4단계 BK21사업 자율주행 xEV 혁신 인재 교육연구단

국제학술대회 사전계획서

학회명	IFAC World Congress 2023.		
개최국	일본	개최장소	Yokohama
발표자	김한솔	학번	A2022007
지도교수	강연식	동행 여부	여
논문 제목	Experimental Validation of Collision Avoidance Method using Real-time Model Predictive Control		
참가목적	Discussion papers submission 발표 목적 참가		
BK사업과의 연구 관련성	장애물 회피 알고리즘을 실제 차량에서의 실험을 통해 자율주행 안전제어 분야에 대한 실제 환경 검증을 마쳐 미래 자동차에 관한 연구를 마무리하였으므로 미래 자율주행 인재 육성에 기여함.		

1. 일정 세부 계획안

NO	날짜	세부일정	활동내역
1	7/12	07:00 ~ 08:00 : 인천 공항 도착 08:00 ~ 08:50 : 탑승 수속 및 출발 09:00 ~ 11:20 : 도쿄 나리타 공항 도착 11:20 ~ 12:30 : 숙소 이동 13:00 ~ 14:00 : 학회장 도착 후 사전 답사 14:00 ~ 15:30 : 도심지 주행기술 관련 동향 파악 (Learning and Applications 세션 참가)	Tutorials and workshops 학회 참석 사전 준비
4	7/13	09:00 ~ 12:30 : 도심지 자율주행 관련 판단 기술 동향 파악 (Decision Making and Planning for Transportation 세션 참가) 12:30 ~ 13:30 : 점심식사 13:30~15:30 : 도심지 자율주행 관련 Learning 기술 동향 파악 (Reinforcement Learning and Deep Learning in Control I 세션 참가)	Plenary and Semi-plenary lectures Technical sessions Banquet
5	7/14	10:00 ~ 12:00 : 도심지 자율주행 관련 Learning 기술 동향 파악 (Machine Learning 세션 참가)	Plenary lectures Technical sessions

		12:30 ~ 13:00 : 점심식사 13:30 ~ 15:30 : Automotive System II 세션 참가 및 발표 18:00 ~ 20:00 Closing ceremony 및 farewell Reception 참가	Closing ceremony Farewell Reception
6	7/15	16:00 ~ 18:00 : 공항 출발 18:00 ~ 19:25 나리타 공항 도착 및 출국 수속 19:25 ~ 22:05 인천 공항 도착	학회 참석 후 입국

2. 예산계획안

일련 번호	지원 항목	계산내역	지원신청액	비고
1	학회등록비	JPY62,000	638,630	학회영수증, 학회등록확인서 첨부
2	항공비	USD343.20	447,500	이티켓, 항공권영수증 첨부
3	숙박비	USD140*3박 = USD420	555,895	출장승인서 기준
4	일비	USD30*4일 = USD120	158,827	출장승인서 기준
5	기타			식대는 지원하지 않음
합 계			1,800,852원	

위의 건에 대하여 사전 계획서를 제출합니다.

2023년 06월 07일

자율주행 xEV혁신인재 교육연구단장 귀하

			결재	담 당	검 토	부단장	연구단장
신 청 인 :	김한솔						
참 여 교 수 :	강연식	(인)					

BrainKorea21 FOUR

4단계 BK21사업 자율주행 xEV 혁신 인재 교육연구단

국제학술대회 인정 확인서

1. 참가 해외연수 기본사항

학회명	IFAC World Congress 2023.		
출장지명	일본	출장기간 (학회기간)	2023.07.12. ~ 2023.07.15
출장목적	Discussion papers submission 발표 목적 참가		

2. 국제학술대회 기준 충족 여부

구분	기준	충족내역(작성)
참가국가수	4개국 이상	○
총 발표논문	20건 이상	○
외국기관 소속 발표자	전체 발표자 중 50% 이상 (국내 개최시 3분의 1 이상)	○
학회 Web Address	학회 Web Address	https://www.ifac2023.org/

위와 같이 해외저명학회의 본부가 주관(국내학회와 공동 주관 포함)하고, 국제학술대회 인정 기준 요건을 갖춘 국제학술대회에 참가함을 확인합니다.

신청인 : 김한솔 김한솔

지도교수 : 강연식 (인)

위와 같이 국제학회 기준 충족을 확인함.

2023년 06월 07일

연구단장 : 이성욱(인)

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If you have changed your affiliation linked to your PIN, then you must log out and log back in for changes to take effect.

Registration fees for 2023 IFAC World Congress are given below. All fees listed below are in Japanese Yen and inclusive of all taxes and service charges.

Attendance	Registration† Category/Rate	Advance Rate Mar 10-Apr 15	Regular Rate Apr 16-July 14	Paper Uploads	Banquet	Welcome Reception	Farewell Reception	Extra Banquet	Accompanying Guest*	Workshops**
On-Site	Full (IFAC Affiliate)	108000	135000	2 (TWO)	YES	YES	YES	NA	35000	20000
On-Site	Full (Non Affiliate)	110000	137000	2 (TWO)	YES	YES	YES	NA	35000	20000
On-Site	Student (IFAC Affiliate)	60000	81000	1 (ONE)	NO	YES	YES	10000	35000	12000
On-Site	Student (Non Affiliate)	62000	83000	1 (ONE)	NO	YES	YES	10000	35000	12000
On-Site	Mon-Wed (IFAC Affiliate)	70000	94500	NONE	NO	YES	NO	10000	35000	20000
On-Site	Mon-Wed (Non Affiliate)	72000	96500	NONE	NO	YES	NO	10000	35000	20000
On-Site	Wed-Fri (IFAC Affiliate)	70000	94500	NONE	NO	NO	YES	10000	35000	20000
On-Site	Wed-Fri (Non Affiliate)	72000	96500	NONE	NO	NO	YES	10000	35000	20000
On-Line	Full (IFAC Affiliate)	90000	112500	2 (TWO)	NO	NO	NO	NA	NA	NA
On-Line	Full (Non Affiliate)	92000	114500	2 (TWO)	NO	NO	NO	NA	NA	NA
On-Line	Student (IFAC Affiliate)	54000	72900	1 (ONE)	NO	NO	NO	NA	NA	NA
On-Line	Student (Non Affiliate)	56000	74900	1 (ONE)	NO	NO	NO	NA	NA	NA

† You are an IFAC Affiliate if you receive bimonthly newsletter and conference announcements from the IFAC.

