

堀研究室(電気制御システム工学)



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1. Integrated Motion Control of a Wheelchair in the Longitudinal, Lateral and Pitch Directions

Recently, various kinds of power wheelchairs have been developed and suggested. In addition to the electric-powered wheelchairs which are now quite broadly used, pushrim-activated, power-assisted wheelchair (PAPAW) has been focused as a new mobility assistance. We propose some novel control algorithm for power assistance in this

wheelchair. The wheelchair needs controlling in the three dimensions: the longitudinal direction, the lateral direction, and the pitch direction. We have proposed three different types of power assist controller for each direction: disturbance attenuation control for the longitudinal direction, tip-over protective control for the pitch direction, and disturbance attenuation control for the lateral direction. We design an integrated controller for wheelchair operation assistance.



Fig. 1 Power Assist Wheelchair (PAW)

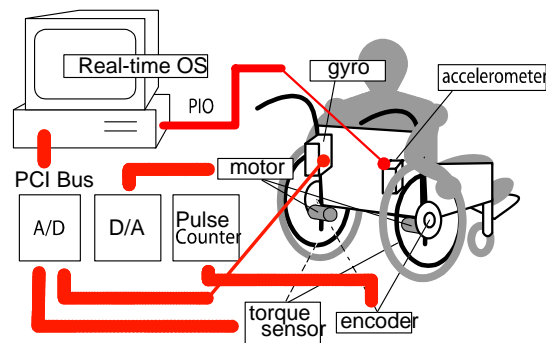


Fig.2 Configuration of PAW

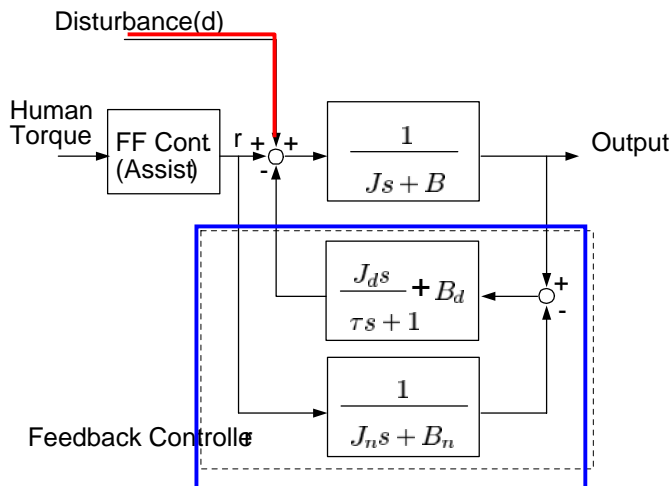


Fig. 3 Power Assist Controller

controller in Figure 3 has variable assist ratio; it changes the amount of assisting torque based on the tilt of a slope. This prevents tipping over of a wheelchair.

Figure 5 is the block diagram of 2-dimension operation assist controller. Since a power assist wheelchair has two motors, the independence of each motor enables us to assist 2-dimension operation of a wheelchair. The blocks in the two red regions is power assist control for the longitudinal direction, and the blocks in the blue region is steering assist control for the lateral direction. Experimental result ensured that the proposed controller that adopts two different strategies for two directions can be successfully implemented.

Figure 1 and 2 shows our experimental setup which consists of a power assist wheelchair with four sensors installed and a computer for advanced motion control.

Figure 3 is the power assist controller for the longitudinal direction operation. Feedforward controller assists applied human torque, and feedback controller helps suppressing external disturbance force.

