DEVELOPMENT OF SAFETY EVALUATION SCENARIOS FOR INFRA-COOPERATED AUTOMATED VALET PARKING SYSTEMS

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ABSTRACT

This paper presents an evaluation procedure for an infrastructure based automated valet parking system. Because parking is one of the difficult and complicated tasks for drivers, park assistance system(PAS) has been already developed and commercialized by several auto-manufacturers. As a further step for PAS, researchers are focusing on automated valet parking system which is a fully automated system of PAS and periodically demonstrated their automated parking system. However, from an institutional point of view, evaluation standard and scenarios for automated parking system are progressing slowly compare to the automated driving. Because of specialty that in valet parking system, driver has to get out of the vehicle, most of the developers can not mass produce the system by legal issues. Thus, the necessity of evaluation procedure for parking system rise. Considering many automated valet parking systems are designed with digital map or infrastructure. Thus, in this paper, automated valet parking system cooperating with infrastructure is focused.

To design the evaluation process for automated parking, we divided the parking situation into two sides. 1) Nominal parking process, which is a static obstacle avoiding case related to static factors. 2) Complicated parking process, which is avoiding not only static obstacles but also moving obstacles such as pedestrians. As a valet parking is a very sequential service, to design evaluation items for nominal parking, we considered a procedure of manual parking and divided valet parking process into three different stages. 1) Driving in the parking lot while moving near to the parking space. 2) Parking to the aimed space. 3) Parking out from the space. Finally, the component of nominal parking scenario classified as static factors to test basic parking performance of the target vehicle and addable evaluation scenarios listed up as dynamic factor which can reproduce the complicated and frequent situation that can happen in the parking lot by combining with the nominal scenario. Both the nominal scenario and additional scenarios are organized as an evaluation matrix.

INTRODUCTION

In recent years, research has been carried out vigiriously about advanced driver assistance systems (ADAS) and autonomous vehicle. One of those automated driving technology, automated parking and parking assistant system are one of the close to mass production technology since parking is considered as troublesome and time-consuming task in driving. Thus various of configuration of sensor set for parking assistance[1-5] has been researched, furthermore, some car-makers, such as BMW and Volvo, periodically demonstrated their automated parking system. Now the researchers are aiming the fully automated parking system as a further step of PAS.

At the same time, the regulation and test procedure for active safety also have been researched including well known ADAS systems such as Adaptive Cruise Control (ACC), Traffic Jam Assist (TJA), Lane Keeping Support

(LKS), Lane Change Assist (LCA), Blind Spot Detection (BSD) and Advanced Emergency Braking (AEB)[6,7]. And the target system of the regulations and test protocols has been extended to automated driving and some legal issues hav been eased such as license system that allows automated vehicle driving in some area in normal road. But still, in a sight of automated parking technology, compare to automated driving, some legal issues are left to test and commercialize. Similarly, the research about test procedure for automated parking has plenty of works to do.
In case of Korea, recently standard about the definition of automated valet parking system had been released[8] and some test procedure of KNCAP related to parking situation such as AEB and rear-side access alarming system had been also already released[9]. But still, the detail factors to be consider to test the actual valet parking system has to be defined and have legal issues to evaluate the test procedure. There are some legal amendment for the automated driving on highway and urban road, valet parking has more issues about operating the acceleration/deceleration and steering system of the vehicle without the driver. And the automated valet parking system is still in develop, there are various automated parking related systems from level 2 to 4. Thus, the test scenario would be better if it can manage the automaed parking system widely according to the level or technical coverage of the test target's system.
In this paper, the infra-cooperated valet parking system divided into lower level maneuver based on the sequence of valet parking. The typical factors which should be considered in a sight of parking area's enviroment and situation are summarized. Then, we present the actual test case generation by cobiming the factors that can manage based on test site and test target system's needs and coverage. Last of all, the proposed test scenario is verified via computer simulation.