* Accompanying guest registration rates will increase to JPY 47250 after the advance registration deadline. Note that guest registration includes banquet, receptions and social tour.

** After the advance registration deadline, workshop rates will change to JPY 25000 and JPY 15000 for full and student registrations respectively. Note that a single workshop registration allows you to attend any of the workshops.

If your manuscript exceeds the nominal page count, 6 pages for regular papers and 12 pages for survey papers, you must first complete the final submission information on paper submission page, the excess page count will appear automatically in the SELECT PAPERS page.

Registration Receipt

IFAC World Congress 2023

IFAC 2023, Pacific Convention Plaza Yokohama, Yokohama, Japan

Itemized Conference Registration Receipt

Registree: Hansol Kim
Affiliation: Vehicle Intelligence Laboratory the master's course, Kookmin University
Address: 10-3, Hancheon-ro 134-gil, Gangbuk-gu, Seoul, Republic of Korea, Seoul, -, 01056, Korea, South
Conference Tax/VAT: Japan Corporate Number: 0100-05-031790 (ALL FEES INCLUDE 10% TAX)
Registree Institutional Tax/VAT:

Item/Event	Qty	Tax/VAT	Amt
Paper Submission	1 @ JPY ¥0	1 @ JPY ¥0	JPY ¥0
Conference Registration	1 @ JPY ¥62000	1 @ JPY ¥0	JPY ¥62000
Welcome Reception	1 @ JPY ¥0	1 @ JPY ¥0	JPY ¥0
Closing Reception	1 @ JPY ¥0	1 @ JPY ¥0	JPY ¥0
ECF6D4F0-B3A7C4D6: Master (0741) on 2023-04-07		**Total Tax/VAT: JPY ¥0**	**Total: JPY ¥62000**
			Registration Tax/VAT: JPY ¥0
			Registration Total: JPY ¥62000

(Jun-ichi Imura)
(NOC Chair)
(IFAC 2023)

우리카드

국외이용 매입조회

성 명 : 국민대학교산학협력단 | 접 수 기 간 : 2023-04-01 ~ 2023-06-07

순번	카드번호	매출일자	매출종류	이용금액(현지)		이용금액(USD)	이용금액(원화)	해외이용수수료	청구금액
	가맹점명	매입일자	MCC	현지통화	국가	적용환율	승인번호	현금이용수수료	결제일자
1	5584-20**-****-0741	2023-04-07	일시불	62,000.00		479.04	636,739	1,891	638,630
	IFAC SYROCO2021	2023-04-10	8398	일본 엔	일본	1,329.20	870865	0	2023-05-23

총건수	미화환산금액 합계(USD)	원화환산금액 합계	해외이용수수료 합계	현금수수료 합계	청구금액 합계
1	479.04	636,739	1,891	0	638,630

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Electronic Ticket Itinerary & Receipt

예약번호 Reservation No.
54180638

승객성명 Passenger Name	KIM/HANSOL MR
항공권번호 Ticket Number	9882483028043
예약번호 Reservation No.	6MZ7I4(54180638)
회원번호 Frequent Flyer No.	650888008

발행점소 Issuing Office SALE FLY KOREA

여정 Itinerary

출발 From	도착 To	편명 Flight	예약등급 Class	출발일 Date(Day)	출발시각 Departure	도착시각 Arrival	비행시간 Flying Time	예약상태 Status	좌석번호 Seat
SEOUL INCHEON	TOKYO NARITA	OZ102	S	12JUL23 (WED)	09:00	11:20	02H20M	OK	

터미널 Terminal 1	터미널 Terminal 1		
경유 Via		경유지 체류시간 Layover Time	
운항항공편 Operated by	ASIANA AIRLINES OZ102	무료수하물 Free Baggage Allowance	1PC
판매항공편 Marketed by	ASIANA AIRLINES	항공권 유효기간 Not Valid Before	
운임종류 Fare Basis	SKKJL	항공권 유효기간 Not Valid After	12OCT23

출발 From	도착 To	편명 Flight	예약등급 Class	출발일 Date(Day)	출발시각 Departure	도착시각 Arrival	비행시간 Flying Time	예약상태 Status	좌석번호 Seat
TOKYO NARITA	SEOUL INCHEON	OZ105	K	15JUL23 (SAT)	19:25	22:05	02H40M	OK	

터미널 Terminal 1	터미널 Terminal 1		
경유 Via		경유지 체류시간 Layover Time	
운항항공편 Operated by	ASIANA AIRLINES OZ105	무료수하물 Free Baggage Allowance	1PC
판매항공편 Marketed by	ASIANA AIRLINES	항공권 유효기간 Not Valid Before	
운임종류 Fare Basis	KKKJL	항공권 유효기간 Not Valid After	12OCT23

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운임정보 Receipt Information

지불수단 Form of Payment	CC CA 558420XXXXXX0741/01 681076	Tour Code	3KJHD13B
운임 Fare	KRW 340000		
세금 및 제반요금 Tax/Fee/Charge			
*세금 Taxes	KRW 28000 BP KRW 5000 OI KRW 19900 SW KRW 9400 TK *한국 출발 세금(BP)에는 국제여객공항이용료(인천/김포공항 17,000원, 기타공항 12,000원), 출국납부금 10,000원, 국제질병퇴치기금 1,000원이 포함되어 있습니다. *The BP Tax includes International PSC(Incheon/Gimpo Airport KRW 17,000, other airports KRW 12,000), Departure Tax(KRW 10,000) and Global Disease Eradication Fund(KRW 1,000).		
*재발행 수수료 Reissue Fee			
*유류할증료 Fuel Surcharge	KRW 45200 YQ		
*발권수수료 Ticketing Service Fee			
합계 Total Amount	**KRW 447500**		
발행항공사/발행일 Issuing Airlines and Date	ASIANA AIRLINES 07JUN23		IATA: 17394355
제한사항 Restriction(s)	NONENDS/MAX3M MILE UG J/C/D/Y/B/M ONLY CHK IN/B S-CHRG		
운임계산 Fare Calculation	SEL OZ TYO124.47OZ SEL132.01NUC256.48END ROE1325.565633		

*항공권에 기재된 날짜, 여정, 운항 항공사, 예약등급, 유효기간 등의 변경 또는 취소/환불시, 판매조건에 따라 제반 규정이 다르게 적용되어 운임 차액 및 수수료가 발생할 수 있습니다.
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온라인 영수증

