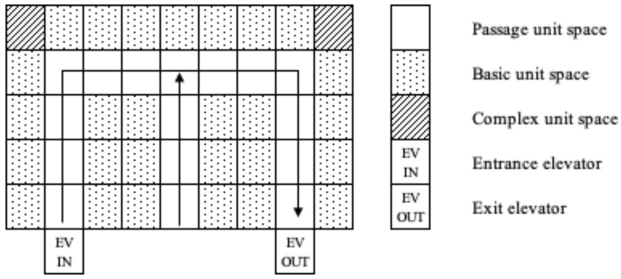
Each floor has a passage connecting the entrance and exit elevators. Passage unit spaces have marker pointing to the exit embedded and cannot accept automatic pallets with cars. Ideally, the passage should be a tree structure with the exit elevator as the root node. This is because creating a closed-circuit passage would reduce the parking space available for the automatic pallet. A passage with tree structure has only one route from any unit space on the passage to the exit, so the distance to the exit is the shortest. Although there are dead ends in the branch passages, the passages are set so as to minimize the complicated unit space. The passages on each floor are located in the same place (Figures 2(a) to 2(c)). The number of floors can be determined from the unique number of the unit space, and the type of each unit space (basic, complex, passage) can be determined from the floor plan information of the parking structure.



(a) 5x6 unit spaces / floor



(b) 5x7 unit spaces / floor



(c) 5x9 unit spaces / floor

Figure 2 Floor plans of *t* multi-storey car parking

(Example 1) When the number of unit spaces in one floor is *U*, the unit space of No.*j* is on the t^{th} floor. *t* is expressed by the following equation.

t=INT((j-1)/U)

INT(X) is a value rounded down to the nearest whole number of X. The 0th floor represents the 1st basement floor.

The number of unit spaces on the shortest passage from No.*j* basic unit space to the exit elevator (including the space of the elevator as 1) is the distance to the exit for No.*j* basic unit space. The distance E(j) is expressed by the following equation.

E(j)=shortest distance {(No.j), the exit elevator}

(Example 2) Figure 3 shows distances from each unit space to the exit on Figure 2 (a).

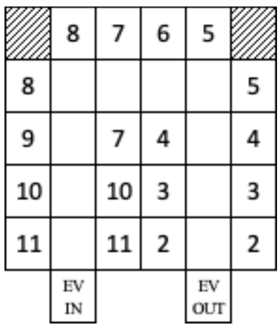


Figure 3 Distances to the exit for each basic unit space on Fig.2(a)

E(k) is the distance from a complex unit space No.*k* to the exit and is expressed by the equation below. The constant 1 in the equation is the number of steps from the complex unit space to the neighboring basic unit space.

$$E(k)=\mathrm{Min}\{U(j_1),U(j_2),\cdot\cdot\cdot,U(j_e)\}+1$$

The equation chooses the shortest distance from the distances between exit and each basic unit space {No.j_1, No.j_2,・・・No.j_e} adjacent to the complex unit space (No.k). When the basic unit space is occupied by the automatic pallet, 4 is added to E(k). As shown in Figure 1, two steps are necessary to move the occupied unit space, and two additional steps are necessary to move the unit space back to the original position.

(Example 3) The exit procedure for the automatic pallet parked in the No.k complex unit space is as follows. Neighboring basic unit spaces are assumed to be occupied by the automatic pallets with cars.

Figure 4 shows the shortest path to the exit. After the automatic pallet in No.X is moved (①), the automatic pallet in No.k can be moved (②). After that, the automatic pallet in No.X is moved back to its original position (③). Other paths and movement methods exist, but they will not be selected because the distance is longer than the above path and the time efficiency is not satisfactory.