SEQUENCE OF INFRA-COOPERATED VALET PARKING TEST

To evaluate the valet parking test scenario, as a first step, the sequence of the parking should be defined. Excepting the static environment conditions such as shape of target parking lot, the entire valet parking service can be devided into two major items, parking and exit. Parking is a sequence that starts from the predefined zone and ends when the vehicle is parked in empty slot. Compare to parking, exit is a sequence that gets out from the parked slot and comes back to the predefined zone where the vehicle started the parking sequence. In short, exit and parking are the opposite process. More specific items and situation are shown in fig. 1.

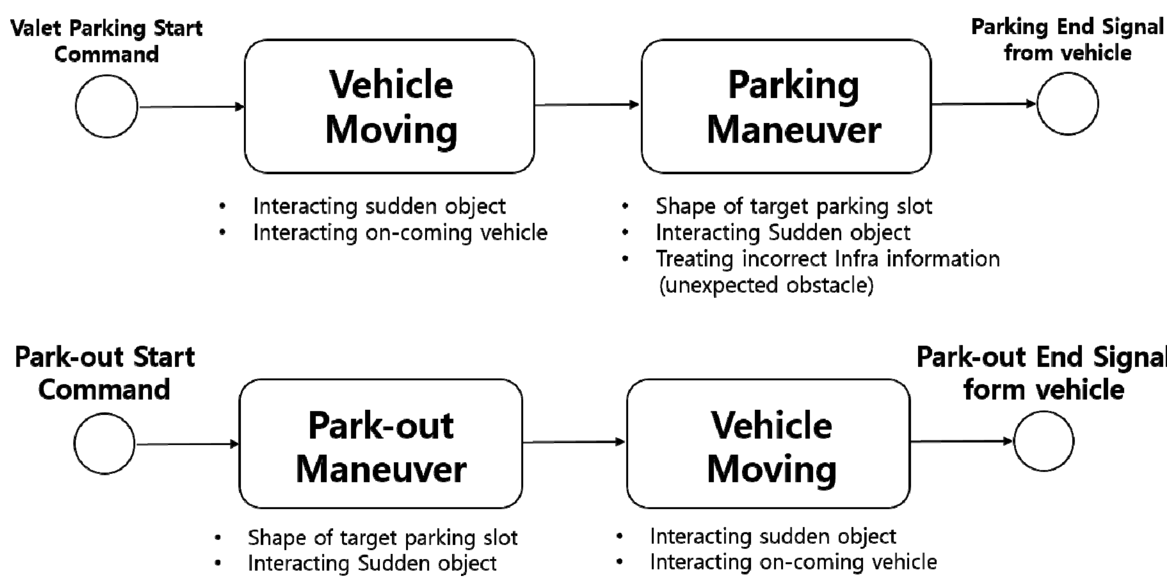


Figure1. Sequence of valet parking service.

Low-level Components for valet parking sequence

The two sequences, parking and exit can be also divided into two phases each. For both sequences, they have same purpose that the vehicle should move from starting point to the end point. The only difference is the fact that parking has to park in, and exit has to get out from the parked slot. Thus they have common phase, the vehicle moving phase. To consider their difference, parking maneuver phase and park-out maneuver phase are divided. In summary, the parking sequence is consisted with vehicle moving phase and parking maneuver phase and the exit sequence is consisted with park-out maneuver phase and vehicle moving phase.

Vehicle moving phase When the vehicle is in vehicle moving phase, it is very similar to the urban road driving cases. The only thing to do is to drive within a designated area, watch out for a collision, and move the vehicle to its destination. To specialize in parking area, vehicle can meet sudden pedestrian or parked out vehicle while driving parking area. Also, unlike to normal driving cases, facing with on-coming vehicle can also occur when two or more vehicles driving in parking area.

Performance evaluation In vehicle moving phase, whether the vehicle is driving within a designated area is the basic object of the phase. The boundary of the designated area is line that divides the parking slot and driving area in this case. It can be easily checked with the trajectory of the vehicle with known vehicle size, or the surround view camera images of the vehicle. Addable scenario item to this phase could be sudden obstacles such as pedestrian or parked out vehicles, which is similar to the urban AEB test scenarios[6]. In parking area, the vehicle should driving their velocity under 10kph, thus the test scenario case only needs for the vehicle speed 10 kph. For the on-coming vehicle interacting case, the subject vehicle has to leave enough space when the on-coming vehicle detected. The width of driving area is at least 6m space in law, thus the half of the space should be opened to on-coming vehicle.