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거래정보

거래처	FLYASIANA.COM	
거래일자	2023-06-07 (수)	
거래수단	국내발행 신용카드(국내 전용)	
승인번호	68107673	
카드번호	558420******0741(일시불)	
승인금액	항공권 운임	KRW 340,000
	세금 및 제반요금	KRW 62,300
	유류할증료	KRW 45,200
	총액	**KRW 447,500**

예약정보

예약번호	6MZ7I4 (5418-0638)
탑승객명	KIM/HANSOL
항공권번호	9882483028043
여정	2023/07/12 (수) 09:00 [OZ102] 서울 / 인천(ICN) → 도쿄 / 나리타(NRT) 2023/07/15 (토) 19:25 [OZ105] 도쿄 / 나리타(NRT) → 서울 / 인천(ICN)

상호 아시아나항공㈜ | 대표이사 원유석 | 사업자번호 104-81-17480

주소 서울시 강서구 오정로 443-83(오쇠동)

Experimental Validation of Collision Avoidance Method using Real-time Model Predictive Control ⋆

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Abstract: This study proposes a collision avoidance algorithm that applies nonlinear model predictive control and its implementation on experimental vehicle. Safe steering avoidance behavior was developed by applying the ISO11270-compliant lateral acceleration constraints to the model predictive controller's optimization procedure. We created a scenario in which the designed model predictive control algorithm could drive while avoiding obstacles with optimum inputs within the specified restrictions. The algorithm was validated through both simulation and experiment.

Keywords: Nonlinear and optimal automotive control, Autonomous vehicles, Trajectory tracking and path following, Simulation tools and commercial software, Vehicle dynamic systems

1. INTRODUCTION

The nonlinear model predictive control (NMPC) approach computes optimal control inputs by using a nonlinear vehicle model to predict the future state of a vehicle. In this study, we employed NMPC to develop an evasive steering assist (ESA) system, which is a steering system-based driving-assistance function for collision avoidance. Eckert et al. [2011] presented the drivers tend to steer to avoid collisions when the TTC(Time To Collision) is within $2s$. But preventing collisions with steering can lead to secondary accidents due to unstable vehicle movement. Choi et al. [2012] and Vougioukas [2007] obtained steering control input using NMPC for the collision avoidance using vehicle dynamics-based constraints. In this study, the NMPC algorithm was implemented on the real-time embedded control system of the experimental vehicle. The algorithm was validated in the MILS(Model In the Loop Simulation) environment using the PreScan simulator with Matlab/Simulink Algorithm. It was experimentally verified using a laboratory experimental vehicle at Midan City, Incheon, Korea.

⋆ This paper was supported by the Basic Science Research Program through the National Research Foundation of Korea, funded by the Ministry of Education, Science and Technology (NRF-2021R1A2C2003254). This paper was supported by Korea Institute for Advancement of Technology(KIAT) grant funded by the Korea Government(MOTIE) (P0020536, HRD Program for Industrial Innovation). This paper was supported by the BK21 Four Program (5199990814084) of the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Korea

2. NONLINEAR MODEL PREDICTIVE CONTROL ALGORITHM

2.1 Path Prediction Model

To simplify model and reduce the algorithm's computation process, the kinematic bicycle model was employed as the prediction model. The model was proved to be valid at lateral acceleration of $4m/s^2$ calculated by applying the asphalt road surface friction coefficient of 0.9 suggested by Polack et al. [2017]. Eq(1) depicts the state vector x and the control input vector u of the vehicle model:

$$x = \{\zeta, \eta, \psi, V\}, u = \{a_{cmd}, \delta_{cmd}\} \tag{1}$$

where ζ and η are the vehicle's coordinates, ψ is the vehicle's heading, and V is the vehicle speed. In the control input vector u, a_{cmd} represents the vehicle acceleration input, whereas δ_{cmd} is a vehicle steering input. Eq(2) is derived by discretizing each element of Eq(1) using the sample time T. where l represents the wheelbase of the vehicle.

$$\begin{aligned}
\zeta(k+1) &= \zeta(k) + \Delta T \cdot V(k) \cdot \cos(\psi(k) + \delta_{cmd}(k)) \\
\eta(k+1) &= \eta(k) + \Delta T \cdot V(k) \cdot \sin(\psi(k) + \delta_{cmd}(k)) \\
\psi(k+1) &= \psi(k) + \Delta T \cdot \frac{V(k)}{l} \cdot \sin(\delta_{cmd}(k)) \\
V(k+1) &= V(k) + \Delta T \cdot V(k) \cdot a_{cmd}(k)
\end{aligned} \tag{2}$$

2.2 Cost Function Design

The future state of the vehicle model was predicted by setting the number of the prediction horizon N for the cost function. The error vector is defined as the difference between the predicted and actual state vector and is computed as Eq(3), and is the vehicle coordinate system reference.

$$\begin{aligned} e &= [e_x, e_y, e_\psi, e_V] \\ e_x &= (\zeta_G - \zeta_c)\cdot\cos\psi + (\eta_G - \eta_c)\cdot\sin\psi) \\ e_y &= -(\zeta_G - \zeta_c)\cdot\sin\psi + (\eta_G - \eta_c)\cdot\cos\psi) \\ e_\psi &= \psi_G - \psi_c \\ e_V &= V_G - V_c \end{aligned} \tag{3}$$

where G represents the global coordinate system and c represents the vehicle coordinate system. The components of the error vector represent errors in the x,y-direction, heading, and longitudinal velocity. Eq(4) shows the cost function, as a quadratic equation for optimization. Eq(5) defines the last term of the cost function and Eq(6) is a cost function that consists of the sum of the error vector and the input vector from the first to the $(N-1)$st terms.

$$J = \Phi(e_N) + \sum_{k=0}^{N-1} L(e_k, uk) \tag{4}$$

$$\Phi = \frac{1}{2}(e_N^T \cdot P \cdot e_N) \tag{5}$$

$$L = \frac{1}{2}(e_k^T \cdot Q \cdot e_k + u_k^T \cdot R \cdot u_k) \tag{6}$$

where P, Q, and R in Eq(5) and Eq(6) represent weight matrices. In Eq(4), the equation constraint for the prediction model was set by employing the Lagrange multiplier vector λ_k. The final cost function is Eq(7).