This two degree of freedom power assist controller helps a rider on a hill illustrated in Figure 4. The gravity's effect is suppressed by the feedback controller. The feedforward

2. Wheelchair Assist Control with Electromyogram Sensor

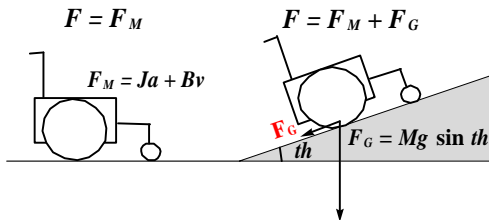


Fig.4 Gravity's Effect on a hill

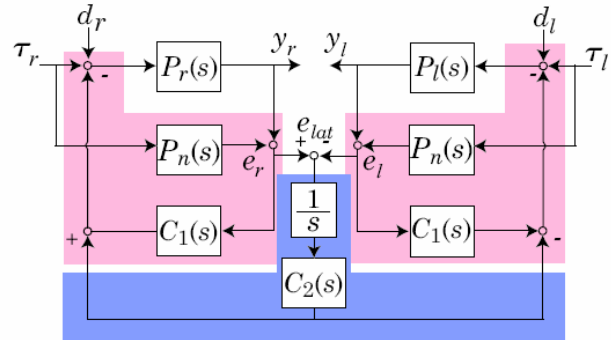


Fig.5 Controller for 2-dimension Assistance

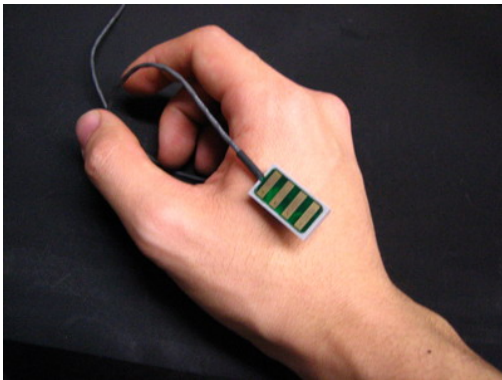


Fig. 6 Electromyogram Sensor

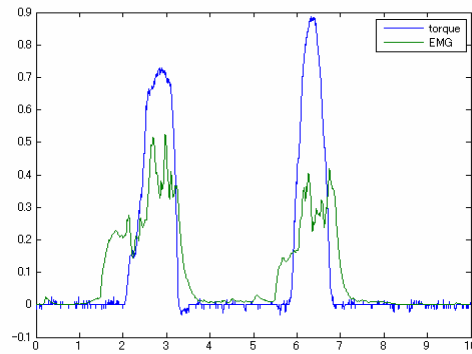


Fig. 7 Outputs of Two Sensors

Electromyogram sensor that is highlighted nowadays is adopted as an input sensor that detects a rider's propelling force. The sensor output is subject to noise but its detection of human will is faster than torsion sensor.

Figure 7 is outputs of two sensors: electromyogram sensor and torsion sensor. This makes clear the fast detection characteristic of electromyogram sensor.

In order to utilize this characteristic, that sensor output is combined with observed human propulsion torque and produce assist torque pattern.

3. Robot Arm Equipped With Bi-articular Muscles

Conventional robots have actuators which drive only one joint, and usually rotational motor are installed in each joint and manipulated with rapid feedback control. On the other hand, animals have actuators which drive one or more joints. For example, bi-articular muscles as well as both mono-articular muscles exist in an arm of animals (Figure 8), which enables animals to mainly use feedforward control during working, running and other unique movements.

Two-joint link model with muscles is shown in Figure 9. **e1** to **f3** represent muscles. **e1** and **f1** are a pair of antagonistic mono-articular muscles attached to joint **R1**, and **e2** and **f2** are to **R2**. **e3** and **f3** are a pair of antagonistic bi-articular muscles attached to both **R1** and **R2**.

If a robot arm has bi-articular muscle structure, it can move with only feedforward position control using muscular viscoelasticity. To demonstrate this characteristic, we

design a simple robot arm using three electric motors. The detailed specification is shown in Figure 10 and 11. Figure 10 is the configuration consisting of three motors for three kinds of muscles and Figure 11 is the manufactured robot experimental setup.

In this model three motors are corresponding to animal three antagonistic muscular pairs. Two motors in the upper side are mono-articular driving mechanisms. Bi-articular driving mechanism is made from a motor and a timing belt in the lower side. Two motors in the right axis use a same shaft but not connected by hardware. The left axis is connected with one motor by a gear and the other motor by a pulley. This configuration in the robot in Figure 11 can realize some fundamental features of bi-articular muscles virtually.