Parking & Park-out maneuver phase Parking maneuver phase is a phase that park the vehicle into the parking slot without collision to the surroundings. Park-out maneuver phase is a phase that get out from the parked slot, which is directly reverse process of the parking. Although these two phases are separated because their region to watch out or consider is different, when we think ideal cases, excepting the moving obstacles, the two sequences have very similar actions, design collision-free path to static surroundings such as wall or other parked vehicles and control the vehicle to track that path. As addable scenarios, pedestrians walking near the selected parking slot, or other moving vehicle in parking area can be considered.

Performance evaluation As the parking and park-out maneuver phase are focusing on the collision and control performance, the major performance to be checked is that the vehicle totally get in to the parking slot or get out from the parking slot without any collision. For parking maneuver, when vehicle ends the parking, the vehicle should be fit in the parking slot well, which means the vehicle should not interfere the parking line. For both parking and park-out phases, the collision should not occur in their progress. For only static obstacle cases, checking the vehicle's trajectory or surround view images of the vehicle would be fine. For the moving obstacle cases, especially for the pedestrians, similar to AEB test, design the expected collision point and check the vehicle actually stops for each cases. For other driving vehicle case in parking area, the test scenarios are representable using reverse case of the rear-side access alarming system test[9].

CONSIDERING FACTORS FOR CO-INFRA VALET PARKING TEST

As shown in the previous chapter, infra cooperated valet parking test, the test condition can divided into static environment condition and dynamic environment condition. Static conditions usually contains weather, road shape, especially for the co-infra parking scenarios, it can be extended to other factors such as surrounding object placement near the target parking slot, shape of the parking slot. The considered static environment factors are as follows in table 1.

Structural Environment The valet parking test cannot held without the parking lot. Thus the structural factor is one of the considerable element in valet parking. The structural elements starts with whether the parking area is outdoor or indoor. If the parking area is placed outside, than the floor of the area would be automatically 1st floor only case and the global navigating system such as GPS would available. On the other hand, for multi-floor parking area, which is often seen in skyscraper or underground parking lot, the vehicle has to overcome the localization or indoor position problem itself. In short, the structural element is composed with whether the parking area is indoor or not and the parking lot has multi-floor or not.

Shape of target parking slot Shape of the target parking slot is one of the typical condition in parking. Especially for the parking or park-out maneuver, it is directly related to their trajectory generation. And this is the factor that parking has differentiation from driving. There are typically three different types of slots, one is perpendicular parking which is often called as T-parking. Another type is parallel parking, which is often used in road parking. And the last type is diagonal parking, which is usually placed in large parking lot area. The slot's shape condition can be affected from both valet parking system maker and test site. Test sites often have most of them for offer various test cases, but the valet parking technology is still in developing, hence the system or algorithm makers might have limits to their available range in shape type.

Table1.
Static factors of valet parking scenario.

<table>
<tr><th rowspan="2">Structural element of parking lot</th><th colspan="3">Geometric Positional Condition (G)</th><th colspan="2">Floor type (F)</th></tr>
<tr><td colspan="3">• (G-1) outdoor area (GNSS available)
• (G-2) indoor area (GNSS unavailable)</td><td colspan="2">• (F-1) Single floor case (floor movement X)
• (F-2) multi floor case (floor movement O)</td></tr>
<tr><th>Shape of target parking slot (S)</th><th colspan="2">T parking
(S-T)</th><th colspan="2">Parallel parking
(S-P)</th><th>Diagonal parking
(S-D)</th></tr>
<tr><th>Object placement near goal (P)</th><td colspan="5">(P-1) only the target parking slot is empty
(P-2) two slots are empty in a row including target space
(P-3) more than three slots are empty in a row including target space</td></tr>
<tr><th rowspan="2">Correctness of Infra' s information</th><th colspan="3">Status of infra (I)</th><th colspan="2">Unexpected object in target space (O)</th></tr>
<tr><td colspan="3">(I-1) Normal (target space is empty)
(I-2) Error(unexpected obstacle in target space)</td><td colspan="2">• (O-1) full size vehicle
• (O-2) two wheeled car
• (O-3) parking cone
*this category only activates in (I-2) case</td></tr>
</table>

