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I-DRIVE: MODULAR SYSTEM ARCHITECTURE AND HARDWARE CONFIGURATION FOR AN INTELLIGENT VEHICLE RESEARCH PLATFORM

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ABSTRACT

There are many researches in the field of autonomous and Intelligent Vehicle in Malaysia, but most of them never have the chance to be tested in actual environment due to constraints in terms of hardware and its configuration. Thus, this paper aims to share with other researchers in the field of Autonomous and Intelligent Vehicle with our independent modular-based system and hardware configuration of an Autonomous and Intelligent Vehicle research platform at our university. Each of the research projects are represented by a module and they are linked by a communication layer. The modules utilised the communication layers to transmit and received data as a part of system communication network, and finally this configuration build up the whole system. Through this approach, it is hoped that the contribution from each research project leads to fully autonomous vehicle and intelligent vehicle. The proposed modular system and hardware configuration have been successfully verified via our platform through lane-keeping research. The proposed platform is demonstrated via I-DRIVE (Intelligent Drive Vehicle) on the standard testing track and Malaysia highway road.

Keywords: autonomous vehicle, intelligent vehicle, lane.

INTRODUCTION

Over the last few years, automotive industry and Intelligent Vehicle research groups progressively focus on development of the Intelligent Vehicle Systems (IVSs) as can be seen from research activity outline presented in [1] and the outcomes done in the last decade [2]. The intention is to increase safety and to reduce both accidents and driver's workload by integrating factors and information caused by human beings, vehicles, roadways and environment

Vision sensing instrument involves the use of camera to detect object. The Navlab-11 was equipped with six video cameras, three in front, one on top, and two looking along the sides [3]. In OSU, a single black and white camera based vision system was used [4]. LISA-Q was equipped with a rectilinear camera and a omnidirectional cameras [5]. VaMoRs-P, the research platform was equipped with active bifocal vision systems [6]. In ARGO, a low cost cameras with stereoscopic vision system consisting of two synchronized cameras is able to acquire pairs of grey level images simultaneously [7]. Motion sensing instrument involve the use of Inertial Measurement Unit (IMU), GPS, differential odometry, compass, inclinometer, and angular gyro [3]. In OSU, a rate gyro providing yaw measurement and internal vehicle sensors for vehicle speed, engine RPM, steering angle, brake pressure, and transmission measurements was equipped in their autonomous vehicle [4] [5] [7].

As for radar/laser sensor, Navlab-11 used three Sick single-axis scanning laser rangefinders mounted in various positions, typically one looking forward and two along the sides and a light-stripe rangefinder typically mounted looking for the curb on the right [3]. A forward-looking laser/radar, providing headway information of the frontal car, differential velocity, heading and headway determination, also a modified Eaton-Vorad side sensing (blind-spot detection) radar, used for detecting completion of the car passing operation [4]. In LISA-Q, laser radar.

In Navlab-11, they used five 500 MHz Pentium computers and a high-accuracy time synchronization. VaMoRs-P used five dozen transputers T-222 (16-bit, for image processing and communication), T-800 (32-bit, for number crunching and knowledge processing) plus a PC as transputer host [6]. ARGO used pentium MMX processor [7].

Each autonomous vehicle that was developed for an objective. In Navlab-11, they focus on research on short-range sensing, to look all around the vehicle for safe driving whereas LISA-Q focus on research is to create a human-centered intelligent vehicle that captures dangerous situations such as vehicle cut-ins, driver distraction, driver drowsiness, problems with the vehicle, and unintended lane departures to inform or warn the driver of potentially dangerous situations [5]. In VaMoRs-P, the platform was able to perform road and object recognitions in look-ahead and look-back regions, servo-maintained an internal representation of the entire situation around in the vehicle using the 4D approach to dynamic machine vision, obstacle detections and tracking in forward and backward viewing range up to about 100 meters distance, and have the capability to track up to five object in parallel in each hemisphere [6]. ARGO focus on autonomous vehicle for obstacle and lane detection [7]. THMR-V and TAIWAN

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iTS-1 focused on high-speed (more than 120km/h) autonomous vehicle [8] [9].