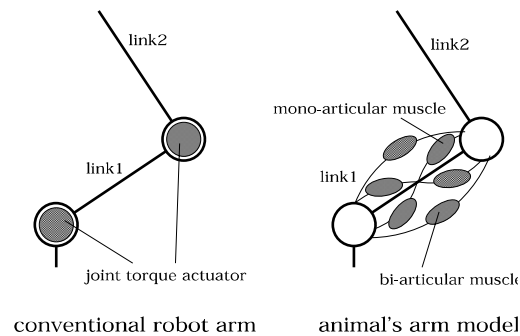


Fig.8 Comparison of Two Arm Model

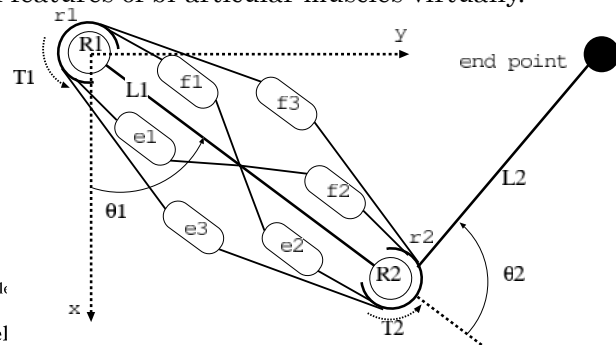


Fig.9 Arm Model with Bi-articular Muscle

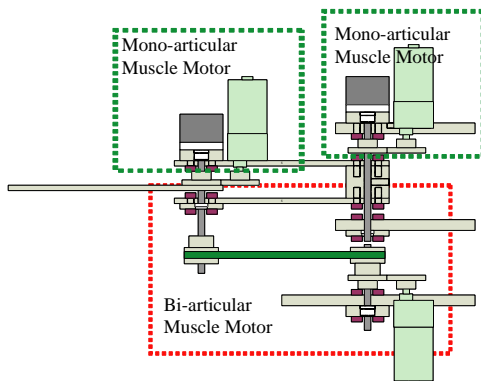


Fig.10 Design of Bi-articular Robot Arm

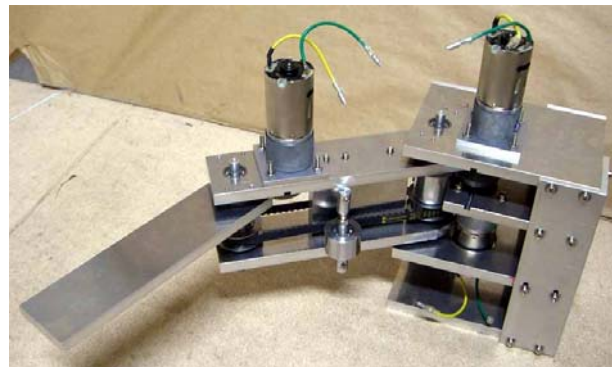


Fig. 11 Robot Arm with Bi-articular Muscle

4. Consideration on Feedforward Controller Design for Self Servo Track Writer

In the production process of HDD, there is a process to write servo tracks using Servo Track Writer (STW). HDD servo controller uses them to move the actuator with magnetic heads to the target track address. The conventional STW such as the pushpin STW, has been used for servo track writing for many years. This takes too much time to write servo tracks because of higher density of servo track. Therefore, we can't produce them in low cost. Additionally servo track writing process should be done in clean room and its maintenance is also very costly. In order to solve these problems, Self Servo Track Writing(SSTW) method have already been suggested. However, servo tracks are easy to diverge if they are written by this SSTW method.

We, thus, propose a control algorithm to realize this SSTW. By this control, performance is

dramatically improved. A kalman filter which will reduce the measurement noise and a proper filter that attenuate error propagation enable us stable self servo track writing. Figure 12 is the comparison of standard deviation of the servo track of two methods.