Object placement near goal Object placement near goal is the factor that defines the availability of the parking slots near the target slot before the system test starts. The graphical concept of this factor is shown in fig. 2. This category can be very minor change compare to the other categories, because if the valet parking system can solve (P-1) case, which is the only target parking slot is empty, then other cases like (P-2) and (P-3) are automatically available. Although the (P-1) is the most challengeable case among them in vehicle control side, but as for detecting the actual slot's area, (P-2) and (P-3) become more challengeable case cause the system need to detect the parking lot line and identify the target space among them. Thus, as for the test environments, this factor also has to be considered differently.

Correctness of Infra' s information The testing target system of this paper is infra-cooperating valet parking system. This means that when the total valet parking sequence starts, infra gives the target parking slot to vehicle, and vehicle moves to the point. In a side of testing the vehicle's valet parking system, this factor is considered to check the ability that the vehicle can overcome the wrong information from the infrastructure. When infra gives the information, there would be actually tow cases. First case is the when the information is true, means the slot's actual availability is same with the known information. In this case, there is no extra issues for the scenario and becomes the basic case. On the other hand, if the known information is inconsistent with actual information, that means there is unexpected objects in the target parking slot. The unexpected objects can be other parked full size or two wheeled vehicles, or just banned with parking cone for other issues such as repair work. The situation that the target slot is unavailable seems already enough for vehicle to react, but the vehicle should make a decision that the space is unavailable itself. Thus, similar to the object placement category different types of object represents different condition to detection system of the vehicle.

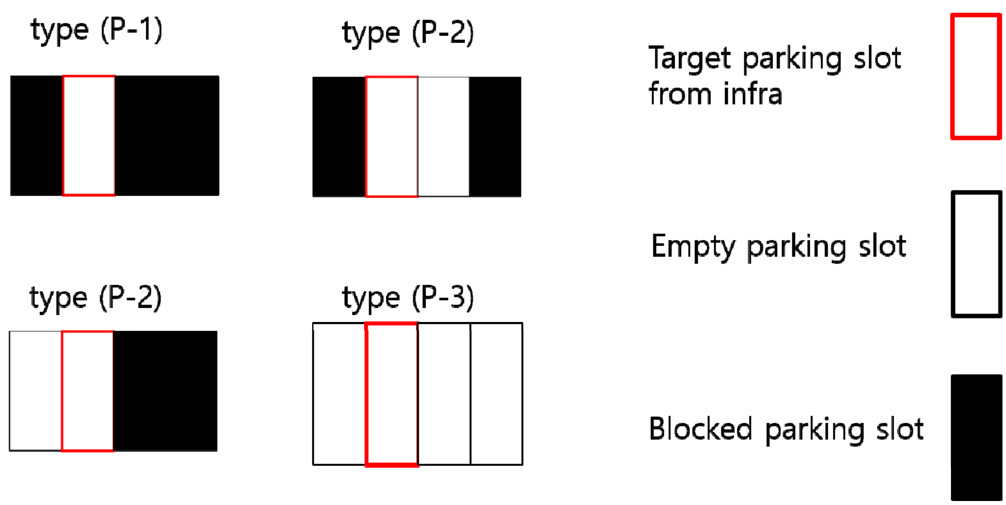


Figure2. Different object placement around target parking slot.

Table2.
Dynamic factors of valet parking scenario.

