

Development of an Intelligent Transport System for EV

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ABSTRACT

Japan is suffering from the problem of an ageing society. In Kitakyushu city more than a quarter of people are aged above 65 years. The roads in this region are narrow with steep gradient and vulnerable roadbed. A big ratio of elderly people are living on their own. These characteristics make driving unsuitable. The problem is magnified by infrequent public transportation. A need-assessment survey for an autonomous vehicle at a community event suggested the applicability of small electric vehicle Toyota COMS. The vehicle is then equipped with features like automatic driving and platooning. The autonomous drive system is built to develop an intelligent transport system (ITS) using various sensors and actuators. Stereo camera and ultrasonic sensors were used to get a judgment of obstacle. Google earth and GPS were used to generate the target path using the Bezier curve method and optimized route is chosen. IMU is used for calculation of vehicle position to make a compensation about the route information. White line recognition ensures that the vehicle follows road geometry. A non-linear model predictive controller (MPC) model is developed to control three driving variables, namely, brake, speed and steer angle. Platooning is realized by driving information exchange based on Zigbee communication. The conventional platooning control methods, improve the power consumption by shortening the inter-vehicular distance. In contrast, the proposed method controls the speed at the time of acceleration ensuring enhanced ride comfort for elderly people. The vehicle is modelled using CarSim® and is integrated with the MPC modelled in Simulink®. The mathematical vehicle model is validated by performing an ISO lane change test and the proposed autonomous drive and platooning system is judged using simulation and some field tests.

KEYWORDS: ITS, Platooning, Autonomous drive, Digital map, Wireless sensor network, Traffic congestion, K&C (Kinematics and Compliance), IMU (Inertial measurement unit)

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1. INTRODUCTION

Car driving is dangerous for the aged people. Human reflexes tend to decrease with age, thereby, restricting the ability to precisely evaluate the distance and the speed difference between the cars. This is the reason for several accidents [1] (see Figure 1). Moreover, tough road conditions like narrow and steep roads (see Figure 2) make driving more difficult. The aim of the autonomous driving system is to understand the surroundings of the vehicle, evaluate potential risks, and help the driver ride safely and efficiently [2], [3].

A need-assessment survey for an eco-autonomous vehicle for elderly people was held at Industry-University Cooperation Fair, Waseda University in October 2010. There were 39 responses in that activity and the aim of the survey was to develop an ITS (intelligent transport system) based on user feedback [4], [5]. Autonomous drive is being made using state of the art ITS tools like Google Earth, GPS, IMU, Stereo Cameras (for image recognition [6]), Ultrasonic sensors (for short range detection [7]), Hydraulic actuators (for brake and

accelerator pedals) and steering control using stepper motors. The platooning was realized using inter-vehicle Zigbee communication module ([8]). The rest of the paper is organized as follows.

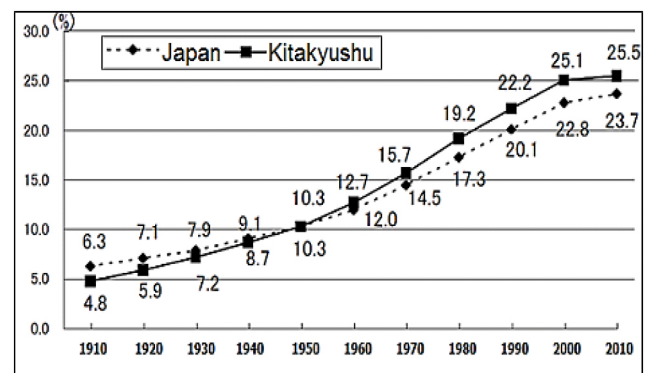


Figure 1. Accident rate of drivers above 65 years (Japan statistics bureau)



Figure 2. Typical road conditions in Kitakyushu, Fukuoka, Japan

Firstly, a mathematical model of the vehicle suspensions was developed in MD-Adams® to get the complex suspension and compliance characteristics which would be used later on for full vehicle model development. Secondly, the vehicle suspensions were optimized by modifying some of the suspension mounting points (hard-points). Then, autonomous drive system is prepared using various sensors as described above. The following section describes how autonomous drive is realized. This section is divided into four parts namely, route generation and position calculation, accelerator and brake pedal calibration, vehicle steering motor calibration and non-linear model predictive controller development.