$$J = \Phi(e_N) + \sum_{k=0}^{N-1} L(e_k, uk) + \lambda_{k+1}^T[f(x_k, u_k) - x_{k+1}] \tag{7}$$

2.3 Setting lateral Acceleration Direction Constraints

By configuring the constraints of NMPC algorithm, the vehicle's physical constraints, state values, and input values were appropriately restricted. The constraints were set as follows. Within the range of 33.5°, the maximum steering angle of the experimental vehicle and the steering angle constraint were set to ±30°. In accordance with ISO 22179, the longitudinal acceleration was adjusted from $-3m/s^2$ to $2m/s^2$. In compliance with ISO 11270, the lateral acceleration was set to $3m/s^2$ as a safe performance criterion for the lane-keeping assist system (LKAS) as suggested by Jhang and Lin [2022]. The vehicle's lateral acceleration follows as Eq(8).

$$a_y = \dot{v_y} + \kappa v_x^2 \approx v_x \times \dot{\psi} \tag{8}$$

where a_y, v_y, κ, and V_x represent the lateral acceleration, lateral speed, curvature, and longitudinal speed, respectively. Since the lateral slip $\dot{V_y}$ is negligibly small, lateral acceleration can be approximated as the product of the longitudinal velocity V_x and the angular velocity $\dot{\psi}$. The angular velocity $\dot{\psi}$ is given Eq(9)

$$\dot{\psi} \approx \frac{v_x}{l}\sin(\delta_{cmd}) \tag{9}$$

Through Eq(8) and Eq(9), the lateral acceleration a_y may be expressed as Eq(10) using the input vector terms steering angle δ_{cmd} and longitudinal speed v_x

$$a_y \approx \frac{v_x^2}{l}\sin(\delta_{cmd}) \tag{10}$$

By inputting the lateral acceleration constraint and the wheelbase in Eq(10), Eq(11) can be calculated and a steering control input that satisfies the lateral acceleration constraint can be set as follows

$$\delta_{cmd} \approx \sin^{-1}(\frac{a_y}{v_x^2} \times l) \tag{11}$$

2.4 Cost Function Optimization Techniques

The cost function of the nonlinear model prediction controller was optimized utilizing conjugate gradient descent. To minimize the Hamiltonian and solve the optimization problem, the previous step's gradient information was added to converge faster than the gradient descent approach. Eq(12) shows the Hamiltonian needed to solve the optimization problem as follows.

$$\begin{aligned} H_k &= L(e_k, uk) + \lambda_{k+1}^T \cdot f(x_k, u_k) \\ &= \frac{1}{2}(e_k^T \cdot Q \cdot e_k + u_k^T \cdot R \cdot u_k) + \lambda_{k+1}^T \cdot f(x_k, u_k) \end{aligned} \tag{12}$$

Changing the cost function in Eq(7) to the Hamiltonian in Eq(12) yields the cost function equation shown in Eq(13).

$$J = \Phi(e_N) - \lambda_k \cdot x_N + \sum_{k=1}^{N-1}[H_k - \lambda_k \cdot x_k] + H_0 \tag{13}$$

$$\begin{aligned} H_u &= \frac{\partial H_k}{\partial u_k} \\ &= \frac{\partial}{\partial u_k}(\frac{1}{2}(e_k^T \cdot Q \cdot e_k + u_k^T \cdot R \cdot u_k) + \lambda_{k+1}^T \cdot f(x_k, u_k)) \end{aligned} \tag{14}$$

where H_u expressed by Eq(14) is a partial differential expression obtained by differentiating H_k by an input vector u. Eq(15) guided the computation of the control input for the following step in the direction of the cost function's decline by the d_k of the Hamiltonian gradient vector H_u.

$$u_{k+1} = u_k + \alpha \cdot d_k (0 < \alpha < 1)$$

$$d_k = \begin{cases} d_k = -c_k (k = 1) \\ d_k = -c_k + \left(\left\| \frac{c_k}{c_{k-1}} \right\|\right)^2 \cdot d_{k-1} \quad (k > 1) \\ c_k = \frac{\partial H_k}{\partial u_k} \end{cases} \tag{15}$$

Iterating the previous procedure until the control input converged within the constant ϵ yielded the optimal control input.

$$\epsilon > \|(u_{k+1} - u_k)\| \quad (\epsilon = Constant) \tag{16}$$

3. MODEL IN THE LOOP SIMULATION

3.1 PreScan Simulator Environment Configuration

Using Siemens' PreScan, the environment of Midan City in Incheon, South Korea, was modeled. Roads in Midan

City were realized using geographic information system (GIS) coordinates, and their width was set to 3.4m as an actual measurement. To implement an NMPC-based collision avoidance algorithm, the following experimental scenario was devised: 1. Follow the straight path; 2. Steer into the left lane to avoid a front obstacle on the straight path at 1.3s of TTC; 3. Follow the left lane to which the vehicle steered; 4. Steer into the right lane to avoid a front obstacle at 1.3s of TTC; 5. Follow the right lane to which the vehicle steered.

4. SIMULATION VERIFICATION

4.1 Comparison and Validation of the Nonlinear Model Prediction Controller and the Pure Pursuit Controller

The performance of the collision avoidance algorithm developed with the NMPC algorithm was compared to that of the lateral control algorithm—the pure pursuit(Snider et al. [2009]). Since constraints could not be set for the pure pursuit, the vehicle's physical conditions were represented by setting the saturation condition on the steering output. A target speed of $30km/h$, a lateral acceleration constraint of $\pm 3m/s^2$, and 1.3s of TTC were selected as the experimental conditions. The two algorithms' comparative metrics were divided into three categories: % Overshoot, rise time, and settlement time. The first comparison index, % Overshoot, was defined as the highest deviation from the target lane after steering avoidance. The time required for the lateral error to increase from 10% to 90% of its ultimate convergence value was chosen as the second comparison index, the rise time. As the final comparison index, the settlement time needed to reach within ±10cm of the lateral error and sustain time was measured.

Table 1. Algorithm performance comparison

	Max Error	% Overshoot	Rise Time	Settlement Time
PurePursuit	0.56m	16.35%	1.2s	3.45s
NMPC	0.28m	8.1%	1.4s	4.5s

Table 1 summarizes the comparison analysis data for two controllers for each index. The NMPC could prevent a maximum peak value that is about half that of the pure pursuit but the NMPC controller's settlement time was a whole second slower. Considering that the vehicle width was 1.86 m and the lane width was 3.40 m, the lateral error occurs within 0.77 m, which is the criterion for lane departure, and both controllers successfully performed steering avoidance without leaving the lane.