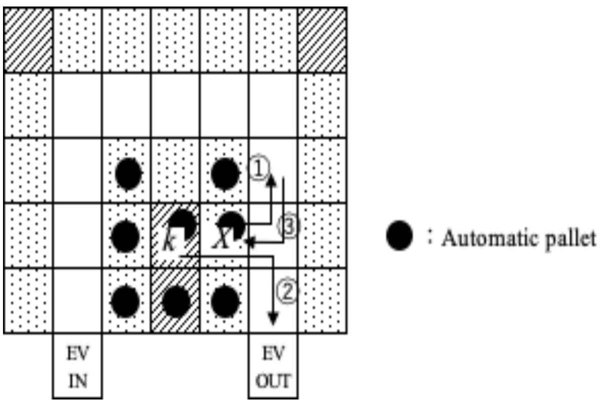


Figure 4 Exit procedure for automatic pallet from No.k

(Example 4) Figure 5 shows the distances from each complex unit space to the exit. Neighboring basic units are assumed to be occupied by automatic pallets.

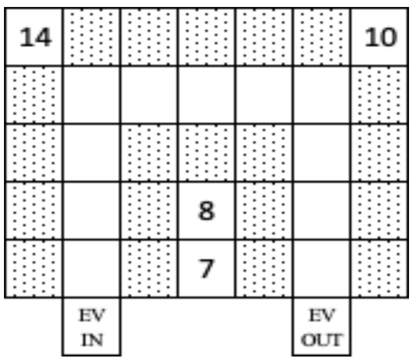
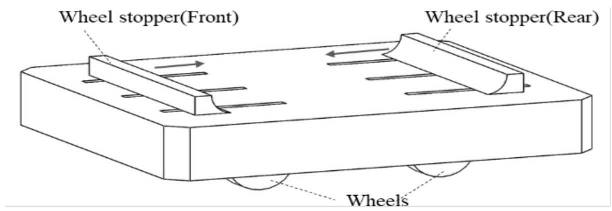


Figure 5 Distance from complex unit spaces to exit on Fig.2(b).

Ⅲ. Improvement on automatic pallet

Funase et al proposed the original automatic pallet [3], which is an autonomous vehicle that can load one car and carry it from entrance to the parking place or vice versa (Figure 6).



In this paper, additional improvements are applied to the pallet to make it easier to park and exit at the desired location. Specifically, two sets of wheels (left and right, front and back) are added to allow the pallet to move four directions without changing the position of the loaded vehicle (Fig. 7 (a), (b), (c)). When one set of the wheels is deployed, the other set is retracted. The wheels are smaller than ordinal ones to improve the stability of the automatic pallet.

The improved automatic pallet has another feature; each of them has nine built-in sensors that can read the unique numbers of 8 neighboring unit spaces and the that of the unit space on which it is parked (Figure 8). These sensors allow the pallet to move through the passage smoothly and to determine the types of neighboring unit spaces (basic or complex) and presence/absence of pallet parking nearby.

The automatic pallet has front and rear wheel stoppers to secure the vehicle loaded on it. When not in use, they are retracted in the pallet. When in use, they are deployed out from the pallet. By shortening the distance between the front and rear wheel stoppers, the vehicle on the pallet is securely retained.

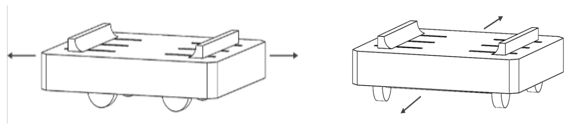
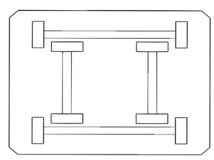


Figure 6. Structure of automatic pallet

(a) Left / right movement (b) Front / back movement



(c) View from bottom

Figure 7. Improvement on automatic pallet: movement

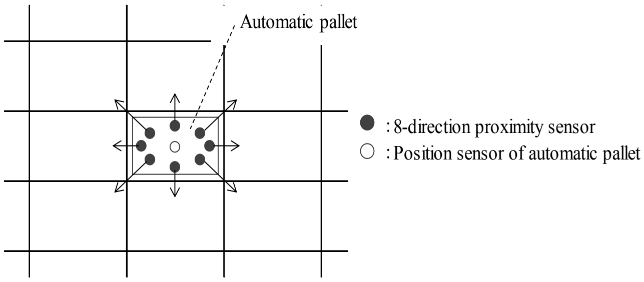


Figure 8. Improvement on automatic pallet: sensors

IV. Automated valet parking system

In this paper, the automated valet parking system proposed by Funase et al [3] is used. A new method to determine parking location proposed in this paper is explained in the next section.