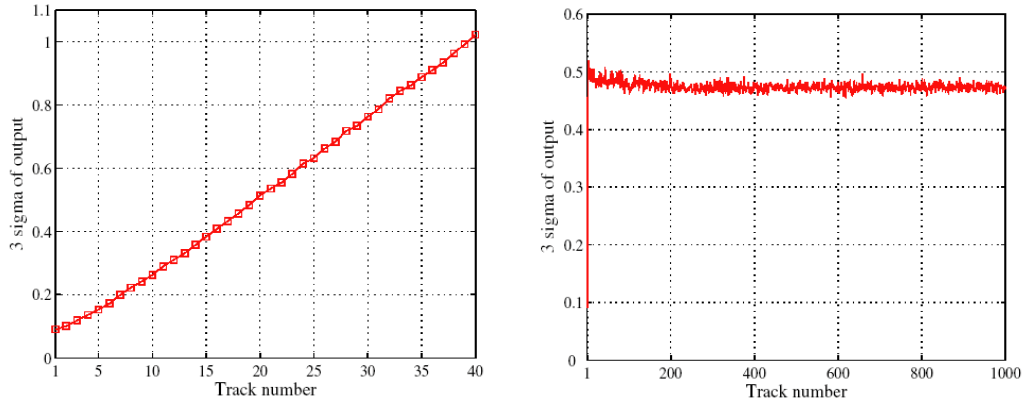


Fig. 12 Comparison of 3σ of head position outputs in Two Methods

5. Control Parameter Optimization in the Hardware-in-the-loop System using Novel Search Algorithm

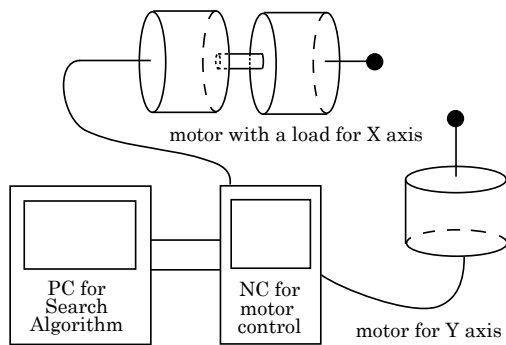


Fig.13 Hardware-in-the-loop System a novel search algorithm and apply it to a hardware-in-the-loop (HIL) system. Figure 13 is the configuration of the HIL system used in this research.

The NC system has two motors to conduct two-dimensional motion. The computer that is connected to the NC system obtains a result of one experiment, calculates the performance function based on the measurement and optimizes the control parameters using search algorithms. As a reference trajectory, a rectangle with the four arc corner trajectory is chosen since this trajectory is said to be difficult trajectory to be tuned as it deals with the timing problem between two axes.

The proposed algorithm attempts to optimize the controller to track this trajectory perfectly and rapidly. Minimization of this trajectory is one purpose of the optimization. The other purpose is reduction of the elapsed time to draw the target trajectory. The algorithm is applied to the HIL system. The experimental results show that the proposed algorithm improves the control performance by selecting adequate control parameter set.

We propose auto-tuning of control parameters. In industry, parameters of controllers (for example NC machine) should be tuned according to the purpose and environment of the system. Especially in the high precision control, this tuning is difficult and time-consuming work for general users and has been the work of sophisticated experts. If an effective search algorithm can optimize these parameters, it can help general users to easily tune the controller. For this reason, we suggest

6. Advanced Motion Control and the Prospect of Super Capacitors in Electric Vehicles

Taking the advantage of high controllability of electric motors and high performance of novel electric energy storage devices, the control of EV can be improved dramatically.

We will mention the main theme of our works on the EV research.

- Advanced integrated dynamics control. Dynamic force distribution control is the basement of those control strategies.
- Application of super capacitors in EV motion control. Two EVs which are powered by EDLC are shown and the related NFS control will be mentioned as the example of the applications.
- Novel cruise control of EV. The real time smart speed pattern generator which realizes "easy driving" and "smooth driving" on driver's command is the important research on this theme.
- Estimations of States and road conditions. As one typical application, side slip angle estimation will be discussed.
- Advanced hybrid braking system. The cooperative control of the hydraulic braking and the motor regenerative braking system is the novel braking control method for the next generation EVs.