During vehicle moving phase	**pedestrian (H)**	**Park-out vehicle (J)**	**교행 vehicle (K)**
	(H-1) Adult(8 kph) (H-2) child (5 kph)	**(J-1) 5 kph** (J-2) 10kph	**(K-1) on-coming vehicle(10 kph)**
During vehicle parking& park-out phase	• **(E-1) adult pedestrian crossing the parking slot while in parking maneuver** • (E-2) child pedestrian crossing the parking slot while in parking maneuver • (E-3) other vehicle passing near the parking slot while in park-out maneuver		

Dynamic factors The above components are static factors that are predefined and maintained during for one test case. In contrast, the dynamic factors, in this case the moving objects, also can be represented in each test cases. Most typical moving objects in parking area are pedestrian and other moving vehicles. The dynamic factors can be listed in a similar table form above, which is shown in table 2. Here, we divide up the situations into two low-level component sequences that mentioned in valet parking sequence part. For each moving objects. Thus the factor (H-) and (J-) represents sudden moving objects while the subject vehicle driving the parking area. Factor (K-) shows the on-coming vehicle cases, and the factor (E-) gives the moving object during parking or park-out maneuver.

TEST CASE CONSTRUCTIION

From the previous two sector, we see that the system should be tested with total sequence level, and show the factors that majorly affects to the systems performance in a sight of autonomous valet parking vehicle. Still the valet parking system is in develop, for actual test, some factors can be considered and others are might not. Thus while constructing the actual test scenarios, firstly, define the systems coverage and divide the static and dynamic factors into the test cases. Table 3 and Table 4 shows one example of the test case generation and the following check list of each cases for one floor outdoor condition parking lot with all different type of parking slot shape.

Table3.
Test case/check list generation using static/dynamic factors.

Test case No.	Static Factor Condition	Dynamic Factor Condition
No.1	(S-T)-(G-1)-(F-1)-(P-1)-(I-1)	none
No.2	(S-P)-(G-1)-(F-1)-(P-1)-(I-1)	none
No.3	(S-D)-(G-1)-(F-1)-(P-1)-(I-1)	none
No.4	(S-T)-(G-1)-(F-1)-(P-2)-(I-2)-(O-2)	(H-1)-(J-1)-(E-1)
No.5	(S-P)-(G-1)-(F-1)-(P-2)-(I-2)-(O-2)	(H-2)-(J-2)-(E-3)
No.6	(S-D)-(G-1)-(F-1)-(P-3)-(I-2)-(O-3)	(K-1)-(E-2)

Test case no.	Check list
Common criterion	- Whether the vehicle keep driving in the designated area - Whether the vehicle fit-in the parking slot after parking - Whether the vehicle interfere the parking line in parking/park-out maneuver
No. 1	**- Common criterion only**
No. 2	**- Common criterion only**
No. 3	**- Common criterion only**
No. 4	**- Common criterion** - Whether the vehicle figure out and notive that the target slot is unavailable

	- Whether the vehicle properly stop and avoid collision with moving objects
No. 5	**- Common criterion** - Whether the vehicle figure out and notive that the target slot is unavailable - Whether the vehicle properly stop and avoid collision with moving objects
No. 6	**- Common criterion** - Whether the vehicle figure out and notive that the target slot is unavailable - Whether the vehicle properly stop and avoid collision with moving objects - Whether the vehicle make enough space for on-coming vehicle

In 6 test cases, the first three cases have no any dynamic factors and the other three test cases have dynamic conditions such as sudden pedestrian occurring. Although the test cases are generated based on the test target system's coverage, in order to system successfully perform the valet parking, test cases that only depends on static factors must be satisfied, in this case, test case no. 1-3. Common criterion shows the least conditions for system to be defined as valet parking system. As an extension of these cases, by considering dynamic factors, test case no. 4-6 shows whether the vehicle can react with some sudden objects or frequent situation when other moving objects are in the parking area. Thus the tested system can be differentiated their performance consider to the system that just doing basic operation of valet parking.

SIMULATION TEST RESULT

In this chapter, the simulation of the proposed test scenario is proposed. For this, valet parking algorithm which is presented in previous research is introduced in the first section. Using this valet parking algorithm, computer simulation was conducted using simulation tool MATLAB and Simulink.