Finally, vehicle platooning algorithm is been discussed. The results of platooning and autonomous drive test are shown in results section.

2. VEHICLE MODELING

The vehicle used for this study has been equipped with MacPherson strut front suspension and twist beam rear suspension. The mathematical model of the front and rear suspension is developed in MD Adams-Car® ([9]). Adams is a mechanical dynamics simulation tool widely used by designers in automotive industry. For modelling the half car suspension models the hard points of the vehicle have been precisely measured. The vehicle is mounted on four jacks and the hard-points were measured in un-laden condition (see Figure 3).



Figure 3. Hard point measurement and model development

These hard points govern the K&C (Kinematics and compliance) characteristics of the vehicle and have to be optimized to have better handling control and ride comfort [10]. The K&C characteristics like camber, caster, toe, king pin inclination, scrub and caster moment arm govern the controllability of a vehicle, while the design

parameters like roll centre height, roll stiffness, ride camber, ride steer, suspension rate, and percentage anti-dive/ anti-squat are responsible for the stability and ride comfort.

It was not possible to optimize all the hard points of existing vehicle because of manufacturing and space constraints. We have chosen a set of easily modifiable hard points.

1. Front suspension LCA (lower control arm) rear (z)
2. Steering tie rod inner (x, z)
3. Steering tie rod outer (x, y, z)
4. Front suspension LCA outer (x, y, z)
5. Rear suspension twist beam mounting point (x, z)

Figure 4 shows following hard points.



Figure 4. Front and Rear suspensions with suggested modifications

These points have been optimized by using a Monte Carlo simulation scheme in MD-Adams Insight® [11] to get the desired K&C characteristics (Table 1 and 2). The half car suspension models are subjected to a parallel and opposite wheel travel study. The wheels move in jounce and rebound by 50 mm. The suspension geometry is modified according to the new hard points obtained after optimization study.

Table 1. Acceptance Criteria: Front Suspension

No	Criteria	Value	No	Criteria	Value
1	Camber	0to-0.5 deg	8	Ride Steer	-6to-10deg/m
2	Caster	3 to 5 deg	9	Ride camber	-12to-18deg/m
		0-0.3 deg			
3	Toe	Toe-out	10	Roll Centre	110-150 mm
4	KPI	8 to 13 deg	11	Anti-Dive	20 to 35 %
5	Scrub	-15to30 mm	12	Anti-Lift	7 to 12 %
6	CMA	20to30 mm	13	Susp Rate	28-38 N/mm
7	SAC	< 3 mm	14	Roll stiffness	1.2-2e3 Nm/deg

Table 2. Acceptance Criteria: Rear Suspension

No	Criteria	Value	No	Criteria	Value
1	Camber	0 to-0.5 deg	5	Anti-Dive	20 to 35 %
2	Ride Steer	-6to-10 deg/m	6	Anti-Lift	7 to 12 %
3	Ride camber	-12to-18 d/m	7	Susp Rate	30-45 N/mm
4	Roll centre	110-150 mm	8	Roll stiffness	5-1.2e3Nm/deg

The set of modified hard points are given in figure 5.

Various suspension K&C characteristics for both front and rear suspensions like camber/caster/toe v/s wheel travel, etc. have been exported to CarSim® [12] to prepare the full vehicle model. There are two reasons for using CarSim for full model development. Firstly, it is easy to integrate vehicle S-function block with the controller model developed in Simulink® [13]. Secondly, we have used driving simulator to test the functioning of the controller which was developed on CarSim simulation background.