These research platforms have serve the objective of the research. However, the architecture of the research platform only serves for single research project. Thus, this paper proposed an independent modular-based system and hardware configuration of an Autonomous and Intelligent Vehicle research platform that can be configurable for various research activities. The architecture and detailed development of a modular architecture system and hardware configuration has been implemented on i-DRIVE platform as shown in Figure-1.

Figure-1. Intelligent vehicle research platform.

This paper is organised as follows: Section A describes the modular architecture of an intelligent vehicle research platform and its hardware configuration and the function of each module. Section B shows the overview of i-DRIVE platform and detailed explanation on each sub-module. Section C gives result on validation and experiment conducted for Vision Processing Unit, Lane-Keeping and Radar Processing Unit. Finally, Section D gives conclusion and future work on i-DRIVE platform.

A. MODULAR SYSTEM ARCHITECTURE

A modular-based architecture for Intelligent Vehicle research platform has been developed. This modular architecture refers to the design of a system composed of separate components that can be integrated together but independently operated from one another. The advantage of this architecture is that it can introduce or replace any component, sub-system or module without affecting the rest of the system. The modular architecture of the platform in Figure-2 are composed of Vision Processing Unit Module, Inertial Measurement Processing (IMU) Module, Steering Control Module, Monitoring module, Perception Processing Module and In-vehicle Controller unit, respectively.

The Image Processing module handles vision-related algorithm and computation for line tracking using a single in-car camera and the output is the lateral offset and heading offset with respect to the centre line of the road at look-ahead preview distance of 10 meter. The Inertial Measurement Processing (IMU) Module takes raw data from the IMU sensor, performs noise filtration and feeds it into an algorithm that will give the information on the yaw rate, pitch and roll. Perception processing Module takes raw data from radar sensor and processes it to give information such as classification class type of vehicle, position of object within radar effective sensing radius and the velocity of approaching object. While, Steering Control Module is used to control the i-DRIVE steering angle thus controlling the front wheel angle. The in-vehicle controller unit provides vehicle's information such as vehicle's speed, braking information, and other related information. All activity and process inside the individual module can be monitored using Monitoring Module. Each module are independent, but the data is accessible by other module through communication layer. The module only focused on the task assigned to it and this increases the reliability and processing speed of the system.

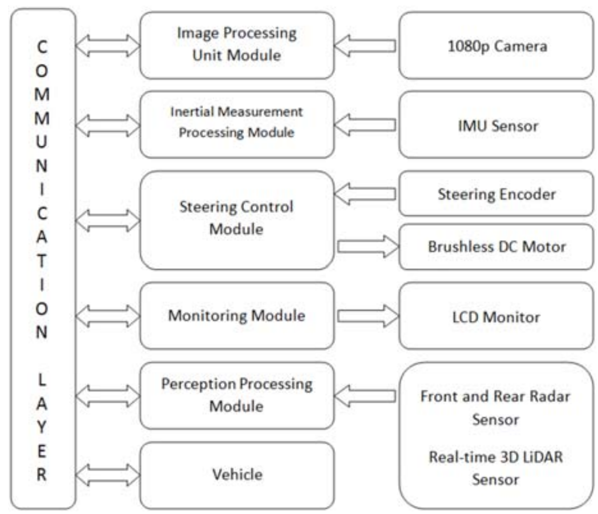

Figure-2. Modular architecture for intelligent vehicle research platform.

B. THE OVERVIEW OF i-DRIVE

As shown in Figure-3, i-DRIVE is equipped with in-vehicle controller, industrial PC for data processing, data acquiring sensors, power system and actuators. The camera grabs the raw image data; both rear radar sensors provides side-distance, position, and velocity measurement any object within the radar's effective sensing radius; the front radar sensor provides forward-distance measurements with respect to the object ahead; GPS gives the vehicle's global positioning; in-vehicle controller and industrial PC are used for computation, arithmetic, signal and controlling processing; and the LCD monitor displays modules activities. The specification of i-DRIVE are listed in Table-1.