In order to evaluate those control strategies, "UOT March II" and "UOT Cadwell EV", which are shown in Figure 14, "Capacitor COMS I" and "Capacitor COMS II", which are shown in Figure 16, are made and used for the experiments.



4WD in-wheel motored EV named "UOT March II"

2WD EV named "UOT Cadwell"

Fig. 14 "UOT March II" and "UOT Cadwell", which are made by the Hori Lab

7. Integrated Dynamics Control

Integrated dynamics control methods, such as the 4WD control, 4WD and 4WS control, are developed rapidly for the next generation EV. Dynamic force distribution control is a method used as the basement for the realization of those advanced control strategies.

As for controlling 4WD EV, which is an over actuated system, more actuators can be used for control. Therefore there is actuator redundancy in the motion control of EV. It is meaningful to use redundant actuator to improve the dynamics of EVs. Constrained optimal control method is used for dynamic force distribution. The general description of over actuated system and the corresponding control method using redundant actuators are shown in Figure 15.

The project of maneuverability improvement control by using dynamic force distribution control is supported by Mitsubishi Motors. The advanced 4WD EV, which is made by Mitsubishi Motors and named EVO-MIEV, is used for the experiment. As Figure 15 shows, the yaw rate can follow the reference behavior with the control of the proposed method. Therefore, it can be concluded that the stability is enhanced and the maneuverability is improved.

8. Applications of Super Capacitors

Figure 16 shows novel EVs powered only by "electrical double layer capacitor (EDLC)". This vehicle provides us useful experimental environment of electric vehicle motion control, since EDLC power system can shorten charging time. About 40 seconds charging enables us 20 minutes driving. The merit of EDLC application for EV and the vehicle control system are shown. EDLC application for EV has following advantages which secondary batteries don't have.

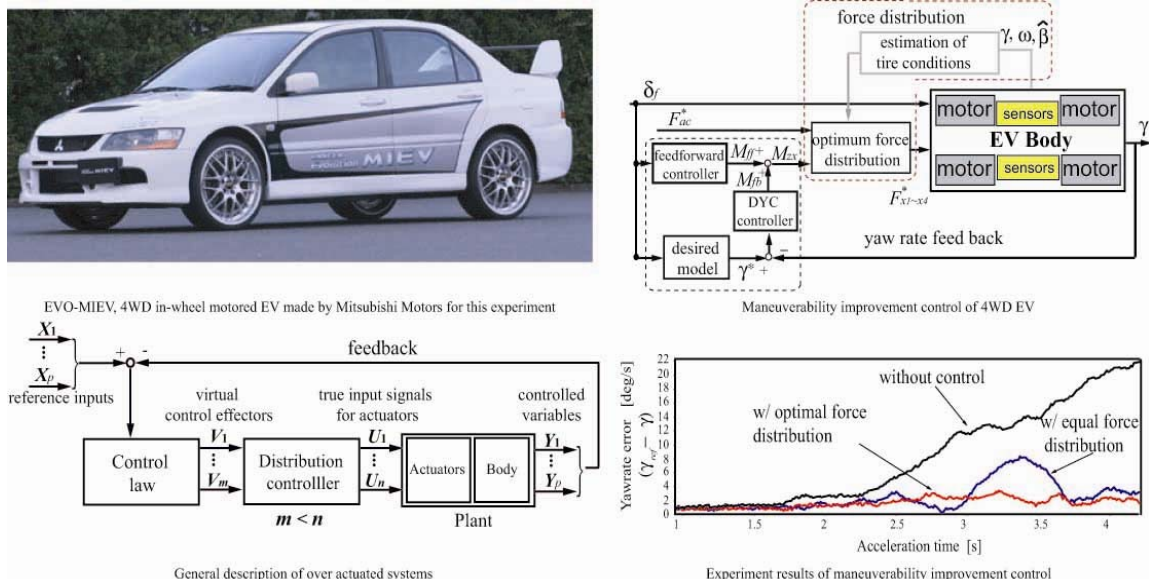


Fig. 15 Integrated control method based on dynamic force distribution control

- Large current charging.
 - Voltage level tells us remaining energy level.
 - Durable for repetitive charge and discharge.
- Environmentally friendly.

