Development of SUT-CARG Car-Like Robots

SUCHART PUNPAISARN, SARAWUT SUJITJORN+
School of Electrical Engineering, Institute of Engineering
Suranaree University of Technology
111 University Avenue, Muang District, Nakhon Ratchasima, 30000
THAILAND

Abstract: This article presents the development of the SUT-CARG car-like robot system. CARG car-like robots consist of four mobile robot agents and are built as integrated systems with IR, sonar, ultrasonic, vision sensors and controller modules. Each robot is controlled by a P-controller. Color tracking and flocking of the robot agents are demonstrated VDO available on line http://www.sut.ac.th/engineering/electrical/carg/.

Key-Words: car-like robot, flocking, color tracking

1 Introduction

In the last few years, multivehicle platforms have been developed by several universities and research labs. Some high-level controls were accomplished by using remote workstations. Researchers at Brigham Young University used a multivehicle testbed for cooperative robotic research in MAGICC lab [1]. Their initial system consisted of fine nonholonomic robots with an onboard Pentium-based computer and wireless communications. Cornell University's RoboFlag testbed [2] included several small robots with local control loops functioning cooperatively to achieve a common goal. Designed for indoor experiment, these robots used an overhead camera for localization. Each robot carried a simple microcontroller unit controlling the actuators onboard. Some of the robot systems involved hovercraft vehicles such as the Caltech multivehicle wireless testbed [3] and the University of Illinois HoTDec. Other testbeds featured unmanned ground vehicles and unmanned aerial vehicles, such as MIT's multivehicle testbed [4], the University of Pensylvania's multiple autonomous robots (MARS) testbed [5,6]. The University of Toronto Institute for Aerospace had successfully demonstrated the practicaly of cyclic pursuit as a distribute control strategy for multiwheeled-robot systems. The MARS platform used ground vehicles based on the Tamiya TXT-1 chassis, which was used in COMET for coordinating control algorithms [7].

In this article, Suranaree University of Technology-Control & Automation Research Group (SUT-CARG) presents a car-like robots platform to be used for future research as a testbed for intelligent control algorithms. A CARG car-like robot consists of four mobile robot agents. Each agent is equipped with an onboard embedded microcontroller interfaced with several sensors and a wireless network access module enable all robots to be controlled through a computer. CARG car-like robots are built as integrated systems of available hardware and software modules. The paper describes the integration of those existing technologies. Color tracking and flocking of CARG car-like robots experiments are described and illustrated. In addition, robot models suitable for design are presented with simulation results.

2 Structure of the CARG Car-Like Robot

CARG car-like robots consist of 4 mobile agents based on the TLT-1 (Tamiya a Little Truck), a one-eighteenth scale radio-controlled (RC) 4x4 Pickup Truck from TAMIYA, Inc. Each truck is modified to be a member of the agents aimed for an operation in a laboratory with flat terrain. Each robot can support a load of 3 kg for various electronic devices including sensors, controller boards and other accessories. The list of the robot's components and associated vendors can be found in Figure 1. Each CARG car-like robot uses various sensors that are implemented in the robot control system with the mechanical specifications shown in Table 1. The robot is recommended for laboratory experiments but robust enough for outdoor operations.

Referring to the Xbee pro, the wireless radio module is used to communicate with the onboard computer for signal monitoring and data recording. The Xbee pro consumes low energy from a 3.5 V battery and provides high speed communication (up to 250 kbps). Onboard sensors consist of two infrared sensors (GP2Y0D02YK, GP2Y0D21Y0F), an ultrasonic ranger (SRF08), a sonar (EZ1), an electronic compass (CMPS03), a camera (CMUcam3), which are coordinated and interfaced by a GP1.0 microcontroller. This GP1.0 microcontroller acquires the robot motion data via each sensor on the sampling requirement (5,600 baud sampling rate).