Valet Parking Algorithm

In the study of Jeong[10], the reasearch proposed valet parking algorithm focusing on moving obstcle while driving in the parking area. The architercture of the test target algorithm is as follow in fig. 3. Based on the surrounding static/moving obstacle data and digital map, the algorithm infer the intention based on IMM filter and represent the drivable area in parking area by using potential field approach.

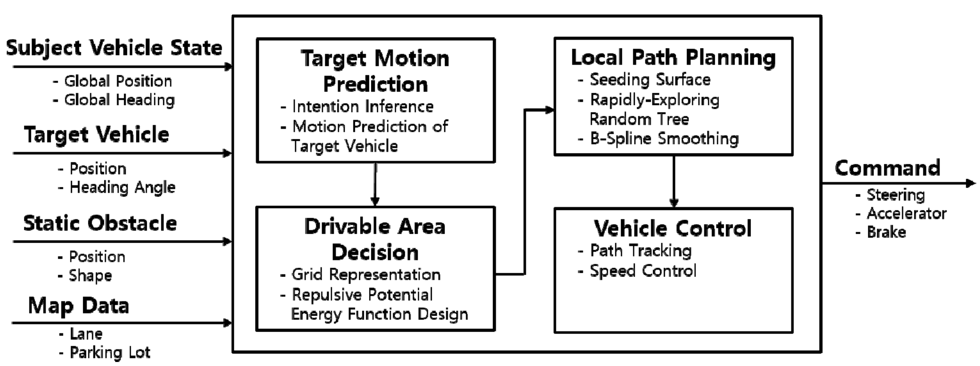


Figure3. Overall architecture of tested Automated Valet Parking

For the detail representation, two different potential energy function is used which is researched by Kim[11]. For the static obstalces or parking line boundary, cleareance based energy function is used which is in equation (1).

$$U_{rep} = \begin{cases} \min\left[U_{rep,\max}\ ,\ k \cdot \left(\dfrac{1}{D} - \dfrac{1}{Q} \right)^2 \right] & if \quad D < Q \\ U_{rep,\max} & else \end{cases}$$

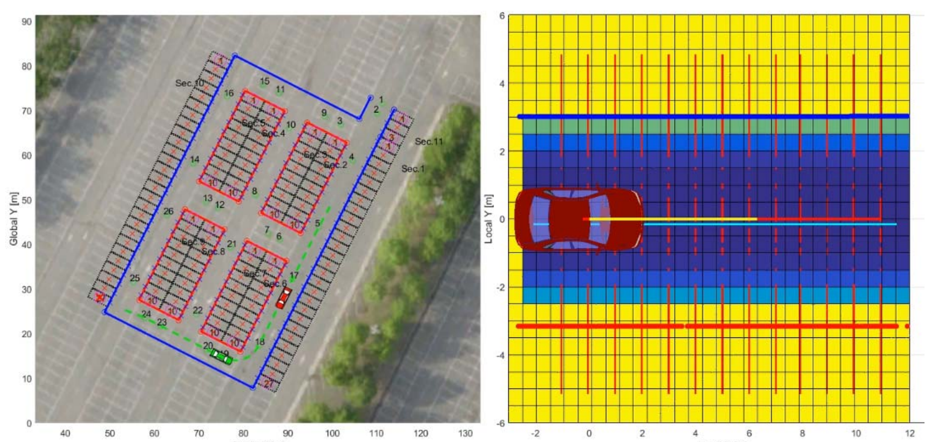
On the other hand, for the moving object, to imply the velocity information of the object, equation (2) is used.

$$U_{rep} = \begin{cases} k \cdot \exp\left(-\left(\dfrac{x_{r,p}}{\dot{x}_{r,p}} \right)^2 - \left(\dfrac{y_{r,p}}{\dot{y}_{r,p}} \right)^2 \right) & if \quad \left\| \rho(x_{r,p}, y_{r,p}) \right\| < \rho_{long} \\ 0 & else \end{cases}$$