Table-1. Specification of i-DRIVE.

Vehicle model	Proton Exora 1.6 CPS
Engine Type	1.6 L CamPro CPS DOHC
Maximum Output [hp(kW)/rpm]	125 (93) / 6500
Maximum Torque (Nm/rpm)	150 / 4500
Maximum Speed (km/h)	170
Transmission	4-speed automatic
Dimensions (mm)	(L)4592 x (W)1809 x (H)1480
Kerb Weight (kg)	1400 to 1486

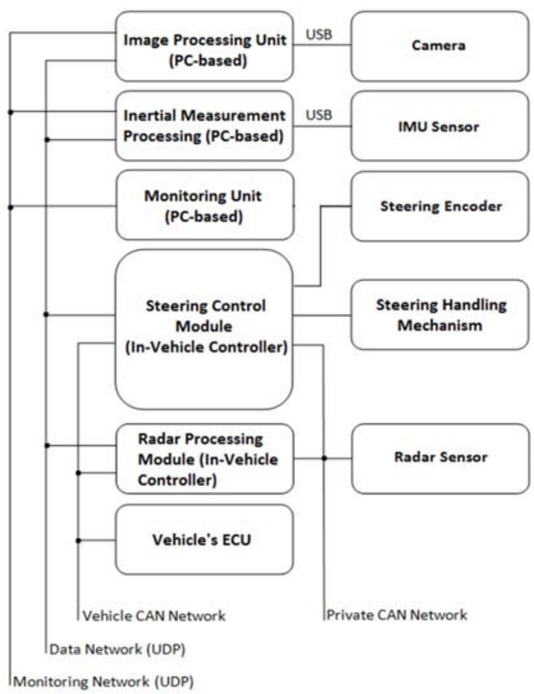

Figure-3. i-DRIVE sensor and equipment placement.

Communication layer

Communication layer is a network configuration that linked the modules for data transferring and remote monitoring purpose. The layer are consists of two communication protocol, User Datagram Protocol (UDP) and Controller Area Network Bus (CAN). In general, the UDP and CAN network are separate into two network. The first UDP network are for data transferring between modules and the second UDP network for remote monitoring. On the other hand, the CAN network are separate into vehicle CAN network and private CAN network. The USB communication line is used to link sensor such as IMU sensor and a single in-car camera to their respected module

For UDP networking, the data transferring network are dedicated network for data transferring between modules, such as lateral offset from Image Processing Module, yaw rate from Inertial Measurement Processing (IMU), vehicle's speed from in-vehicle controller unit, and radar information from Perception Processing Module. The monitoring network is used data transferring that involves monitoring activities between modules. Our network configuration for modular architecture are designed to be an open network access, any modules within the same network can be monitor and access by other modules for the purpose of debugging, monitoring or data request such as lateral error and yaw rate.

Referring to Figure-4, the CAN network are divided into Vehicle CAN Network and Private CAN Network. The Vehicle CAN networks are used as a mean of communicates between in-vehicle controller units to other In-vehicle Embedded Controller for vehicle's parameter such as vehicle's speed. While, the Private CAN network are used by the In-vehicle Embedded Controller to communicate with other In-vehicle Embedded Controller and sensors or devices that utilize CAN communication protocol to transfer data. Lastly, Universal Serial Bus (USB) communications are used as a communication medium between IMU sensor and camera to their respective processing module.