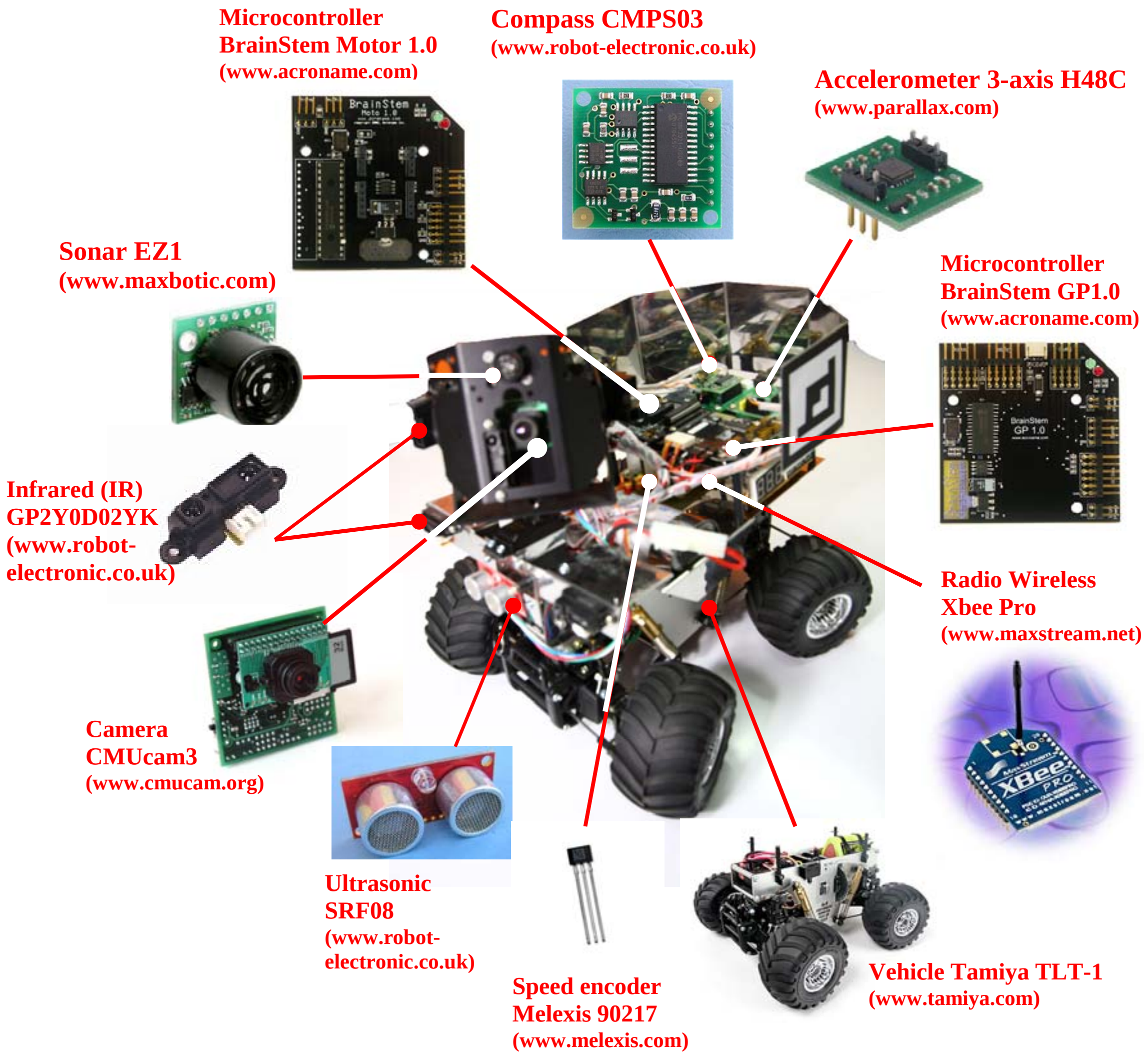


Fig. 1 CARG car-like robot

The CMUcam3 is used for vision purposes, when the CARG car-like robots attempt to perform group behaviors for instance flocking [8], formation of robot [9], multi-robot cooperation and communication systems [10]. The camera is also used to identify, and assist on the agent following control as well as estimate their positions and orientations. Moreover, the CARG car-like robot applies CMUcam3 in various tasks, for instance color tracking (CARG Hunting Robot), recognition and position information, obstacle detection, and route identification. The CMUcam3 functions independently on its own microcontroller. For more information please visit the website *www.sut.ac.th/engineering/electrical/carg*

Two infrared (IR) arrays (GP2Y0D21Y0F, 24 cm range and GP2Y0D02YK, 80 cm range) are mounted on the front part of the CARG robot to detect the ranges of obstacles as. Each IR sensor gives its output in binary proportional to the detected distance against the obstacle. The sensor transmits the distance information via I^2C bus in realtime.