Automated valet parking system fully automates the following two tasks which are performed by staff in conventional valet parking systems:

1) To find a parking place and move the car to the place.
2) To move the car to the exit when asked by the user.

Other researchers propose various automated valet parking systems, but they are all based on the system in which cars are automatically guided in the parking. Cars vary widely in shape and performance, which makes it difficult to guide them automatically.

The system used in this paper employs pallets guidance, which limits the target of automatic guidance on one type of vehicle. This results in a higher accurate guidance in the system.

A. Automatic entrance procedure

Cars arriving at the entrance of the parking lot are parked in the designated section of the turntable where the automatic pallet is embedded (Figure 9). If the car is not properly parked in the section, an alarm will prompt the driver to park the car within the section. When parked properly as instructed by the system, the driver gets off and locks the key, and registers his/her face with the authentication camera. The registered facial image is associated with information such as the date and time of entrance and the unique number of the assigned automatic pallet, which is printed on paper and handed to the user. The printed paper is only a record for the user and may be used when trouble occurs. It is not required for ordinally exit procedure.

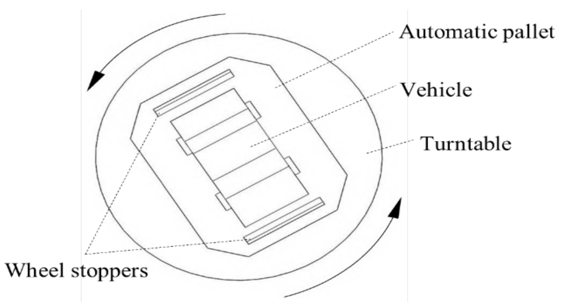


Figure 9 Turntable with automatic pallet used in entrance/exit procedures

When the car is parked properly, the retracted front and rear wheel stoppers are deployed out. The front wheel stopper moves backward, and the rear wheel stopper moves forward to securely retain the front and rear wheels of the car. After securing the car, the automatic pallet loaded with the car is lowered into the basement by an elevator. From the basement, it is guided to the multi-storey car park through an underground passageway. The facial image, the unique numbers of the automatic pallet and the unit space are associated by a database. A new automatic pallet is carried and set on the turntable (Figure 10). A series of these operations are performed automatically.

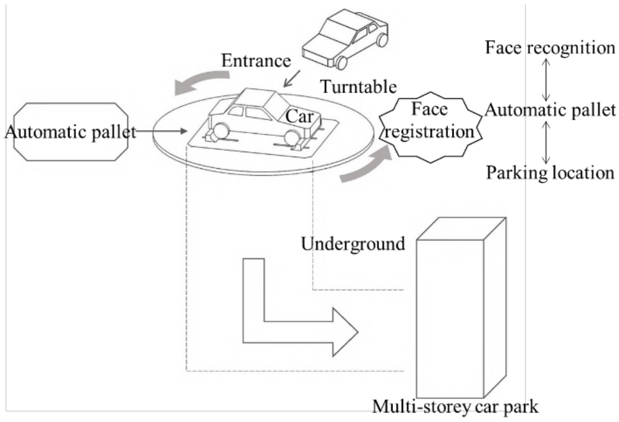


Figure 10 Mechanism of automatic entrance

B. Automatic exit procedure

The exit procedure is conducted in the opposite flow of the entrance procedure described in subsection A. Drivers and users go to the boarding area and have the registered face confirmed by the face authentication camera. Through this authentication procedure, the automatic pallet associated with the facial image is automatically guided from the parking unit space to the boarding area.