Model validation is performed by performing a field as described in section 6.1. Once sufficient correlations obtained, then the vehicle model is exported to Simulink to integrate with the controllers.

Design Variables										Responses Inclusions									
	Minimum			Maximum	Value		Oper	Target	Cost		Minimum			Maximum	Value		Oper	Target	Cost
r_02	4.1547			5.4294	5.1511		MaxTo	6	0.84892	r_14	417.65			332.69	332.69		r_01	Anti_Dive	
r_06	0.012628			0.018232	0.019652		Ignore			r_01	16.922			14.594	14.594		r_02	Camber	
r_07	8.5084			22.938	15.146		Max	16	0.85432	r_02	412.19			347.06	347.06		r_09	CMA	
r_08	-52.337			129.19	48.655		Min	50	-1.3453	r_07	379.65			376.84	376.84		r_10	KPI	
r_09	-5.7924			9.2276	5.9335		Ignore			r_10	93.465			79.037	79.037		r_11	Ride_Steer	
r_10	-0.89689			0.78123	0.50277		Ignore			r_11	453.8			380.3	380.3		r_12	Roll_Center	
r_11	-108.26			384.07	124.541		MaxTo	150	25.46	r_12	396.92			304.2	304.2		r_08	Roll_Stiffness	
r_12	1.7799e+005			2.9947e+005	2.5969e+005		MaxTo	2.6e+005	311.07	r_13	61.463			53.032	53.032		r_13	Scrub	
r_13	24.373			41.119	35.57		Ignore			r_06	409.47			401.51	401.51				
r_14	-303.92			204.95	35		GrEq	35											

Design Variables										Responses Inclusions									
	Minimum			Maximum	Value		Oper	Target	Cost		Minimum			Maximum	Value		Oper	Target	Cost
IB_Chassis_x	1200			1265	1248.6					r_04	40.627			33.997	33.997				
IB_Chassis_z	-420			-460	-435.4					r_05	0.015279			0.015279	0.015279				
										r_02	42981			1513.4	1513.4				
										r_07	1456.9			21.579	21.579				
										r_06	32.001			-0.59999	-0.59999				
										r_03	3895.3			172.39	172.39				
										r_01	0.056264			-0.0032825	-0.0032825				
Overall																			13.421

Figure 5. Set of optimized hard points obtained from ADAMS-Insight

3. SYSTEM DEVELOPMENT

In this study, a small single-seater EV Toyota COMS was used. The EV is modified and is equipped with two stereo cameras, ultrasonic sensor, wheel speed sensor, GPS, IMU (Inertial measurement unit) and the AND 5454 Real time control module [14] (see Figure 6). Sensor-fusion technology is utilized to identify the obstacles. For the detection of short distance obstacles, we used ultrasonic sensor which delivers high sensitivity at a low price advantage. For long distance obstacle detection, we built up an algorithm for obstacle recognition by stereo camera. GPS and IMU are used for recognizing the vehicle body angle and current position.

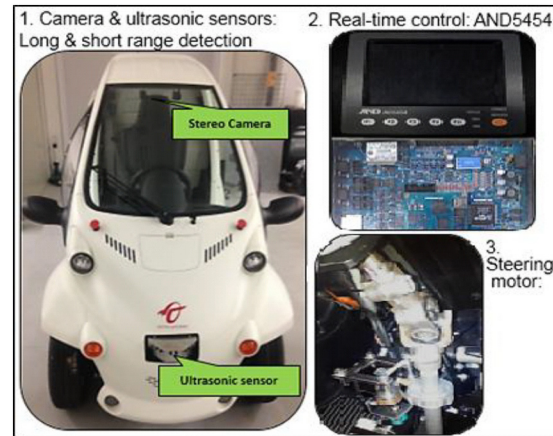


Figure 6. Vehicle built-up for Autonomous driving

Generally, autonomous vehicles use lidar technology for position recognition. However, lidar technology is currently too expensive (about 8000 USD) for wide deployment [15] while we aim to develop a low-cost autonomous vehicle which is affordable for elderly people. Moreover, the speed of operation is limited to 40 kmph in our case (for which image recognition and ultrasonic sensors are sufficient) while lidar is more robust and is meant for high speed applications.