Table 1 CARG car-like robot's mechanical specification

Dimensions	Length	30 cm
	Width	22 cm
	Height	25 cm
Weight	Load (Max)	3 kg
	Unload	1.5 kg
Max Speed		1.6 m/s
Max Torque		55 N/m
Carry Capacity		2.5 kg
Min Steering Radius	2 wheel steering	80.5 cm
	4 wheel steering	30 cm

One ultrasonic range finder (SRF08) is mounted on the front part of the robot, another one on the rear part. The sensor offers a measurement range of 0-6 m with a wide viewing angle of 60-degree beaming. The measurement range is set to 0-1.5 m for our CARG robots. These sensors communicate with the GP1.0 microcontroller board through an I^2C interface bus.

MaxSonar-EZ1 is a very compact and versatile sonar distance sensor. It outputs range information in three forms: TTL serial, PWM and 0-2.5 V analog. The MaxSonar-EZ1 has a scanning rate of 20 Hz (50mS). Interfacing modes are selective as serial I^2C (0 to Vcc with 9,600 baud rate), analog (Vcc/512)/inch and PWM (147 µs/inch), respectively. CARG robot has one MaxSonar-EZ1 on its front. To achieve a wider beaming angle, it is possible to mount two more of these sonar sensors.

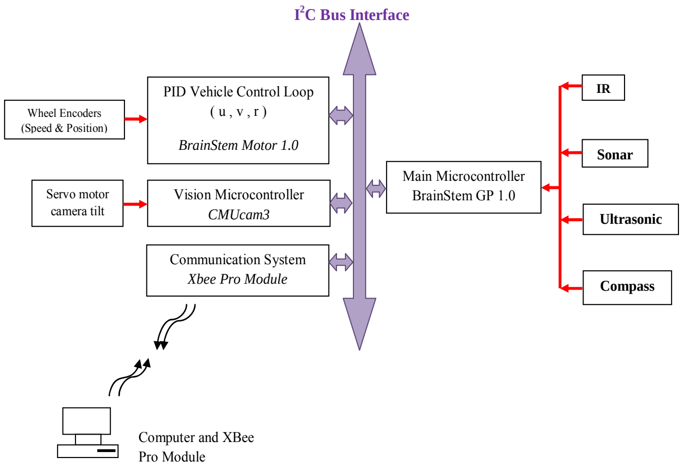


Fig. 2 CARG car-like robot control units

An electric compass (CMP03) is specifically used as an aid to navigation and useful for the flocking movement control. It is sensitive to the earth magnetic field.

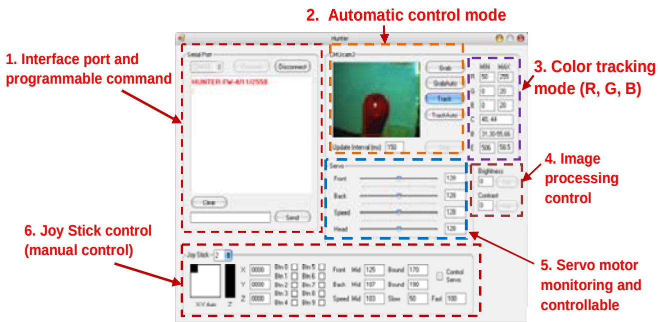
Eventhough an optical encoders is extremely insensitive to noise, it is not suitable for an environment subject to daylight. A hall effect sensor, Melexis 90217, is chosen and modified to work with 6 magnets to provide a better resolution for the CARG car-like robot. By measuring wheel rotation with an appropriate signal conditioning circuitry, the sensor can detect the translational and rotational speeds of the robot.

The CARG car-like robot control system is designed to provide a simple interface between sensors and microcontrollers. The control structure of the CARG car-like robot is represented by the diagram shown in Figure 2. Some of the sensors (IR, sonar, ultrasonic range finder and electronic compass) are connected directly to the main controller (GP1.0) for realtime data acquisition. Three controller modules (motor controller, CMUcam3 and wireless communication modules) are connected to the main controller through the I^2C bus interface.