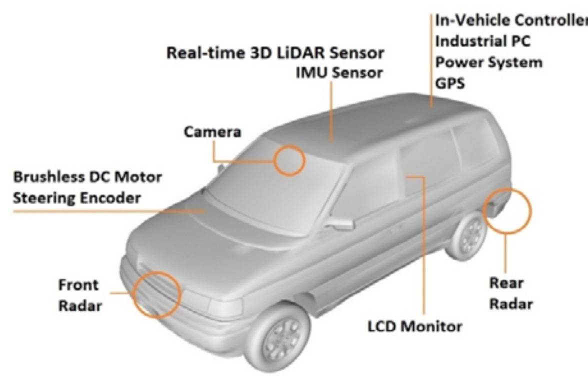

Figure-4. Communication layer.

Vision processing unit

Vision Processing Unit is an Industrial PC-based controller that handle vision related algorithm and computation for lane tracking. The input is taken from a single in-car camera that captures the image of the road at the rate of 25 frame per second with look-ahead preview distance of 10 meter. The image from the camera is converted to black and white mode to create a high contrast between the road and white line on the road. The converted image is then filtered for noise and feed to a ransac algorithm to produce a best fit straight line, illustrated by line a and b in Figure-5. The Vision Processing Unit then will process the best fit straight line and compute the lateral offset with respect to the centre of the lane, line c in the Figure-5. The lateral offset is denoted as positive value for lateral offset on right side and negative value for lateral offset on left side.

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Inertial measurement processing module

The Inertial measuring unit (IMU) combines inertial sensors such as linear accelerometers and rate gyroscope, whose measurements are relative to inertial space, into one platform. By knowing the angular rate and or acceleration of an object, its change in position can be calculated by integrating the signal over time. For i-DRIVE, an IMU sensor with sampling frequency of 10kHz/channel (60kS/s), output frequency up to 2kHz and latency less than 2ms was used. The IMU sensor was placed at the vehicle's centre of gravity. Raw data from IMU sensor are in the form of data protocol that need to process by Inertial Measurement Processing Module. The processed data than broadcasted into communication layer

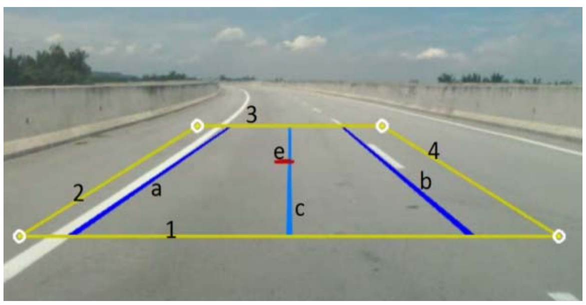

Figure-5. Image processing for lane detection.

Inertial steering control module

Steering Control Module is used to control the i-DRIVE steering angle thus controlling the front wheel angle. Refer to Figure-2, steering control module consists of two parts, the mechanism to control the steering and an encoder to gives steering position or angle. To control the i-DRIVE's steering, a brushless DC motor was attached to the steering shaft with a helical gear. The brushless DC motor is a speed controllable 24 volt DC with rated power of 30 Watt and gear ratio of 30. The steering shaft was drove by two units of 1:1 ratio helical gear. One of the gear welded to the universal joint of the steering shaft and the other gear was attached to the brushless DC motor. At the end of steering shaft, a position encoder was attached to extract steering angle. In early prototype, a pair of spur gear was for the steering control mechanism. However, it introduce intolerable backlash to the system that effect the encoder reading. To render this problem, a helical gear was replaced with the spur gear and it has proven to significantly reduce the backlash effect but reduce the speed reaction. Nevertheless, the reaction speed of the helical gear is within our design requirement

Perception processing module

i-DRIVE platform and the other two placed at rear end of the platform. Referring to Figure-3. The radar sensors gives tracking parameters of i) x position, ii) y position, iii) velocity of the x component, iv) velocity of the y component and v) radar cross section value. It has the capability to measure range and angle of multiple stationary and moving target simultaneously. It works in adverse conditions, almost unaffected by weather, independent of sunlight, capable to operate in wide temperature interval, withstands high shock and vibration levels.

Front Radar sensor provides the forward-distance measurements with respect to the object ahead. While both rear radar sensors provide the side-distance measurement with respect to the object on each side, the radar sensor's effective field of view was tuned to be overlap with i-DRIVE blind spot area. Detailed information on front and rear radar sensor is described in Table-2.