If the parking lot is a toll system, paying a fee according to the parking time releases the front and rear wheel stoppers. If the parking lot is free of charge, the wheel stoppers are released as soon as the automatic pallet arrives at the boarding area. After the wheel stoppers are released, the user can drive the car out of the parking. The usage history information is recorded for each authenticated face image. A schematic diagram of these is shown in Figure 11.

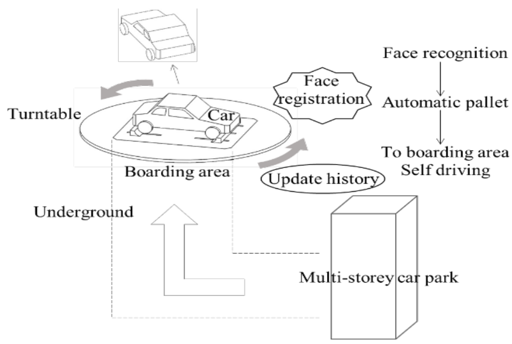


Figure 11 Mechanism of automatic exit

V. Parking location determination method

In this section, the parking location determination method proposed in this paper is described in detail.

A. Preparatory steps

(1) First, a tree structure passage including the passage connecting the entrance and exit elevators on the 1st basement floor is determined. In many existing multi-level parking lots, the passages are directed circuits, which have a drawback of less parking spaces than the number of trees. Therefore, in determining the tree structure in this proposal, the root nodes for the entrance and exit procedures are respectively the entrance and exit elevators. In addition, a marker pointing to the exit is embedded in the passage unit spaces.

(2) On each floor from the 1st floor to the m^{th} floor, the same passage route as the 1st basement floor is designated. All floors are assumed to have the same shape and space.

(3) When the unit space (No.j) is a passage unit space, S(j)=0. When it is a basic unit space, S(j)= 1 or 2. When it is a complex unit space, S(j) =3 or 4. Also, when the automatic pallet is not parked on the unit space, S(j) = 1 or 3. When it is parked, S(j) =2 or 4. For example, S(j)=2 means the automatic pallet is parked on the basic unit space.

(4) The forward/backward/left/right movement speeds of the automatic pallet are assumed to be same and constant. The time required to move through r unit spaces aligned in a straight line is represented by $r{\cdot}T$ (Fig. 12). T is the unit time of the automatic pallet. The time required to switch the movement axis of the automatic pallet between x and y axes is assumed to be 0.

The vertical movement speed of the elevator is assumed to be same and constant. The time required for vertical movement from floors i to j is expressed as $|i-j|\cdot T'$, where T' is the unit time required for the elevator to move one floor vertically.

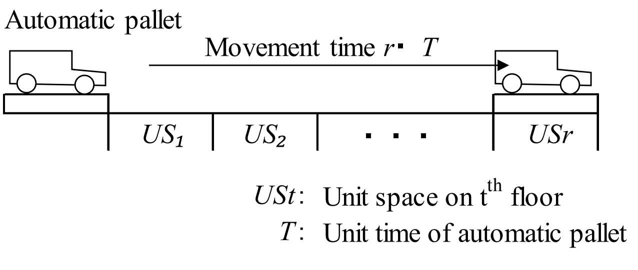


Figure 12 Horizontal movement time of automatic pallet

(5) The movement of the automatic pallet can be divided into the following three cases:

(a) movement for exit procedure

(b) movement for parking location improvement

(c)movement to the first parking location

The priority among the cases is set to be (a)> (b)> (c) to improve the exit procedure and avoid collisions between automatic pallets.

(6) Table 1 shows the two cases in which the three types of movement in (5) are carried out properly according to the priority. In other cases, the position of the automatic pallet contradicts with the above priority. For example, if the layer 1 to 3 is in the order of (c), (a), (b) or (a), (c), (b), the initial parking location (c) is closer to the exit than the movement for improvement (b). If the layer 1 to 3 is in the order of (c), (b), (a) or (b), (c), (a), the pallet in the exit procedure (a) is located farther to the exit than the initial parking place.