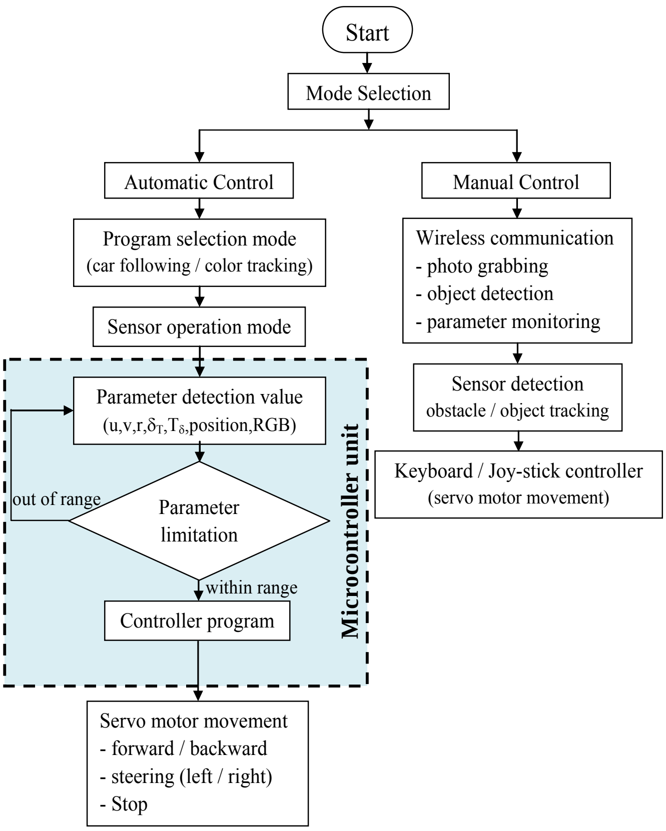
3 CARG Robot's Control Software

3.1 Control and interface program (CIP) for the CARG car-like robot

Control software and image processing programs are written in C. To coordinate the multi robot network, a piece of software called "control and interface program" (CIP) for user are created. The CIP possesses, there are monitoring and commanding windows for a user to access and control the CARG robot. As in Figure 3a, the user can command the robot through the computer's keyboard, mouse or joy-stick. In SUT-CARG lab, the CARG robot can be connected to a wireless access point and run on a laptop/desktop computer with wireless capability. The CIP flow diagram is shown in Figure 3b.



(a)



(b)

Fig. 3 CARG Robots CIP

3.2 Operation modes

The CIP has several features that allow the user to configure the robot's levels of autonomy. The user can set wireless translation, rotational velocities, grabbing photo, color tracking mode, brightness & contrast control for each CARG car-like robot. Under the automatic control mode, anyone of the robots can be setup as a master or a slave for the agent following mode. Furthermore, a journey-path can be assigned to each robot via the command window of the CIP.

Fig. 4 CARG robots in flocking mode

4 Obstacle Avoidance and Steering

Obstacle avoidance is a prime necessity of an autonomous robotic system [11]. The obstacle avoidance behavior can be seen as a part of a hierarchical hybrid system [12] which combines both continuous and discrete events.

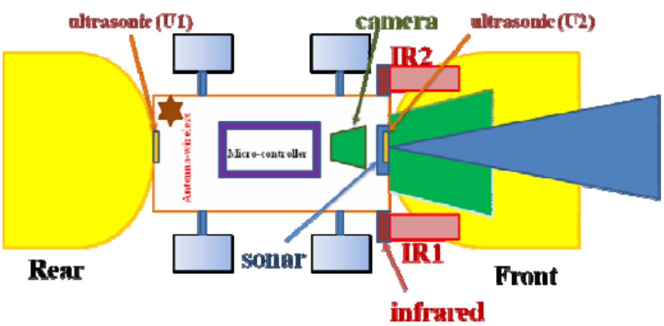


Fig. 5 CARG Robots' sensor capability spacing

In this work, some simple technical rules to define the obstacle avoidance are used. The obstacle avoidance will be operated once the sensor detects that an object comes closer than a preset threshold. Figure 5 shows the locations of all sensors used for the obstacle detection of the CARG robot. There are two ultrasonic sensors (U1-U2) for 0-1.5 m detection at front and rear, a Z1 sonar for wide angle and 0-2.5 m detection, and two infrared sensors (IR1-IR2) for 0.28 m short length detection for the front wheels of the robot.