Graph (a) in Figure 1 shows that the lateral acceleration of both algorithms is limited to within $3m/s^2$. Graph (b) demonstrates that the constraints are used to calculate the steering input value. The target path and the lateral and longitudinal errors of the vehicle are depicted in Graphs (c) and (d). Graph (e) displays that the cost function tends to increase and then decrease as it converges on the opposing lane when the collision avoidance algorithm works. Graph (f) shows the vehicle speed set by the acceleration input of the NMPC algorithm.

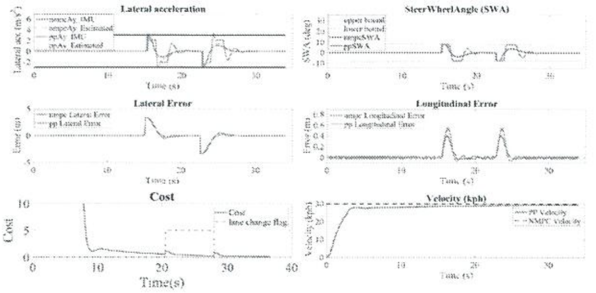

Fig. 1. Simulation Result Graphs for the NMPC Controller and for the Pure Pursuit

5. VEHICLE EXPERIMENT

5.1 Experimental Design Using the Actual Vehicle

The simulation-validated NMPC-based collision avoidance algorithm was implemented and tested on an actual vehicle. The experiment was conducted in Midan City, Incheon, South Korea, with identical conditions to those configured in the simulation. For safety reasons, two 0.55 m wide safety drums were installed in the center of each lane in place of automobiles. All obstacles were presumed to be static at predetermined coordinates

5.2 Experimental Vehicle Specifications

As seen in Figure 2, the experimental vehicle used in this study was a Sonata DN8.

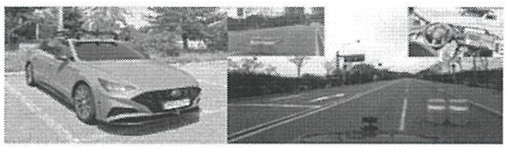

Fig. 2. Experimental Vehicle and Experimental Setting

5.3 NMPC Optimization Computation Time and its Constraints

The maximum number of iterations for the optimization process during the sample time of 0.05s was experimentally derived and used to restrict the number of iterations for the optimization operation. Restricting the number of iterations guaranteed the vehicle's control period, 20 Hz real-time performance. Figure 3 depicts the graphs of the

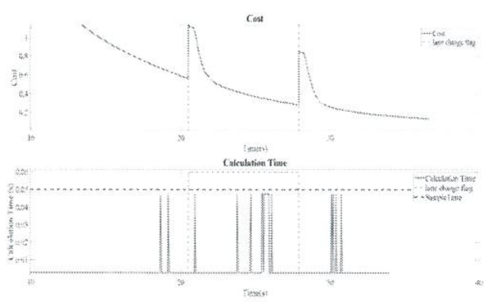

Fig. 3. Cost Function Calculation Result Graphs

cost function and calculation time during the algorithm's simulated implementation. On the indicated dashed red line, the avoidance algorithm was in effect and the rapid increase in the cost function can be observed in Graph (a). Graph (b) indicates that the calculation time was maintained at $0.05s$ at the point when the cost function increased rapidly. From this result, it is shown that the cost function may not have reached minimum because of limited iteration number. However, the optimization algorithm keeps minimizing the cost function in the next time step because the control inputs obtained in the previous time step is passed to the next time step as an initial guess for the optimization process. Therefore, the vehicle trajectory converged to the desired lane smoothly.

5.4 Experiment Results for the Actual Vehicle

The experiment was done at an identical conditions with those of the simulation. Compared to the simulation, TTC was raised by $0.5s$ for safety reasons.

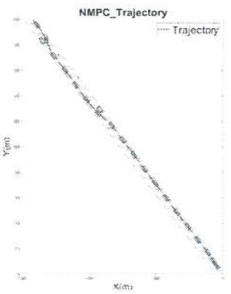

Fig. 4. Results from Following Paths Set by the NMPC-based collision Avoidance Algorithm

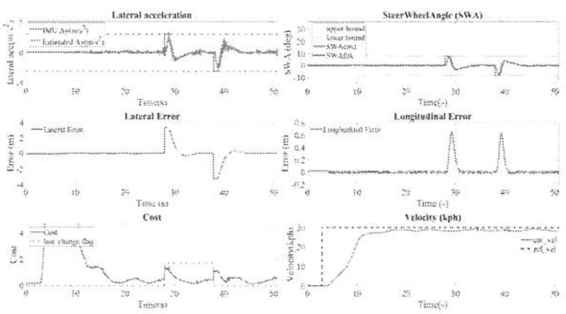

Fig. 5. Graphs of the NMPC-based collision Avoidance Algorithm Results

Figure 4 depicts the vehicle movement guided by the NMPC-based avoidance algorithm. The constraints were set by comparing the IMU sensor's measured data values with the results of Eq(10), which approximated the lateral acceleration, as seen in Figure 5's Graph (a). Graph (b) illustrates that the avoidance algorithm was executed utilizing the maximum steering angle allowed by the lateral acceleration limitation. Graphs (c) and (d) depict the vehicle's lateral and longitudinal deviations. Since the maximum peak value in the lateral direction was $0.36\ m$, there was no lane departure during steering avoidance. Graph (e) displays the trend of the NMPC cost function. There is a phase in which the cost function temporarily increases due to IMU sensor data noise; however, it tends to decrease as the vehicle's trajectory converges to the side lane after avoiding obstacles. Graph (f) shows the velocity of the vehicle in response to the acceleration input from the NMPC algorithm.

6. CONCLUSIONS

This study utilized a nonlinear model predictive control approach to develop the collision avoidance of the ADAS feature. Optimized control inputs were derived using the vehicle's dynamic model as a prediction model and unstable movement that can occur during steering avoidance was prevented by incorporating the vehicle's dynamic constraints into the optimization calculation. The algorithm's stability was validated not only within a simulation environment but also in a real-world environment using an actual vehicle. Using an actual vehicle in the real-world experiment, it was verified that the computational load could be reduced by limiting the number of computing iterations during the optimization process. It was shown that the control input might not have reached the optimum when a sudden switch had occurred for the lane change. However, it can continue the iteration in the next time step because the control input sequence is passed to the next time step as an guess of the optimization algorithm. Therefore, it was observed that the cost function kept reducing to the optimal point during the maneuver. In conclusion, the suggested collision avoidance algorithm satisfied a given set of lateral constraints within the specified TTC and converged without deviating from the lane after avoiding obstacles.