Of two cases, case 1 is more likely one. In case 2, the parking place improvement operation (b) is temporally suspended when the exit procedure (a) starts. The pallet on the passage during procedure(b) is moved to the nearest unoccupied basic unit space, and after the procedure (a) has completed, the improvement operation restarts. The movement of (c) in this case can be carried out independently of the other movements.

Table 1. Two cases of three types of movement of automatic pallet

Tree structure of passage	Case 1	Case 2
Layer 1 (near the root)	(a)	(b)
Layer 2 (Layer 1 and below)	(b)	(a)
Layer 3 (Layer 2 and below)	(c)	(c)

(7) Every unit space from the 1st basement to the m^{th} floors is assigned a unique serial number. Since the numbers are assigned to each floor according to the single rule, the number of unit space on the i^{th} floor which is at the same position directly above the unit space No.j on the 1st basement floor is $i\cdot A+j$. Here, A is the number of unit spaces per floor.

(8) For i = 0, 1, 2, ･･･, m, the system finds the exit distance E(ji) to the exit for each unit space (No.j_i) on the i^{th} floor. Even if the floors are different, the exit distance of the unit spaces located at the same horizontal position is the same. That is, when $i \neq t$, $E(i\cdot A+j)=E(t\cdot A+j)$.

(9) When the exit distances of unit spaces (No.j) on the i^{th} floor are arranged in ascending order, $N_i(t)$ represents the unit space with t^{th} shortest exit distance.

(10) For i = 0,1,2,･･･, m, the system creates a table containing a) the rank of exit distance (Ej_i) sorted in ascending order for unit space (No.j_i) on i^{th} floor, b) unit space unique number and c) exit distance. This table is called the exit distance table.

(11) The position of the unit space in this multi-storey car park is represented by three-dimensional coordinates (x, y, z). x and y show respectively the longitudinal and lateral distances from the origin. z is the number of floors. The origin is the front row at the left end on each floor (Figue13). The coordinate values (x, y, z) of the unit space of No.j are put in Cx(j), Cy(j), and Cz(j) respectively.

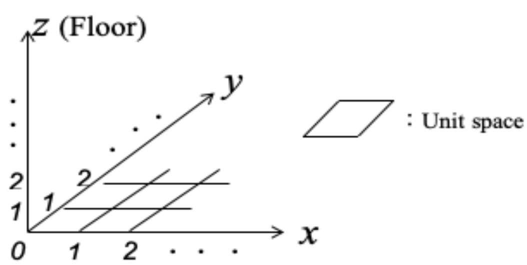


Figure 13 Three-dimensional coordinates showing the position of unit space in a multi-storey parking

(12) When the position of the three-dimensional coordinates (*x*, *y*, *z*) is the unit space (No.*j*), it is represented by P (*x*, *y*, *z*)=*j*. When the unit space (No.*j*) is occupied by the No.*t* automatic pallet, it is represented by Q(*j*)=*t*.

(13) When the No.*t* automatic pallet is parked in the unit space (No.*j*) is represented by A(*t*)=*j*.

(Example 5) Table 2 shows the exit distance table on the 1st basement floor in Figure 2 (a). Figure 14 shows the unit space unique number.

Table 2 Exit distance table on the 1st basement floor in Fig.2(a)

Order *t*	**Unit space** $N_0(t)$	**Exit distance** $E(N_0(t))$
1	28	2
2	30	2
3	22	3
4	24	3
5	16	4
6	18	4
7	12	5
8	5	5
9	4	6
10	3	7
11	15	7
12	2	8
13	7	8
14	13	9
15	6	10
16	19	10
17	21	10
18	25	11
19	27	11
20	1	13