CARG robot has an improved steering ability from the previous front wheel steering to four-wheel steering. This reduces the steering radius to 30 cm, about 63% shorter than the previous one of 80.5 cm. Figure 6 depicts all possible movements of each robot and its steering capability.

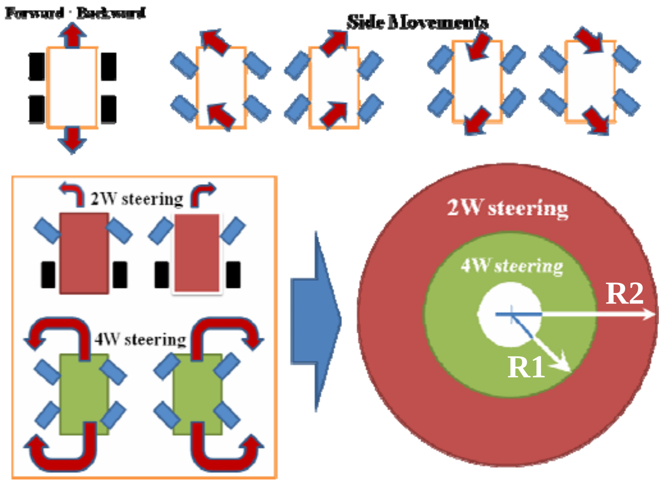


Fig. 6 CARG Robots' capability

5 Models and Simulation Results

CARG robot dynamic model is analyzed based on 3 degree of freedom (DOF) of a nonlinear system. This case study refers to the references [13, 14] that offer the models relating the longitudinal movement (u), the lateral movement (v) and the yaw angle (r). The robot acceleration and velocity vector of the fundamental dynamic model describing the behavior of a robot is given by equations (1) – (3). The controller design problem becomes finding the control δ_T and T_δ so that the system converges to the equilibrium position.

$$\dot{u} = vr + \frac{u^2(fk_1 - k_2)}{M} + \frac{\delta_T}{M} \quad (1)$$

$$\dot{v} = -ur - \frac{(c_f + c_r)v}{Mu} + \frac{(bc_r - ac_f)r}{Mu} + \frac{T_\delta}{M} \quad (2)$$

$$\dot{r} = -\frac{Mfhur}{I_z} - \frac{(ac_f - bc_r)v}{I_z} - \frac{(b^2c_r + a^2c_f)r}{I_z u} + \frac{aT_\delta}{I_z} \quad (3)$$

Using the models (1-3) with the following initial conditions: $u(0) = 10$ m/s, $v(0) = 0.5$ m/s, $r(0) = 0.05$ rad/s, δ(0) = 0 rad and T(0) = 0 N, the simulation results as shown in Figure 8 can be obtained. The models will be further used for our control system design to be base on a new architecture of ANNs.

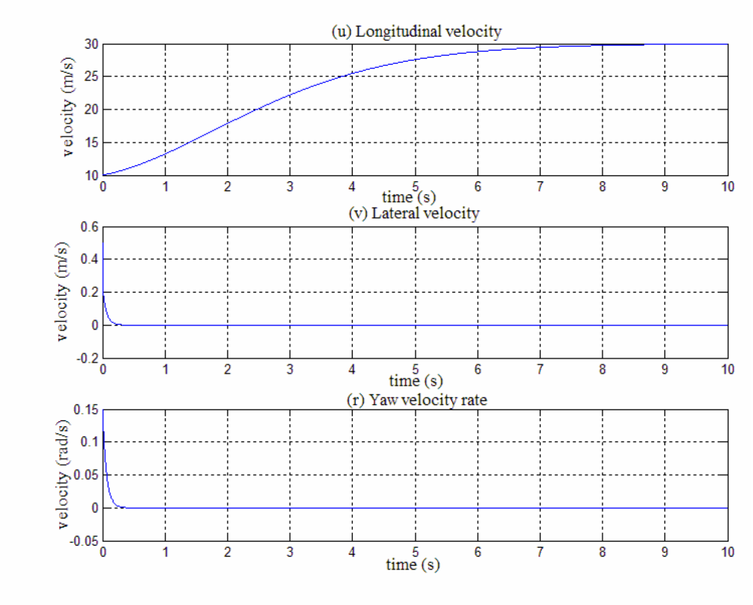


Fig. 8 u, v and r converge to equilibria

7 Conclusions

SUT-CARG car-like robots have been built from the integration of available hardware and software modules. CARG-robots consist of 4 robot agents that can be independently controlled by the CIP software. CIP has been developed to control flocking and color tracking through a selection on a screen display. In the near future, an ANN control system will be implemented on CARG-robots platform for more flexible algorithms and control capabilities.