Table-2. Specification of radar sensors.

Parameter	Front radar	Rear radar
Distance Range (m)	1 to 90	1 to 50
Azimuth Angle (degree)	± 50°	± 75°
Elevation Angle (degree)	± 8°	± 6°
Cycle Time (ms)	50	38
Radar Frequency Band (GHz)	24.0 ~ 24.25	24.05 ~ 24.25

In-vehicle controller unit (ECU)

In-vehicle Controller Unit or ECU is a generic term for any embedded system that controls one or more electrical system or subsystem inside a vehicle. An in-vehicle controller unit used CAN communication protocols to transmit and receive data, user can listen to the desired information from the CAN network provided the CAN address of the desired information. Once the in-vehicle controller unit is connected to a CAN network, information such as vehicle speed; front left and right wheel speed; rear left and right wheel speed; throttle position; steering angle, direction, speed and more than 348 vehicle's information can be access. Refer to Figure-4, i-DRIVE in-vehicle controller unit was connected to Vehicle CAN Network and in the same CAN network are Steering Control Module and Perception Processing Module.

C. i-DRIVE VALIDATION AND EXPERIMENT RESULT

In this section, the validation process of i-DRIVE research platform was presented. The validation process involve three experiment, i) Experiment on Vision Processing Unit, ii) Experiment on Lane-Keeping, and lastly iii) Experiment on Perception Processing Unit. The objective of this three experiment merely to verify the functionality, identify issue and bugs, effectiveness of network configuration, and reliability of the system.

Road test result for vision processing unit

The Vision Processing Unit has been tested for more than 900km on Malaysia highway, Kuala Lumpur - Kuala Selangor Expressway (LATAR) and ProjekLebuhraya Utara Selatan Berhad (PLUS). The experiment involve i) Vision Processing Unit, ii) Communication and Network Layer, and iii) Power

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ARPN Journal of Engineering and Applied Sciences

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Supply system. It was conducted under the following conditions. The functionality of Vision Processing Unit was validated by two factors. The first factor are on the successfulness of the module to work under the following condition i) sunny day ii) raining day with sunlight iii) sunset iv) sunset and raining and lastly v) clear sky night time and the second factor are the time taken for the Vision Processing Unit to finish initialised and provide the first data of lateral offset value when tested on during conditions stated above. For the record, the Vision Processing Unit gives lateral offset data at rate of 1ms once it have been initialised, regardless the test condition. Nevertheless, it is important for us to measure the time taken for initialization because in one of our experiment, we wanted to study the effect of controller when the Region of Interest (ROI) of the Vision Processing Unit out of track or unable to detect the lane for a period of time. The result was presented on the Table-3.

Table-3. Experiment result for vision processing.

Test conditions	Ability to detect line	Initialization time (second)
Sunny Day	✓	3 to 6
Raining Day With Sunlight	✓	4 to 5
Sunset	✓	2 to 3
Sunset And Raining	✓	4 to 5
Clear Sky Night	✓	2 to 3

Surprisingly, the vision module performs extremely well during clear sky night and sunset compared with other condition. It is observed that, during night time and sunset, the contrast between the road and the white line on the road is prominent, thus reduce the computation time for noise filtration and ransac algorithm to produce a best fit straight line. Although the result was not as expected, but the Vision Processing Unit have been proven to function as desired. Although, improvement in initialization time are required and necessary..

Road test result for lane-keeping

Lane-keeping experiment was conducted to study behaviour and response of Steering Control unit when integrated together with Vision Processing Unit and Inertial Measurement Processing Unit. For this experiment, a simple PID controller based on work in [10] was designed for the i-DRIVE to perform a slow speed lane-keeping task. Feedback input from the lateral offset (obtain from Vision Processing Unit) and yaw rate (obtain from Inertial Measurement Processing Unit) was feed into the PID controller thus controlling the steering wheel angle of the i-DRIVE. The experiment involve i) Vision Processing Unit, ii) Communication and Network Layer, iii) Power supply system, iv) Steering Control Module, v) Inertial Measurement Processing Unit, and vi) In-vehicle Controller Unit.