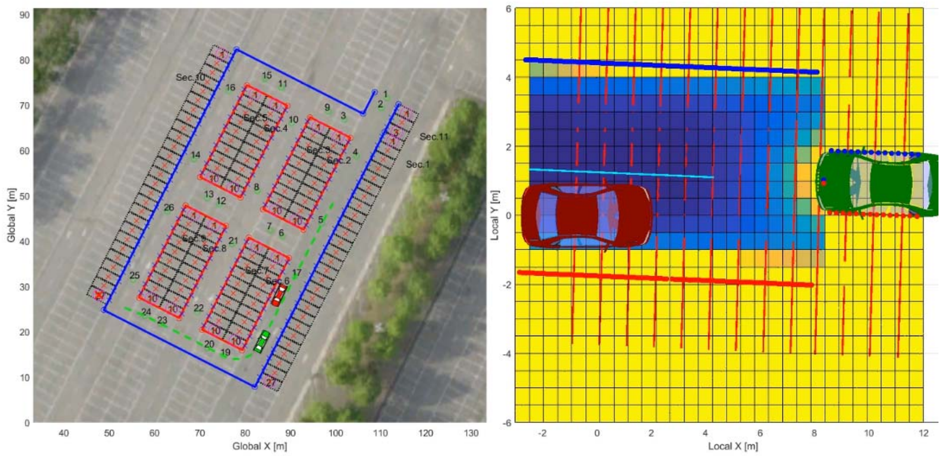
While in simulation, the surround representation result of this algorithm can also be used as check the actual collision occur or not for the test case.

Simulation Result

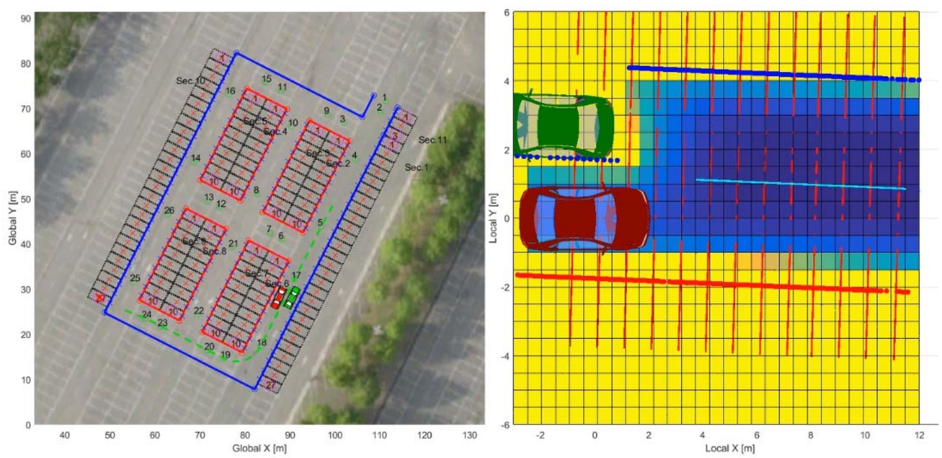
Computer simulation was conducted using simulation tool Carsim and MATLAB/Simulink. In this paper, the simulation result of total progress of Parking into T park slot including on-coming vehicle condition in a snap-shot image form.



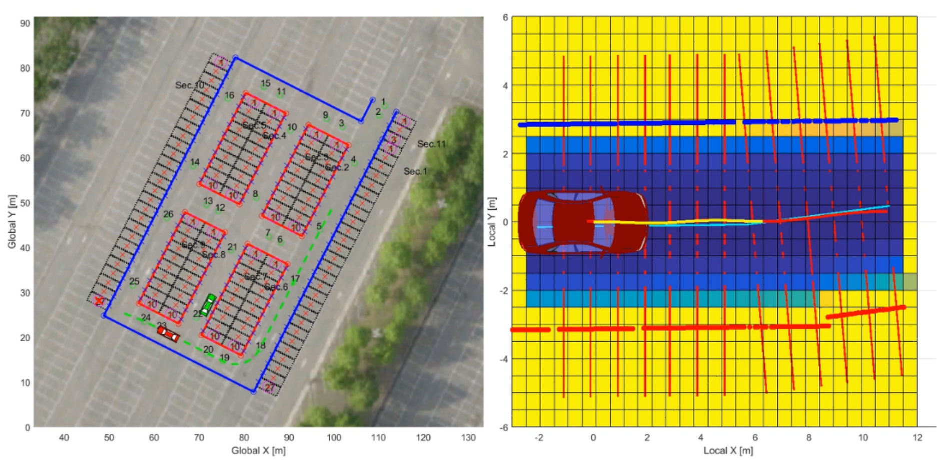
(a) Normal driving before meeting on-coming vehicle