8 Acknowledgements

The authors wish to thank Suranaree University of Technology for the research grants as well as expenses for the conference participation.

References

[1] T.W McLain and R.W. Beard, *"Unmanned air vehicle testbed for cooperative control experiments."*, Proc. American Control Conf., Boston, MA, 2004, vol. 6, pp.5327-5331.

[2] R.D Andrea and M. Babish, *"The RoboFlag testbed."*, Pro. American Control Conf., Boston, MA, 2004, vol. 1, pp. 656-660.

[3] Z. Jin and team, *"MVWT-II: The second generation Caltech multivehicle wireless testbed."*, Proc. American Control Conf., Boston, MA, 2004,vol. 6, pp. 5321-5326.

[4] E. King and team, *"Coordination and control experiments on a multi-vehicle testbed."*, Proc. American Control Conf., Boston, MA, 2004, vol. 6, pp. 5315-5320.

[5] L.Chaimowicz, B.Grocholsky, J.F. Keller, V. Kumar, and C.J. Taylor, *"Experiments in multirobot air-ground coordination."*, in Proc. IEEE Int. Conf. Robotics Automation, New Orleans, LA, 2004, vol. 4, pp. 4053-4058.

[6] A. Joshua and team, *"Experiments in multirobot coordination."*, Robotics and Autonomous Systems, 2006, 54 265-275.

[7] D. Cruz, J. Mc Clintock, B. Perteet, O.A.A. Orqueda, Y. Cao and R. Fierro, *"A Multivehicle platform for research in networked embedded systems."*, IEEE Control Systems Magazine, 2007, vol. 27 , pp.58-78.

[8] R. Olfati-Saber, *"Flocking for multi-agent dynamic systems: Algorithms and theory."*, IEEE Trans. Automat. Control, 2006, vol. 51, no. 3, pp. 401-420.

[9] R. Fierro, A.Das, V. Kumar, and J.P. Ostrowski, 2001, *"Hybrid control of formations of robots."*, Proc. IEEE Int. Conf. Robotics Automation, Seoul, Korea, pp. 157-162.

[10] R. Fierro, L. Chaimowicz, and V. Kumar, *"Multi-robot cooperation."*, Autonomous Mobile Robots: Sensing, Control, Decision Making and Applications (Control Engineering series), S.S. Ge and F.L. Lewis, Eds. New York: Taylor & Francis, 2006, ch. 11, pp. 417-459.

[11] J. Borenstein and U. Raschke, *"Real-time obstacle avoidance for non-point mobile robot."*, SME Trans. Robot. Res., 1992, vol 2, pp. 2.1-2.10.

[12] R.Alur and team, *"Hierarchical hybrid modeling of embedded systems"*, Embedded Software, (LNCS series 2211), T. Henzinger and C. Kirch, Eds. New York: Springer-Verlag, 2006, pp. 14-31.

[13] A. Alloum, A. Charara and H. Machkour, *"Parameters nonlinear identification for vehicle's model."* Proc. IEEE, Conf. Control Applications, Hartford, CT, 1997, pp. 505-510.

[14] J.R. Zhang, A. Rachid and S.J. Xu, *"Velocity controller design for automatic steering of vehicles."*, Proc. Of the American Control Conference, Arlington, VA, 2001, pp. 696-697.

Notation List

M = Mass of the full vehicle, (kg)
T = Traction or braking force (N)

H = Height from CG to road, (m)
I_z = Initial moment around z-axis, ($kg.m^2$)
a = Distance from front tyres to CG, (m)
b = Distance from rear tyres to CG, (m)
f = Rotating friction coefficient
g = Acceleration of gravity force, (m/s^2)
c_f = Cornering stiffness coefficients of front tyres, (N/rad)
c_r = Cornering stiffness coefficients of rear tyres, (N/rad)
k_1 = Lift parameters from aerodynamics, ($N.s^2/m^2$)
k_2 = Drag parameters from aerodynamics, ($N.s^2/m^2$)
δ = Wheel steering angle (rad)