Based on that novel vehicle, an EV stabilization control method using acceleration information is proposed. Normal force has strong connectivity with driving force and its sudden decrease causes tire slip, which makes the whole vehicle motion unstable. The normal force stabilization control will be discussed as an example of the application of those EVs powered by the super capacitors. The experimental results of the NFS control are shown and its effectiveness will be discussed.

Theoretically EDLC is not based on chemical reaction and its internal resistance is small, large current charging is possible. EDLC is also more than 100 times as durable as for repetition of charging and discharging. In addition, EDLC voltage level tells us remaining energy level very precisely against the estimation of energy level on secondary battery is

very difficult. Using these advantages, we developed experimental vehicle named "Capacitor-COMS". Less than 1 minutes charging realizes 20 minutes driving.

Consequently, we can control and design the mobility of HCG in lateral direction, which is one of vehicle turning characteristics, by the differential torque of right and left motors. It is very important to control the mobility of HCG because it is related to not only "ride quality", but also "vehicle active safety" in turning motion. Normal force has strong connectivity with driving force whose sudden decrease would make vehicle motion unstable.

The development of experimental vehicle powered only by EDLC is shown in Figure 16. Short charging time realized by EDLC power system provides us useful experimental environment.

The mentioned novel vehicle stabilizing control method using lateral acceleration information is also described in Figure 16. The experimental results indicate the effectiveness of NFS control method. Dangerous steering input is effectively suppressed and is controlled with reference variables. By controlling, the novel vehicle active safety is realized in turning motion.



C - COMS I



C - COMS II

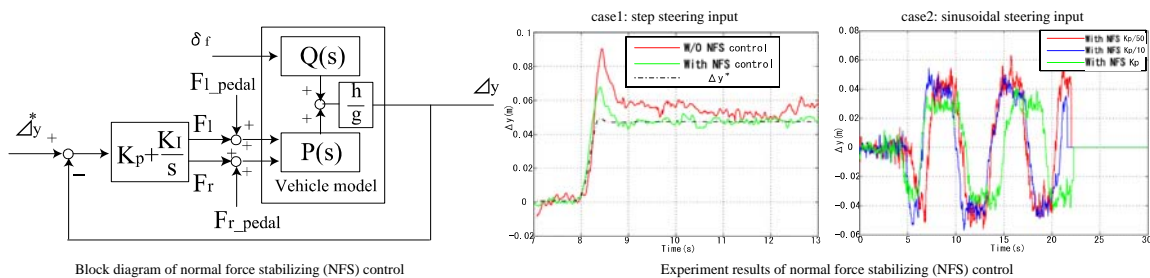


Fig. 16 EVs powered by EDLC and the corresponding NFS control

9. Novel Cruise Control

We especially consider the design of a speed pattern which can be generated in real time taking account of driver's command. We name this research as the control by using real time smart speed pattern generator (RSSPG). Three parameters of RSSPG can be determined arbitrarily and separately based on the optimal control theory. The purpose of this research is to improve the safety and ride comfort in ordinary traveling or even in emergency conditions.

The flow chart of RSSPG and the block diagram of control based on that RSSPG are shown in Figure 17. Three parts, which are estimation of driver's intention, generation of speed

pattern, and motion control of EV, are considered.