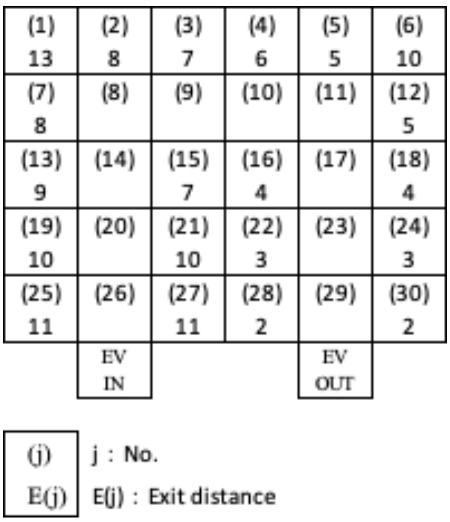


Figure 14 Unique number and exit distance for unit space on 1st basement floor in Fig.2(a)

(Example 6) Table 3 shows the positions of the unit spaces in Table 2.

Table 3 Position of unit space in Table 2

Order *t*	Unit space N□(*t*)	3-D coordinates (Cx(N□(*t*)),Cy(N□(*t*)),Cz(N□(*t*)))
1	28	(4,1,0)
2	30	(6,1,0)
3	22	(4,2,0)
4	24	(6,2,0)
5	16	(4,3,0)
6	18	(6,3,0)
7	12	(6,4,0)
8	5	(5,5,0)
9	4	(4,5,0)
10	3	(3,5,0)
11	15	(3,3,0)
12	2	(2,5,0)
13	7	(1,4,0)
14	13	(1,3,0)
15	6	(6,5,0)
16	19	(1,2,0)
17	21	(3,2,0)
18	25	(1,1,0)
19	27	(3,1,0)
20	1	(1,5,0)

B. Algorithm for determining the first parking place

For i = 0, l, 2, ..., m, let pi be the number of automatic pallets parked on the i^{th} floor The number of automatic pallets parked in the multi-storey car park is represented by p^*. When the car is loaded on No.*t* automatic pallet, the initial parking place is the unit space on the floor where T in Equation (1) has the minimum value. For example, if the second option E (N1 (p_1 +l))+2E'(T') is the minimum value, it will be the unit space of No.N_1 (p_1+1) on the first floor. The three-dimensional coordinates (x, y, z) are (Cx(N_1 (p_1+l)), Cy(N_1 (p_1+l)), Cz(N_1 (p_1 + l))) and P(x, y, z) = N_1 (p_1 + 1). Also, Q (P (x, y, z))=t, A(t) = N_1 (p_1 + l). When pi reaches the maximum number of cars that can be parked on the i^{th} floor, the option that includes pi is deleted from Equation (1). Also, when p^* is the maximum number that can be parked in the multi-storey car park, the entrance procedure is held on hold until the vacant space becomes available.

$$T = Min\{E(N_0(p_0+1)),\ E(N_1(p_1+1)) + 2E'(T'),\ E(N_2(p_2+1)) + 2E'(T')\cdot 2,\ \cdots, E(N_m(p_m+1)) + 2E'(T')\cdot m\} \quad (1)$$

E'(T') is a time required to move the elevator by one floor, which is same amount of time required to move one unit of exit distance.

The elevator is stationed on the 1st basement floor. When the elevator goes up to the i^{th} floor to accept an automatic pallet on it, it will return to the 1st basement floor again. This operation is represented in muptiplier of 2 in the equation (1) The unit space selected by this algorithm is the parking location with the shortest exit time in the multi-storey car park.

The following improved vertical search method is used to find a parking location of the specified No.j unit space.

[Algorithm 1]

(1) Find the floor k where the unit space (No.j) is located by the method described in Example 1.

(2) For the passage on k^{th} floor, examine a search tree whose root is the entrance elevator.

(3) Similar to the vertical search method, the unit space of No.j is searched from the root with priority on depth. However, for the improved method, at the branch point, the option that minimizes the distance from the 3D coordinates ($Cx(j)$, $Cy(j)$, $Cz(j)$) of the unit space of No.j is selected. This procedure is repeated until the No.j unit space is found.