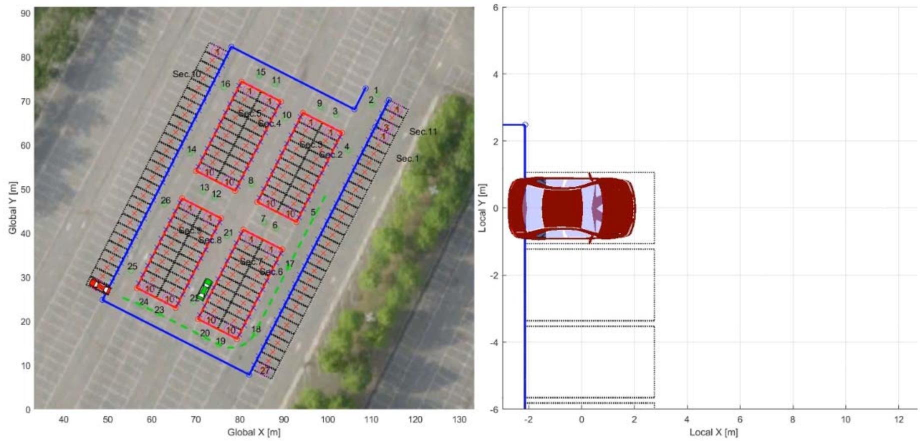
(b) Detect the on-coming vehicle & space generating on-coming vehicle



(c) Waiting for on-coming vehicle to pass



(d) Come back to global trajectory and keep move to goal



(e) Front side parking with fit-in left/right parking line of the goal

Figure4. Snap shot images of one example of valet parking simulation Testing condition with (S-T)-(G-1)-(F-1)-(P-1)-(I-1), (K-1)

<u>Simulation Case: T- slot parking with on-coming vehicle</u> The simulation result of the parking scenario in fig. 4. As the parking scenarios should check whether collision and interference occur or not, the simulation result proposed with graphical image of global situation to see the progress of total sequence and local coordinate of subject vehicle to check the collision or interference. The static factor condition is (S-T)-(G-1)-(F-1)-(P-1)-(I-1), which means outdoor parking lot with target slot shape T parking, and the information from the infra is correct. For the dynamic factor, (K-1) is applied before the subject vehicle enters the corner point of the global trajectory. The proposed images are mainly focusing on moment when the on-coming vehicle and subject vehicle met. The subject vehicle is shown as red vehicle and the on-coming vehicle is shown as green. Left images show the global position of both vehicle and right side images show the local path and boundary of the environment in local coordinate of the subject vehicle. As the result shows, the subject vehicle avoid the collision with the on-coming vehicle and finally parked into the target slot. Although the used parking algorithm had its coverage parking sequence, the scenario case can be applied as a partial test form.

CONCLUSIONS

In this paper, a procedure for evaluating scenarios for infra-cooperating valet parking system has been developed. The proposed test scenario divide the infra-cooperating valet parking with three sequential phases, vehicle moving, parking, park-out maneuver. To construct the factor matrix of the test condition, several frequent situation that can be face in parking lot area are list up and classified into static condition and dynamic condition. Then as a final step, test cases are generation step is suggested considering the test target system's coverage and the test site's condition, to manage both level 4 parking system and lower level parking assist systems. As an one example, one of the valet parking algorithm is applied with generated test case. The simulation shows that the proposed valet parking test scenario can be applied to one total functional sequence data and check whether the parking system works well including the performance of basic purpose
In order to develop the specific regulation such as rating criteria and detail procedure of each test scenario, additional vehicle experimental test should be conducted with various test cases applied to systems.

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