There are two part of the lane-keeping experiment, the first part study the i-DRIVE behaviour for start and go condition and the second part study the platform's behaviour for constant speed. To achieve constant speed, the i-DRIVE platform was manually driven to achieve the desired vehicle speed before switching to the lane-keeping control strategies. The experiment was conducted at a newly developed industrial area where the roadways are similar to Malaysia Highway. The roadways have two lanes with clear and highly contrast white marking on dark grey roadway

Road test result for perception processing module

Lane-An experiment on collision avoidance algorithm was conducted to verify the functionality, robustness of the threat assessment and data collection of Perception Processing Module. The experiment involve i) Perception Processing Module, ii) Communication and Network Layer, iii) Power supply system, and iv) In-vehicle Controller Unit. The threat assessment algorithm was validated based on the alert, warning and active signals and steering feedback given by the system, refer to Figure-6 and Table-4.

The collision avoidance algorithm overrides the steering control to steer the host vehicle (i-DRIVE) back to the centre of its original lane in order to prevent collision. However, three conditions must be satisfy before the steering control are activated. First, when the turn signal is turned on by the driver to indicate that he/she want to change lane. Secondly, when the target vehicle is detected in alert region and lastly when the lateral distance between host vehicle and target vehicle is below one meter and decreasing. The experiment was conducted to satisfy all the condition mention earlier and it was recorded in Table-4.

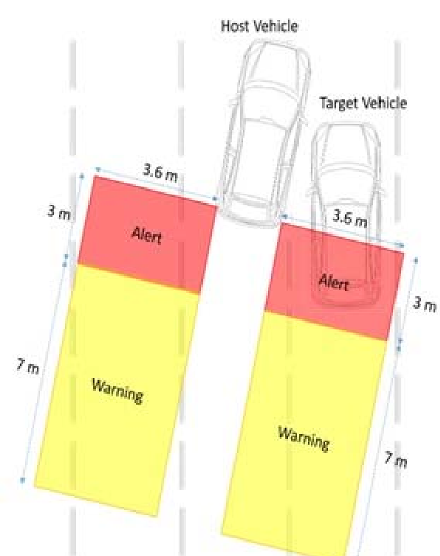

Figure-6. Illustration of alert and warning region for perception processing module.

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Table-4. Experiment result for collision avoidance algorithm test.

	Speed (km/h)		Alert signal	Warning signal	Active signal	Steering feedback
	HV	TV				
1	40	40	✓	×	✓	✓
2	60	60	✓	×	✓	✓
3	80	80	✓	×	✓	✓

Based on the result in Table-4, when a target vehicle (TV) approach host vehicle (HV) while the host vehicle intended to change lane, the alert signal was invoked by the perception processing module as an indicator to the driver. However, if the lateral distance between host vehicle and target vehicle is below one meter or decreasing, the Perception Processing Module will activate the steering feedback to override the steering control. Thus, it can be conclude that the Perception Processing Module have achieved the design requirement based on finding presented on Table-4.

D. CONCLUSIONS AND FUTURE WORKS

In this paper, a modular-based architecture for Intelligent Vehicle research platform have been proposed. It composed of Vision Processing Unit, Inertial Measurement Processing (IMU), Steering Control Module, Monitoring unit, Perception Processing Module and In-vehicle Controller Unit. The implementation of modular-based architecture enables research group in Vehicle System Engineering (VSE) Lab at Malaysia-Japan Institute of Technology to test their research algorithm and work in parallel without effecting other researcher's work. This one off development platform surely help future researcher in VSE Lab, especially in the field of Intelligent Vehicle. The preliminary function verification of i-DRIVE has been successfully completed and future development is still ongoing.

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