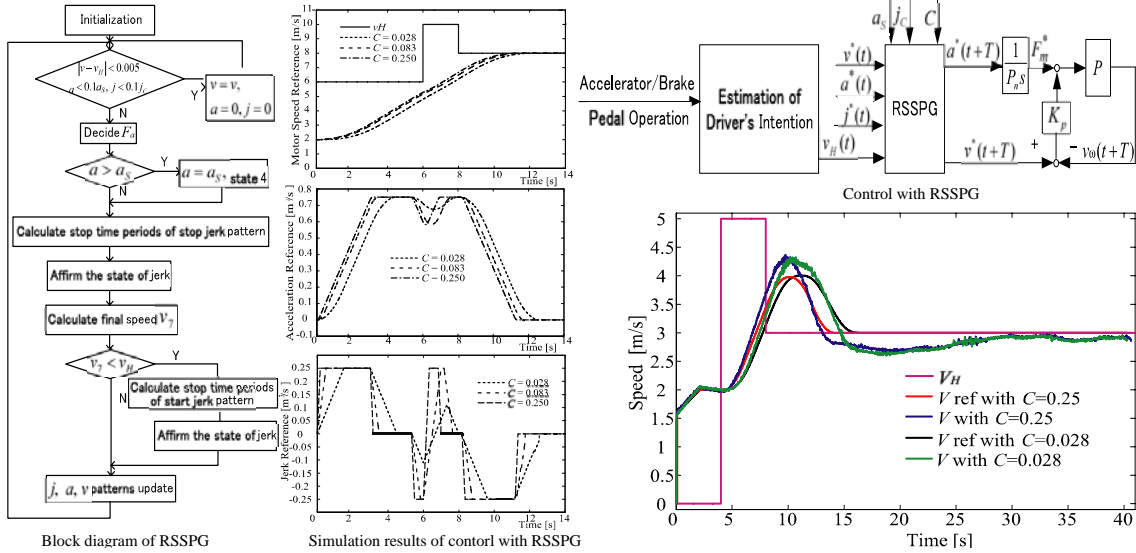


Fig. 17 RSSPG and the corresponding motion control of EVs

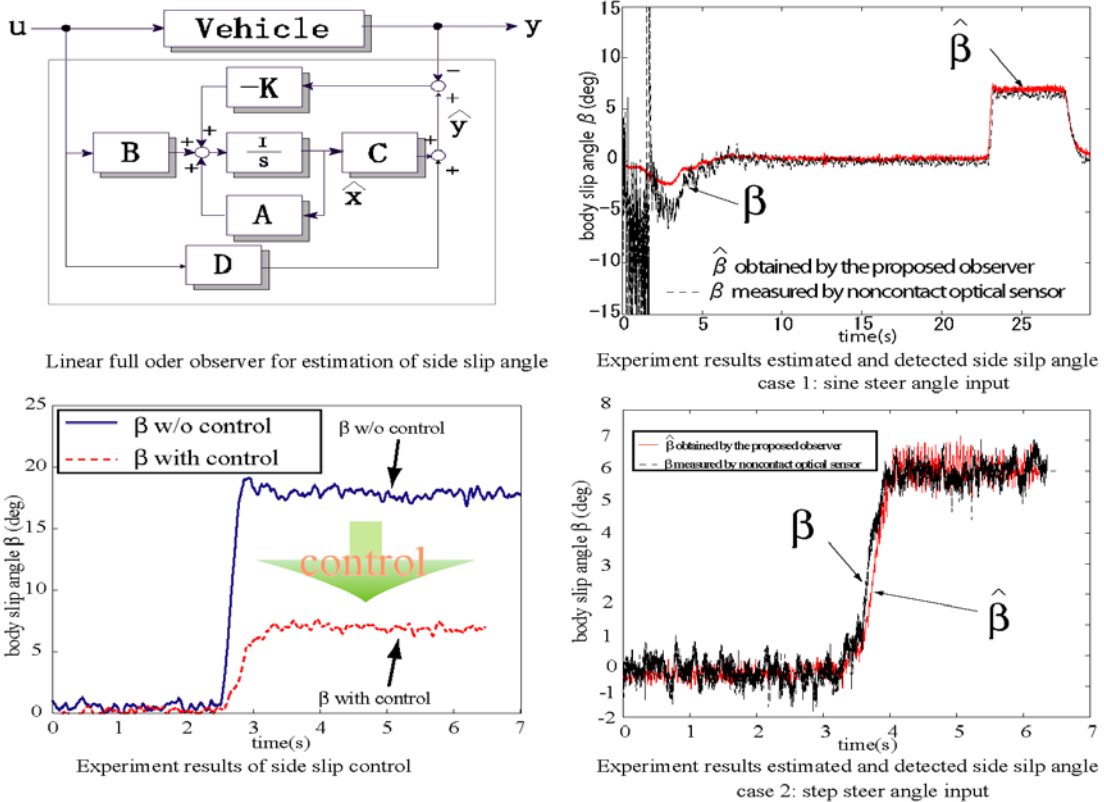


Fig. 18 Observer for estimations of side slip angle β and the corresponding experiment results