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Second Call for Papers

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IFAC 2023 YOKOHAMA

The 22nd World Congress of the International Federation of Automatic Control

July 9 – 14, 2023, Yokohama, Japan

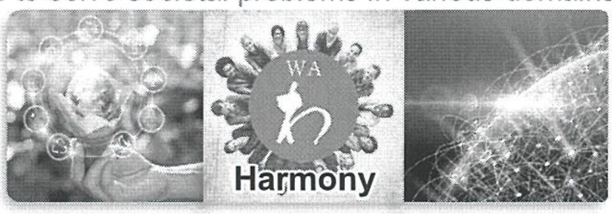
The IFAC World Congress is the largest event in the field of control science and technology, held every three years since 1960. It offers the most up-to-date and complete view of control techniques, with the widest coverage of application fields, and is attended by a worldwide audience of scientists and engineers from academia and industry. **The IFAC World Congress 2023 will be held in Yokohama, Japan,** which is the second congress hosted in Japan with the first being IFAC 1982 in Kyoto.

Conference Format

The IFAC2023 national organizing committee would make every effort to realize face-to-face meetings as possible. Still, there will also be an option to participate on-line, to accomodate the likely lasting influences of the COVID-19 pandemic.

Program Highlights

The vision of IFAC2023 is "Wa", which literally means "harmony" in Japanese. In a broad sense, it represents the design of large harmonious control loops to solve societal problems in various domains. The congress program includes special sessions to focus on this vision from various aspects, through *plenary and semi-plenary lectures, forums, panel discussions, demonstrations, tutorials, workshops*, as well as regular technical sessions.



Paper Categories

- Regular paper (R): up to 6 pages in the proceedings (up to 8 pages for initial submission)
- Survey paper (S): up to 12 pages in the proceedings (up to 16 pages for initial submission)
- Discussion paper (D): from 2 to 4 pages, for discussing specific topics, particularly from non-academic participants (not to be included in IFAC-PapersOnLine (POL))

Submission Categories

- Regular contributions (R/S/D)
- Invited contributions (R/S/D): invited by the organizers, selected under regular criteria
- Open Invited Track contributions (R/S/D): focus on specific research topics, based on proposals
- Demonstrator contributions (R/D): for promoting and showcasing research or education-oriented devices, innovative prototypes and transferring technologies to the enterprise.
- Dissemination contributions: papers recently accepted by IFAC journals, not to be included in IFAC-POL
- Tutorials and Workshops

Important Dates

Sep. 15, 2022	Open Invited Track proposals deadline
Oct. 15, 2022	Invited Session proposals deadline
Oct. 31, 2022	Regular / Invited papers submission deadline
Nov. 30, 2022	Tutorial / Workshop proposals deadline
	Discussion papers (Invited Sessions / Open Invited Tracks) deadline
Feb. 1, 2023	Discussion papers due (Regular) deadline
Feb. 21, 2023	Notification of acceptance
Mar. 31, 2023	Final paper submission deadline

IFAC2023 Technical Areas

Systems & Signals
Design Methods
Computers, Cognition & Communication
Mechatronics, Robotics & Components
Cyber-Physical Manufacturing Enterprise
Process and Power Systems
Transportation & Vehicles Systems
Bio- & Ecological Systems
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IFAC2023 Industry Group is a large and active community including colleagues from academia and industry. It takes in organizing various collaborative events such as panel discussions, forums, exhibitions and technical tours. (Chair: Kazuya Asano)

Industry subgroups

Mechatronic Systems	Aerospace Technology
Power & Energy Systems	Marine Systems
Machinery and Robotics	Environmental Systems
Steel Manufacturing Process	Biological & Medical Systems
Chemical Processes	Systems Science & Technology
Automotive Control	Internet of Things
Smart Cities	Artificial Intelligence
Smart Agriculture	Measurement and Instrumentation
Control in Construction	

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Japan Association of Automatic Control (JAAC)

Co-Organizers

The Society of Instrument and Control Engineers (SICE)
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Join the IFAC Control Orchestra!

The IFAC2023 organizers are planning to form an orchestra ensemble, including only musicians from the automatic control community, to make a live performance on site during the world congress. We are looking for colleagues who have some musical experience. If you have some musical experience and are interesting in this event, please subscribe to the orchestra mailing list through the congress website.

Performance at IFAC2020

4단계 BK21사업 자율주행 xEV 혁신 인재 교육연구단

국제학술대회 사전계획서

학회명	IFAC World Congress 2023.		
개최국	일본	개최장소	Yokohama
발표자	강연식	학번	A2022007
지도교수	강연식	동행 여부	여
논문 제목	Experimental Validation of Collision Avoidance Method using Real-time Model Predictive Control		
참가목적	Discussion papers submission 교신 저자 참가		
BK사업과의 연구 관련성	장애물 회피 알고리즘을 실제 차량에서의 실험을 통해 자율주행 안전제어 분야에 대한 실제 환경 검증을 마쳐 미래 자동차에 관한 연구를 마무리하였으므로 미래 자율주행 인재 육성에 기여함.		

1. 일정 세부 계획안

NO	날짜	세부일정	활동내역
1	7/12	07:00 ~ 08:00 : 인천 공항 도착 08:00 ~ 08:50 : 탑승 수속 및 출발 09:00 ~ 11:20 : 도쿄 나리타 공항 도착 11:20 ~ 12:30 : 숙소 이동 13:00 ~ 14:00 : 학회장 도착 후 사전 답사 14:00 ~ 15:30 : 도심지 주행기술 관련 동향 파악 (Learning and Applications 세션 참가)	Tutorials and workshops 학회 참석 사전 준비
4	7/13	09:00 ~ 12:30 : 도심지 자율주행 관련 판단 기술 동향 파악 (Decision Making and Planning for Transportation 세션 참가) 12:30 ~ 13:30 : 점심식사 13:30~15:30 : 도심지 자율주행 관련 Learning 기술 동향 파악 (Reinforcement Learning and Deep Learning in Control I 세션 참가)	Plenary and Semi-plenary lectures Technical sessions Banquet
5	7/14	10:00 ~ 12:00 : 도심지 자율주행 관련 Learning 기술 동향 파악 (Machine Learning 세션 참가)	Plenary lectures Technical sessions

		12:30 ~ 13:00 : 점심식사 13:30 ~ 15:30 : Automotive SystemⅡ 세션 참가 및 발표 18:00 ~ 20:00 Closing ceremony 및 farewell Reception 참가	Closing ceremony Farewell Reception
6	7/15	16:00 ~ 18:00 : 공항 출발 18:00 ~ 19:25 나리타 공항 도착 및 출국 수속 19:25 ~ 22:05 인천 공항 도착	학회 참석 후 입국

2. 예산계획안

일련 번호	지원 항목	계산내역	지원신청액	비고
1	학회등록비	JPY137,000	1,299,282	학회영수증, 학회등록확인서 첨부
2	항공비	USD343.20	447,500	이티켓, 항공권영수증 첨부
3	숙박비	USD180*3박 = USD540	714,722	출장승인서 기준
4	일비	USD50*4일 = USD200	264,712	출장승인서 기준
5	기타			식대는 지원하지 않음
합 계			2,726,216원	

위의 건에 대하여 사전 계획서를 제출합니다.

2023년 06월 07일

자율주행 xEV혁신인재 교육연구단장 귀하

신 청 인 : 강연식 (인) 참 여 교 수 : 강연식 (인)	결재	담 당	검 토	부단장	연구단장

BrainKorea21 FOUR

4단계 BK21사업 자율주행 xEV 혁신 인재 교육연구단

국제학술대회 인정 확인서

1. 참가 해외연수 기본사항

학회명	IFAC World Congress 2023.		
출장지명	일본	출장기간 (학회기간)	2023.07.12. ~ 2023.07.15
출장목적	Discussion papers submission 교신 저자 참가		

2. 국제학술대회 기준 충족 여부

구분	기준	충족내역(작성)
참가국가수	4개국 이상	학회에서 개시되지 않음
총 발표논문	20건 이상	학회에서 개시되지 않음
외국기관 소속 발표자	전체 발표자 중 50% 이상 (국내 개최시 3분의 1 이상)	학회에서 개시되지 않음
학회 Web Address	학회 Web Address	https://www.ifac2023.org/

위와 같이 해외저명학회의 본부가 주관(국내학회와 공동 주관 포함)하고, 국제학술대회 인정 기준 요건을 갖춘 국제학술대회에 참가함을 확인합니다.

신청인 : 강연식 (인)

지도교수 : 강연식 (인)

위와 같이 국제학회 기준 충족을 확인함.

2023년 06월 07일

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If you have changed your affiliation linked to your PIN, then you must log out and log back in for changes to take effect.

Registration fees for 2023 IFAC World Congress are given below. All fees listed below are in Japanese Yen and inclusive of all taxes and service charges.

Attendance	Registration† Category/Rate	Advance Rate Mar 10-Apr 15	Regular Rate Apr 16-July 14	Paper Uploads	Banquet	Welcome Reception	Farewell Reception	Extra Banquet	Accompanying Guest*	Workshops**
On-Site	Full (IFAC Affiliate)	108000	135000	2 (TWO)	YES	YES	YES	NA	35000	20000
On-Site	Full (Non Affiliate)	110000	137000	2 (TWO)	YES	YES	YES	NA	35000	20000
On-Site	Student (IFAC Affiliate)	60000	81000	1 (ONE)	NO	YES	YES	10000	35000	12000
On-Site	Student (Non Affiliate)	62000	83000	1 (ONE)	NO	YES	YES	10000	35000	12000
On-Site	Mon-Wed (IFAC Affiliate)	70000	94500	NONE	NO	YES	NO	10000	35000	20000
On-Site	Mon-Wed (Non Affiliate)	72000	96500	NONE	NO	YES	NO	10000	35000	20000
On-Site	Wed-Fri (IFAC Affiliate)	70000	94500	NONE	NO	NO	YES	10000	35000	20000
On-Site	Wed-Fri (Non Affiliate)	72000	96500	NONE	NO	NO	YES	10000	35000	20000
On-Line	Full (IFAC Affiliate)	90000	112500	2 (TWO)	NO	NO	NO	NA	NA	NA
On-Line	Full (Non Affiliate)	92000	114500	2 (TWO)	NO	NO	NO	NA	NA	NA
On-Line	Student (IFAC Affiliate)	54000	72900	1 (ONE)	NO	NO	NO	NA	NA	NA
On-Line	Student (Non Affiliate)	56000	74900	1 (ONE)	NO	NO	NO	NA	NA	NA

† You are an IFAC Affiliate if you receive bimonthly newsletter and conference announcements from the IFAC.

* Accompanying guest registration rates will increase to JPY 47250 after the advance registration deadline. Note that guest registration includes banquet, receptions and social tour.

** After the advance registration deadline, workshop rates will change to JPY 25000 and JPY 15000 for full and student registrations respectively. Note that a single workshop registration allows you to attend any of the workshops.

If your manuscript exceeds the nominal page count, 6 pages for regular papers and 12 pages for survey papers, you must first complete the final submission information on paper submission page, the excess page count will appear automatically in the SELECT PAPERS page.

IFAC

Invoice/Receipt #C13111D0-9C65CE75

Transaction By: Yeonsik

Transaction Date/Time: 2023-06-06

Payment Mode: Credit card (Brand: master, Card Number: 0741)

Item/Event	Deadline	Fee	Tax/VAT	No.	Total
Conference Registration **Included Items:** Included Banquet, Welcome Reception, and Closing Reception	Standard Registration	1 @ JPY ¥137000	JPY ¥0	1	JPY ¥137000
Included Banquet **Meal Options:** Non-Vegetarian	Standard Registration	1 @ JPY ¥0	JPY ¥0	1	JPY ¥0
Welcome Reception	Standard Registration	1 @ JPY ¥0	JPY ¥0	1	JPY ¥0
Closing Reception	Standard Registration	1 @ JPY ¥0	JPY ¥0	1	JPY ¥0