(4) $p_k \leftarrow p_k+1$, $p^* \leftarrow p^*+1$

After arriving at the target floor, the entrance elevator will unload the automatic pallet and immediately return to the 1st basement floor. When entrance order is made during this operation, the above movement is put on hold temporarily and will be restarted once the elevator returns to the 1st basement floor. The initial values of p_k (k = 1,2, ･･･, u) and p^* are 0. u is the number of automatic pallets prepared.

The entrance elevator returns to the first basement floor immediately after unloading the automatic pallet to the destination floor. When another entrance request is received during this movement, the automatic pallet related to the new request is temporarily put on standby. Once the elevator returns to the first basement floor, the standby automatic pallet is restarted.

C. Parking location improvement algorithm

After a user orders his/her car to be delivered to the boarding area, the unit space (No.j) where the corresponding automatic pallet was parked becomes empty. To this empty spot, the system moves the automatic pallet parked in the unit space on the same floor whose exit distance rank is larger by one than No.j unit space. This operation is carried out to all the automatic pallets on the same floor. The operation is described in Algorithm 2.

[Algorithm 2]

(1) First, the equation below finds the floor (i^{th} floor) where the unit space (No. j) is located. k is the number of unit spaces per floor.

$$i = \mathrm{INT}((j-1)/k)$$

(2) Next, from the exit distance table, the system finds the rank (r) of the exit distance of the unit space (No.j).

(3) For $t=r, r+1, r+2, \cdot\cdot\cdot, p_i-1$

・$Q(N_i(t)) \leftarrow Q(N_i(t+1))$

・$A(Q(N_i(t)) \leftarrow N_i(t)$

p_i is the number of automatic pallets parked on the i^{th} floor. When $r = p_i$, no improvement operation is performed. The initial value of $Q(t)(t = 1, 2, \cdot\cdot\cdot, e)$ is 0. e is the sum of the numbers of the basic and the complex unit spaces per floor.

(4) $p_k \leftarrow p_k-1$, $p^* \leftarrow p^*-1$

If the next exit request (O) is made during the above movement, the pallet currently being operated is moved to the target unit space first and the current operation is temporarily suspended. The information required for restarting the operation is pushed to the stack. Then, the exit request is accepted and the pallet requested is guided to the exit. Once the exit order has been completed, the suspended operation is popped and restarted.

D. Exit algorithm

The driver goes to the boarding area and have his/her face confirmed by the face recognition camera. The facial image Then, from the automatic pallet No.t corresponding to the facial image, the system find out the number of unit space No.j, where the automatic pallet with the recognized driver's car is placed ($A(t) = j$).

The system simultaneously determines whether the unit space searched is a complex unit space ($S(j)$ = 3 or 4) or a basic unit space ($S(j)$ =1 or 2). If it is former, the passage to the exit is guided by the operation shown in Figure 1. If it is latter, the passage to the exit is guided without additional procedure. After arriving at the exit, the system sets $A(t)$=0 and $Q(j)$=0.

The exit distance, the number of direction changes and the number of floors the elevator descends can be determined from the unit space where the car was parked. This information allows the system to calculate the time required for exit procedure. For the guidance time of the pallet from the exit at the 1st basement floor to the boarding area, a previously investigated value is added as a constant to the above calculated time.

VI. Conclusion

In this paper, the automated valet parking system proposed by Funase et al [3] was used. Specifically, following two aspects were focused for the improvement:

Improvement on automatic pallet mobility and operability to increase the number of parking spaces per floor.

A new algorithm for a time-efficient parking location determination method for automated valet parking to improve the time-efficiency of exit procedure.

The improvements on the pallets allow more flexible maneuverability and better controllability by installing additional wheels and sensors. The algorithm improvements allow the system to control the pallet and shorten the time required for exit operation.

These improvements could be vital contributing components for the implementation of future automated valet parking. However, the system proposed in this paper is still in the theoretical phase and further research and experiments are required.

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