According to the driver's acceleration or braking demand, driving styles, and the favorite travel feelings, the driving force is determined and the jerk will be depressed. The

simulation results in Figure 17 show that a new speed pattern is really recalculated in real time, when the change of driver's commands occurs during mid-pattern. The experiment is also used to verify this idea.

10. EV States and Road Conditions Estimation

Several merits of the electric motors are used for the estimations of EV states and road conditions, such as the side slip angle, lateral velocity, and the tire frictions, which are difficult known in real time. For example, we use full order observer, which is shown in Figure 18, to estimate side slip angle β . In order to test the robustness, we verify the proposed method when change the velocity, steering angle δ and road conditions. Experiment results are shown in Figure 18, which demonstrate that the proposed observer is robust and even if the factors mentioned above are changed, the observer can still estimate the β accurately. Based on the estimations, the control of β is also studied and the PID controller is designed by the 2-DOF strategy. As Figure 18 shows, the slip angle is controlled to be smaller. It indicates the safety performance index of the EV.

11. Advanced Hybrid Braking System

The hydraulic braking system and the electric regenerative braking system are controlled to work together. Almost all braking systems are made of hydraulic actuator. They have a long response delay, but they can generate sufficient braking torque. Contrary, electric motor has quick and accurate output torque, and can be used both in traction and braking. However, the power of electric motor is smaller, and it is impossible to generate sufficient braking torque only with electric motor.

Therefore, we propose a novel braking system using electric motor which compensates for hydraulic actuator. In this system, we use disturbance observer, regarding difference from command of hydraulic actuator as disturbance.

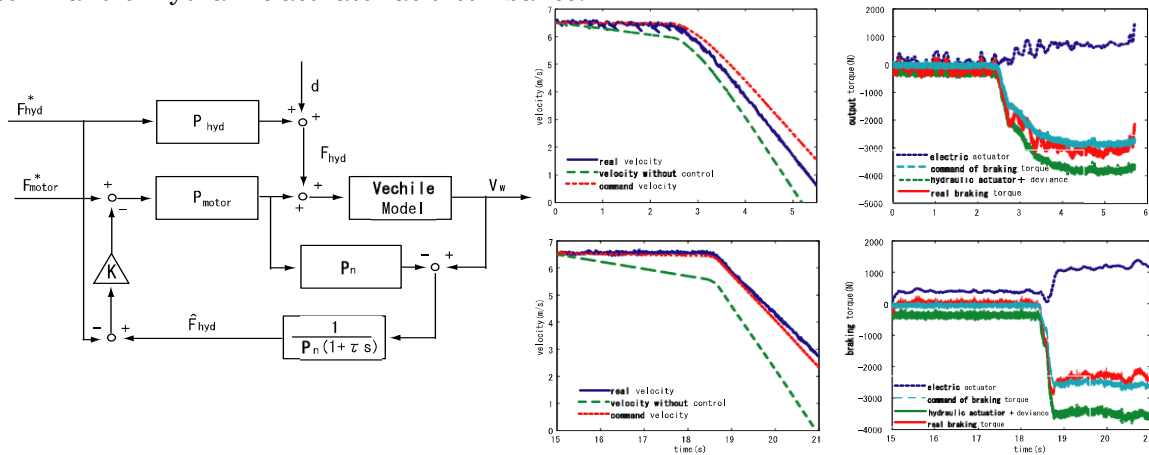


Fig. 19 Block diagram of control of the braking system and the experiment results

The block diagram and experiment results are shown in Figure 19. As the experiment results show, when the velocity sensor and thus the low pass filter are used, the large time delay makes it difficult to apply the advantage of electric motor effectively. On the other hand, control by using the acceleration signal depress the vibration and therefore use the motor effectively.