The steering, accelerator and brakes have been re-modelled to accommodate linear actuators. Figure 7 shows the structure of the control system. The system is composed of the monitoring PC, router, controller, the image processing PC and remote monitoring PC respectively. The monitoring PC collects IMU and GPS data, and generates the driving path and it also communicates with the remote monitoring PC in case of an emergency or failure via router.

The image processing PC collects data from the camera and ultrasonic sensors, does obstacle recognition using sensor fusion algorithm, and also performs white line recognition. The router takes charge of communication between monitor PC, following vehicle and the controller.

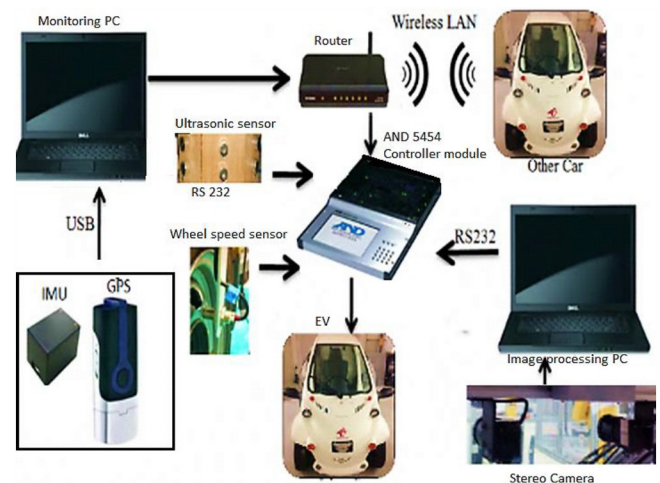


Figure 7. Realization of Autonomous drive

4. AUTONOMOUS DRIVING

The autonomous drive is realized by a control system architecture shown in Figure 8. Vehicle state is obtained by various sensors as described in section 3. The input from the sensors goes to the non-linear model predictive controller block which generates control commands, namely, brake input, throttle input and steering wheel rotation.

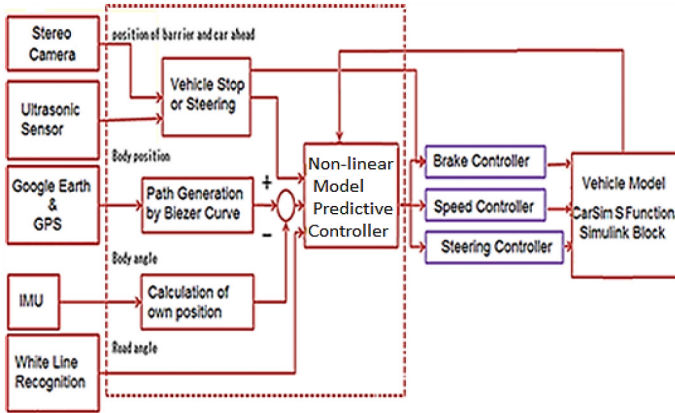


Figure 8. Control system architecture for autonomous drive

Various algorithm are discussed in the following sub-sections.

4.1. Position Calculation & Route Generation

As described earlier, for determining the road geometry and the vehicle position with the road GPS and IMU were used. We designed the position predictive model, driving route, start point, sub-goals and end position based on Google Earth information. Figure 9 shows the route selected for study. Selected road is around the Campus of Information, Production Systems of Waseda University, Kitakyushu, Japan. The road data is received as a KML (Keyhole mark-up language) file which gives geographic values of the track (road width is also measured) in the form of latitude and longitude. The KML file from Google Earth® ([16]) is then exported to the Global Mapper Tool™ ([17]). This tool gives the flexibility to design paths based on data points.