Subtotal: JPY ¥137000 **Tax/VAT:** JPY ¥0 **Final Fee:** JPY ¥137000

우리카드

국외이용 매입조회

성 명 : 국민대학교산학협력단　　　　접 수 기 간 : 2023-05-01 ~ 2023-06-19

순번	카드번호	매출일자	매출종류	이용금액(현지)		이용금액(USD)	이용금액(원화)	해외이용수수료	청구금액
	가맹점명	매입일자	MCC	현지통화	국가	적용환율	승인번호	현금이용수수료	결제일자
1	5584-20**-*****-0741	2023-06-07	일시불	137,000.00		995.34	1,295,435	3,847	1,299,282
	IFAC WORLD CONGRESS 20	2023-06-12	8398	일본 엔	일본	1,301.50	815573	0	2023-07-23

총건수	미화환산금액 합계(USD)	원화환산금액 합계	해외이용수수료 합계	현금수수료 합계	청구금액 합계
1	995.34	1,295,435	3,847	0	1,299,282

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전자 항공권 여정안내서
Electronic Ticket Itinerary & Receipt

예약번호
Reservation No.
88131902

승객성명 Passenger Name	KANG/YEONSIK MR		
항공권번호 Ticket Number	9882483027998	발행점소 Issuing Office	SALE FLY KOREA
예약번호 Reservation No.	6MMQXV(88131902)		
회원번호 Frequent Flyer No.	346370130		

여정 Itinerary

출발 From	도착 To	편명 Flight	예약등급 Class	출발일 Date(Day)	출발시각 Departure	도착시각 Arrival	비행시간 Flying Time	예약상태 Status	좌석번호 Seat
SEOUL INCHEON	TOKYO NARITA	OZ102	S	12JUL23 (WED)	09:00	11:20	02H20M	OK	
터미널 Terminal 1	터미널 Terminal 1								

경유 Via		경유지 체류시간 Layover Time	
운항항공편 Operated by	ASIANA AIRLINES OZ102	무료수하물 Free Baggage Allowance	1PC
판매항공편 Marketed by	ASIANA AIRLINES	항공권 유효기간 Not Valid Before	
운임종류 Fare Basis	SKKJL	항공권 유효기간 Not Valid After	12OCT23

출발 From	도착 To	편명 Flight	예약등급 Class	출발일 Date(Day)	출발시각 Departure	도착시각 Arrival	비행시간 Flying Time	예약상태 Status	좌석번호 Seat
TOKYO NARITA	SEOUL INCHEON	OZ105	K	15JUL23 (SAT)	19:25	22:05	02H40M	OK	
터미널 Terminal 1	터미널 Terminal 1								

경유 Via		경유지 체류시간 Layover Time	
운항항공편 Operated by	ASIANA AIRLINES OZ105	무료수하물 Free Baggage Allowance	1PC
판매항공편 Marketed by	ASIANA AIRLINES	항공권 유효기간 Not Valid Before	
운임종류 Fare Basis	KKKJL	항공권 유효기간 Not Valid After	12OCT23

*상기의 모든 정보는 항공사 및 공항 사정에 의하여 변경될 수 있습니다. All conditions may vary according to circumstances of airlines and airports.
*아시아나항공은 인천공항의 제1여객터미널에서 운항합니다. Asiana Airlines uses the terminal 1 of Inchecon International airport, please confirm your terminal again.

운임정보 Receipt Information

지불수단 Form of Payment	CC CA 558420XXXXXX0741/01 679794	Tour Code	3KJHD13B
운임 Fare	KRW 340000		
세금 및 제반요금 Tax/Fee/Charge			
*세금 Taxes	KRW 28000 BP KRW 5000 OI KRW 19900 SW KRW 9400 TK *한국 출발 세금(BP)에는 국제여객공항이용료(인천/김포공항 17,000원, 기타공항 12,000원), 출국납부금 10,000원, 국제질병퇴치기금 1,000원이 포함되어 있습니다. *The BP Tax includes International PSC(Incheon/Gimpo Airport KRW 17,000, other airports KRW 12,000), Departure Tax(KRW 10,000) and Global Disease Eradication Fund(KRW 1,000).		
*재발행 수수료 Reissue Fee			
*유류할증료 Fuel Surcharge	KRW 45200 YQ		
*발권수수료 Ticketing Service Fee			
합계 Total Amount	**KRW 447500**		
발행항공사/발행일 Issuing Airlines and Date	ASIANA AIRLINES 07JUN23		IATA: 17394355
제한사항 Restriction(s)	NONENDS/MAX3M MILE UG J/C/D/Y/B/M ONLY CHK IN/B S-CHRG		
운임계산 Fare Calculation	SEL OZ TYO124.47OZ SEL132.01NUC256.48END ROE1325.565633		

*항공권에 기재된 날짜, 여정, 운항 항공사, 예약등급, 유효기간 등의 변경 또는 취소/환불시, 판매조건에 따라 제반 규정이 다르게 적용되어 운임 차액 및 수수료가 발생할 수 있습니다.
When cancelling/refunding tickets or making changes to the stated travel dates, routes, operating airlines, booking classes and ticket validity, such requests are subject to the overall rules that can apply within a varying scope in accordance with the fare and sales conditions resulting in potential fare differences and fees.
*공동운항편의 경우 운항 항공사에서 구입 시와 운임이 다를 수 있으며, 사전좌석배정, 특별기내식, 무료수하물 등의 제반 서비스는 운항 항공사 기준에 따라 다르게 운영될 수 있으니 자세한 사항은 사전에 확인하여 주시기 바랍니다.
The fare of codeshare flights may differ when purchased through the operating carrier, and services such as advance seat reservation, special meals, free baggage allowance may differ according to the rules of operating carrier.

온라인 영수증

ASIANA AIRLINES

거래정보

거래처	FLYASIANA.COM	
거래일자	2023-06-07 (수)	
거래수단	국내발행 신용카드(국내 전용)	
승인번호	67979426	
카드번호	558420******0741(일시불)	
승인금액	항공권 운임	KRW 340,000
	세금 및 제반요금	KRW 62,300
	유류할증료	KRW 45,200
	총액	**KRW 447,500**

예약정보

예약번호	6MMQXV (8813-1902)
탑승객명	KANG/YEONSIK
항공권번호	9882483027998
여정	2023/07/12 (수) 09:00 [OZ102] 서울 / 인천(ICN) → 도쿄 / 나리타(NRT) 2023/07/15 (토) 19:25 [OZ105] 도쿄 / 나리타(NRT) → 서울 / 인천(ICN)

상호 아시아나항공㈜ | 대표이사 원유석 | 사업자번호 104-81-17480