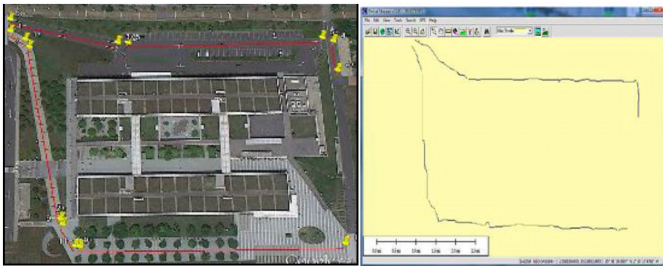


Figure 9. Test road in Google Earth & Global Mapper interfaces respectively

The start point no.1 is set as the original point in correlative coordinate. The automatic route generation system is designed in such a way that wherever the user sets the start point and the end point the system will automatically send the followed path geometry

data to the controller. The latitudinal and longitudinal road data are transformed to Cartesian coordinates using WGS 84 transformation ([18]). WGS 84 transformation is shown in figure 10.

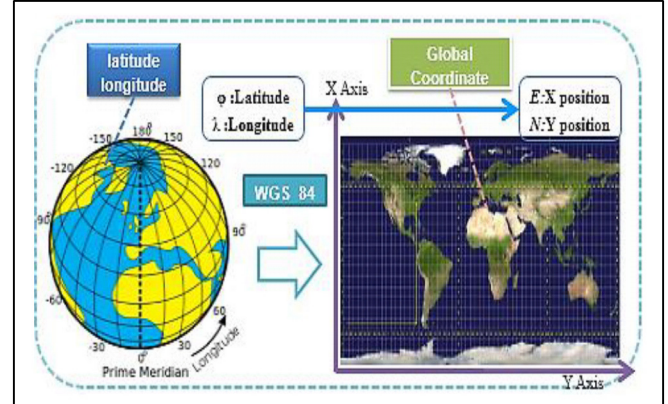


Figure 10. WGS 84 transformation: Geographical to Cartesian coordinates

The governing equations of WGS 84 transformation are

$$v(\varphi) = \frac{1}{\sqrt{1 - e^2 \sin^2 \varphi}} \quad (1)$$

$$A = (\lambda - \lambda_0) \cos \varphi \quad (2)$$

$$s(\varphi) = \left(1 - \frac{e^2}{4} - \frac{3e^4}{64} - \frac{5e^6}{256}\right) \varphi - \left(\frac{3e^2}{8} + \frac{3e^4}{32} + \frac{45e^6}{1024}\right) \sin 2\varphi + \left(\frac{15e^4}{256} + \frac{45e^6}{1024}\right) \sin 4\varphi - \frac{35e^6}{3072} \sin 6\varphi \quad (3)$$

$$E = E_0 + k_0 a v \left(A + (1 - T + C) \frac{A^3}{6} + (5 - 18T + T^2) \frac{A^5}{120} \right) \quad (4)$$

Where, $T = \tan^2 \varphi$, $C = \frac{e^2}{1 - e^2} \cos^2 \varphi$, a (Earth radius) = 6378.13 km, e (Flattening rate) = 0.081819, φ = Latitude, λ = Longitude

The data received from google map is a discrete point data. As one can see in Global Mapper interface that at some of the bends, path turning angle is 90 degrees which is not practicable for a vehicle to achieve. Smooth path needs to be generated to avoid a 90 degree turn at bends. Moreover, the course must satisfy the steering constraints and other vehicle dynamics constraints. In addition to this the path design should be safe and comfortable since the vehicle is meant for old age drivers where ride comfort is the primary concern. The course is designed using Bezier curves ([18]).

Bezier curve is widely used in vector graphics to model smooth curves that can be scaled indefinitely. Bezier curves are parametric curves defined as: