行政院國家科學委員會專題研究計畫　期中進度報告

總計畫：先進車輛控制及安全系統之設計與模擬(1/2)

計畫類別： 整合型計畫
計畫編號： NSC94-2213-E-009-125-
執行期間： 94 年 08 月 01 日至 95 年 07 月 31 日
執行單位： 國立交通大學電機與控制工程學系(所)

計畫主持人： 李祖添

計畫參與人員： 陳冠銘,林炳榮,張捷,林添睦

報告類型： 精簡報告

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中　華　民　國 95 年 5 月 29 日

行政院國家科學委員會補助專題研究計畫 期中進度報告

先進車輛控制及安全系統之設計與模擬-總計畫 (1/2)

計畫類別：□ 個別型計畫　　■ 整合型計畫
計畫編號：NSC 94－2213－E－009－125
執行期間：　94　年　08 月　01 日至　95　年　07 月　31 日

計畫主持人：李祖添 教授
共同主持人：
計畫參與人員： 陳冠銘、林炳榮、張捷、林添睦

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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執行單位：國立交通大學電機與控制工程學系

中　華　民　國　95　年　05　月　31　日

行政院國家科學委員會補助專題研究計畫期中報告

先進車輛控制及安全系統之設計與模擬-總計畫（1/2）
計畫編號： NSC 94-2213-E-009-125

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主持人：李祖添 國立交通大學電機與控制工程學系

Abstract

In this project, the integration design and implementation of a longitudinal automation system will be presented. The proposed system has a hierarchical structure composed and consists of an adaptive sensory processor, a supervisory control and a regulation control. The system validness and preferable comfort can be achieved by the experimental tests under various kinds of traffic flows. In addition, the integration of GPS and INS will be developed to enhance the stability and performance of the vehicle control system.

Keyword: longitudinal control, vehicle, GPS/INS

I. Introduction

Vehicle automations are currently being introduced into the assistance to relieve human drivers from undesired routines of driving task. Since many studies have shown that over 90 percent of highway accidents are occurred due to driver -related errors, the main initiative is to improve safety of the automation system interacted with the human driver. As to the vehicle longitudinal automation control, some famous practical works [1-3] introduce the features like adaptive cruise control (ACC). The more understandings of the automation of vehicle longitudinal control task are provided in [4]. Besides, to increase more capability being with human drivers, the conception of human-in-the-loop (HITL) needs to be more considered into the system design.

The safety consideration into the vehicle longitudinal automation is the safety headway distance adjustment to avoid the collision with the vehicle ahead. To accommodate the automation system to different driving conditions, the corresponding operation modes and the automatic transition frame should be developed. There is no initial demand for road environment, and also for the action of the human driver which can be viewed as a disturbance to the automation system. It is essential to consider the adequate stability and robustness into the controlling design. Moreover, drivers’ comfort is also the most important initiative counted for automation design.

The Global Position System (GPS) used in navigation has long-term stability and acceptable accuracy. Base on such features, the divergent effect of an Inertial Navigation system (INS) might be calibrated with the aid of GPS [5, 6]. The integration of GPS and INS will provide the useful information of road condition and vehicle attitude for control design.

This project proposes the longitudinal automation system, which is implemented on a real vehicle named TAIWAN *i*TS-1, with the interaction of the human driver. The special modifications to the automation system are to ensure safety and smooth operation with workload reduction for the human driver.

II. System Structure

As illustrated in Fig. 1, the road environment mainly refers to the longitudinal

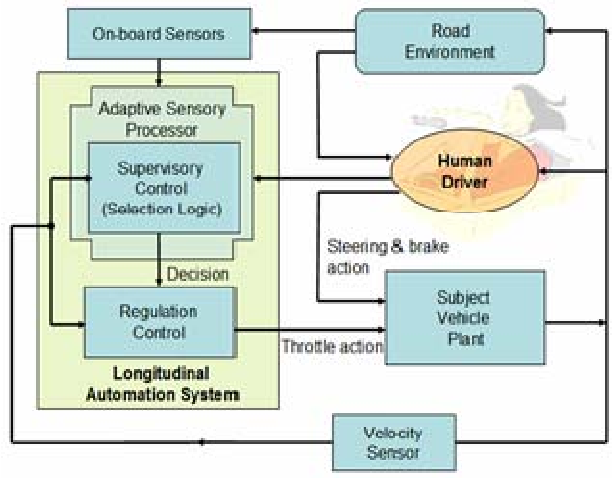

Fig.1. Overall structure of the human-in-the-loop longitudinal automation system.

direction in front of the subject vehicle, and the on-board sensors include laser radar and angle sensor of the steering wheel (SW). The adaptive sensory processor deals with measurements from radar according to the action of human driver and the velocity of the vehicle. Based on the recognized data, the supervisory control makes the decision of operation modes and desired velocity command to the regulation control for the execution of velocity tracking. The throttle pedal is driven by the longitudinal automation system to achieve the controlling objective. Although the brake pedal can be automated in our mechanism, in this work it is not used and reserved for the human driver to take the awareness of emergency. As far as the longitudinal automation convinced to the human driver is concerned, the controlling operation for the subject vehicle comprises the velocity tracking cruise mode and automatic vehicle following mode. In the velocity tracking cruise mode, the objective is to control the subject vehicle to track any desired velocity commanded from the human driver. At the time of the detection from the preceding vehicle, the automation system will automatically switch to the automatic vehicle following mode. The objective of this mode is to make sure of safety headway distance maintaining for the subject vehicle without the need of vehicle-to-vehicle communication. In addition, the automation system will automatically switch back to the velocity tracking cruise mode if there is no vehicle detection in the front.

III. Longitudinal Automation System

By considering the turning behavior of the vehicle, a linear bike model of lateral dynamics from steering angle δ_f to lateral velocity v_y and yaw rate r is employed as

$$\begin{bmatrix} \dot{v}_y \\ \dot{r} \end{bmatrix} = A \begin{bmatrix} v_y \\ r \end{bmatrix} + B\delta_f \tag{1}$$

where

$$A = \begin{bmatrix} \dfrac{-(C_f + C_r)}{mV} & -V + \dfrac{-aC_f + bC_r}{mV} \\ \dfrac{-aC_f + bC_r}{I_z V} & \dfrac{-(a^2 C_f + b^2 C_r)}{I_z V} \end{bmatrix}, \quad B = \begin{bmatrix} \dfrac{C_f}{m} \\ \dfrac{aC_f}{I_z} \end{bmatrix}$$

a and b denote the distances from the front and rear axles to the center of gravity (CG) of the vehicle, m denotes the total mass of the vehicle, V denotes the forward velocity, I_z denotes the yaw moment of inertia, and C_f and C_r denote the total cornering stiffness of the front and rear tires, respectively.

In addition, to detect the existence of the preceding vehicle, the look-ahead information of the subject vehicle must be considered. The dynamics of the point at a look-ahead distance of the moving vehicle can be described as

$$\dot{y}_d = V\varepsilon_d - v_y - rd \tag{2}$$

$$\dot{\varepsilon}_d = V / R_f - r \tag{3}$$

where y_d and ε_d denote the lateral offset from the centerline and the angle between tangent to the road and the vehicle at a look-ahead distance d, and R_f denotes the road curvature.

A. Supervisory Control

There are two stages in the supervisory control. In the first stage, the desired acceleration is determined according to the selected operation mode and available feedback signals. In the second stage, the desired acceleration is converted to the desired velocity which is passed into the regulation control. Define the velocity tracking error as

$$e_V = V - V_{des} \quad (4)$$

and select the sliding surface as

$$S_{CC} = e_V = V - V_{des} \quad (5)$$

To force S_{CC} = 0, the control law can be chosen as

$$\dot{S}_{CC} = -K_{CC} S_{CC} \quad (6)$$

where K_{CC} >0 is chosen by the designer.
The desired acceleration is

$$a_{f\,des} = \frac{-\dot{a}_f}{K_{CC}} \pm a_{f\,\max} \quad (7)$$

The objective of the automatic vehicle following mode for headway distance tracking is to design the control law of the desired acceleration which can be derived as

$$a_{f\,des} = \frac{1}{\sigma}(K_{VF} S_{VF} + \dot{R}) \quad (8)$$

In the second stage, the conversion from the desired acceleration to the velocity is designed as

$$\dot{V}_{des} = a_{f\,des} - k_t (V - V_{des}) \quad (9)$$

where k_t >0 is a damping gain.

B. Regulation Control

The objective of the regulation control is to execute the desired velocity commanded from the supervisory control. The block diagram of the regulation control with the vehicle longitudinal dynamics is shown in Fig. 2.

The regulation control scheme is composed of a proportion -derivative (PD) controller and a FLC. There is a single control input defined by the error of the commanded and current

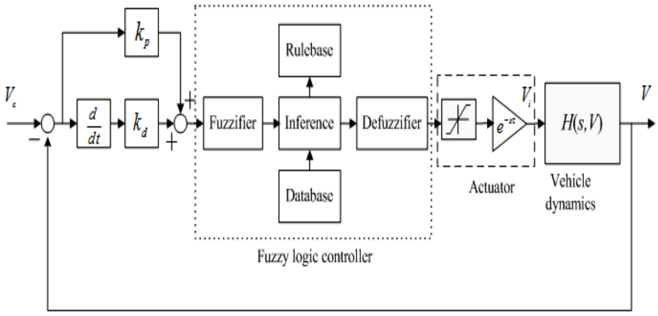

Fig. 2. The block diagram of the closed-loop velocity regulation control.

TABLE I

D_s	*NB*	*NS*	*ZO*	*PS*	*PB*
u	*NBu*	*NSu*	*ZOu*	*PSu*	*PBu*

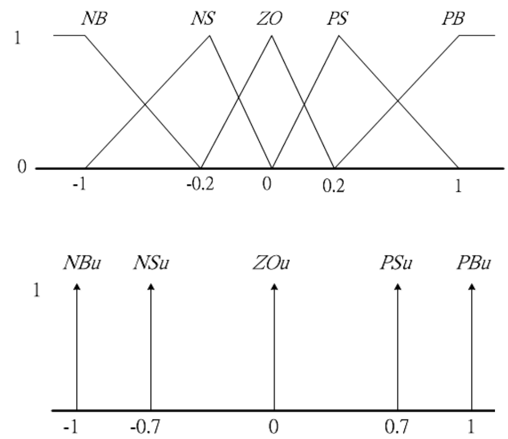

Fig. 3. Membership function of the fuzzy input (up) and the fuzzy output (below).

velocity, i.e., $e = V_c - V$, and the control output is the applied voltage to the throttle motor actuator. The characteristics of the throttle motor actuator can be modeled as one saturation function with a transport delay. Besides, $H(s, V)$ presents the dynamics from the derived throttle angle to the vehicle velocity. This PD type FLC with a single-input is convincingly representative to the single-input FLC (SFLC) proposed in [7].

For conventional FLC's, the fuzzy rule base is constructed in a two-dimension (2-D) space for using the error and error change phase-plane, i.e., $(e, \dot{e})$. It can be inspected that most 2-D fuzzy rule bases have the so-called skew-symmetric property. One new fuzzy input composed of the error and error change can be presented as

$$D_s = k_d \dot{e} + k_p e \qquad (10)$$

Therefore, the 2-D fuzzy rule base of the error and error change phase-plane can be reduced into 1-D space of D_s for SFLC as listed in Table I. Both the ranges of the fuzzy input and the output are the same from -1 to 1, and the corresponding membership functions are plotted in Fig. 3, respectively.

In the defuzzication operation, the center of mass (COM) method is applied to calculate the control output

$$u^* = \sum_i^5 \mu_i(D_s) \times u_i \Big/ \sum_i^5 \mu_i(D_s) \qquad (11)$$

where μ_i represents the weighting value of each rule i, and u_i is the crisp value of each rule consequence.

IV. GPS/INS System Design

In this section, the state estimation of vehicle system is addressed. Fig. 4 shows the block diagram of GPS/INS integration [6]. The state equation of errors is given in Appendix [8]. GPS depends on the concepts of positions and absolute coordinates. The angular velocity and acceleration information can be measured by using gyros and accelerometers from inertial measurement units (IMU). The errors of IMU might increase with time by the integral procedure. So INS combined with GPS can calibrate the errors. Figs. 5 and 6 show the sensors and peripheral circuits of IMU and GPS, respectively. The Kalman filter will be utilized to estimate the vehicle states and reduce the effect of measurement noise.

V. Experimental Results

The proposed longitudinal automation

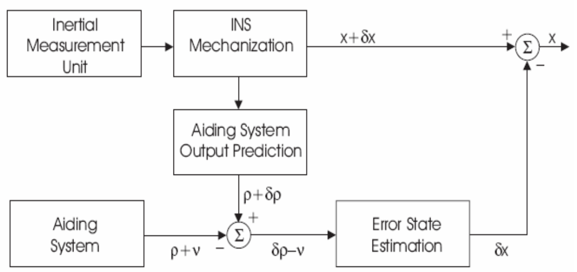

Fig. 4. The block diagram of GPS/INS integration [6].

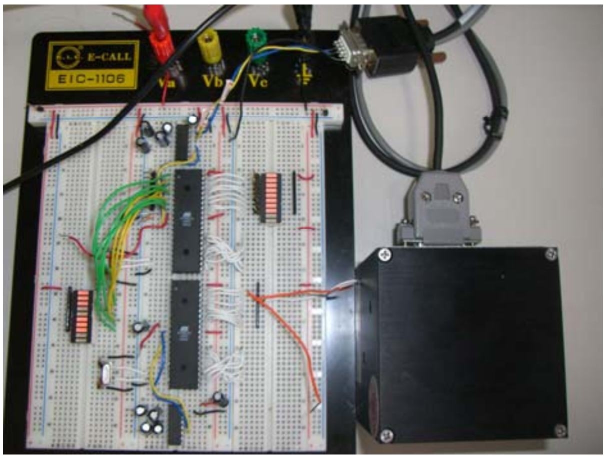

Fig. 5. IMU system.

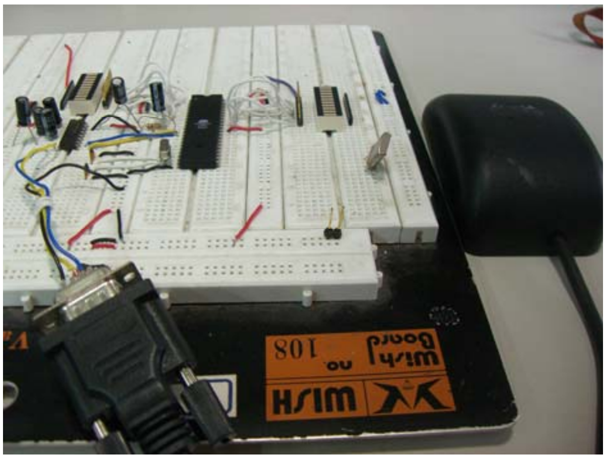
Fig. 6. GPS system.

system is implemented on a commercial vehicle named TAIWAN *i*TS-1, Savrian, manufactured by Mitsubishi motor company. The feedback velocity of the vehicle is measured from the wheel-velocity instrument of the front left-tire. For the headway distance measurement, one laser radar (LMS291, manufactured by SICK), is employed and connected through RS-232 to the automation system. The permissible distance of radar in forward direction is set to 80 m, The whole automation is built in the Microautobox, which is a real-time hardware with rapid prototype of control design. The throttle pedal is adjusted by a DC-motor with the feedback signal of the throttle position sensor, to yield the velocity tracking for vehicle control. To exhibit the validness of the proposed longitudinal automation system, many experiments have bee taken in the expressway (Chutung-Nanliao segment, Taiwan), in which the legal highest velocity is 90 km/h. Initially the subject vehicle is in the automatic vehicle following mode, and maintains the safety headway distance according to the current velocity (about 75 km/h). The sampled history of experiments with the scheme of adaptive sensory processor is depicted in Fig. 7. As shown in the second graph, here the fixed headway time is set as 1 second the same, such that the desired headway distance is about 21 m.

There is no missing detection of the preceding vehicle during the vehicle following control mode, and the throttle action also performs smooth, as in the bottom graph. Once the preceding vehicle changes the original lane, the subject vehicle automatically switches to the velocity cruise tracking mode and accelerates to the original desired velocity 90 km/h, as shown in the third graph. It can be seen that the steady-state throttle voltage after the acceleration is larger values for the higher velocity than the slower velocity. If one vehicle cuts in the forward direction, or radar detects the slower vehicle ahead within the feasible range (40 m), then the throttle pedal of the subject vehicle will be adjusted to follow the preceding vehicle with the safety distance according the current velocity. Besides the high velocity operation, although not shown, the operation of low velocity (20

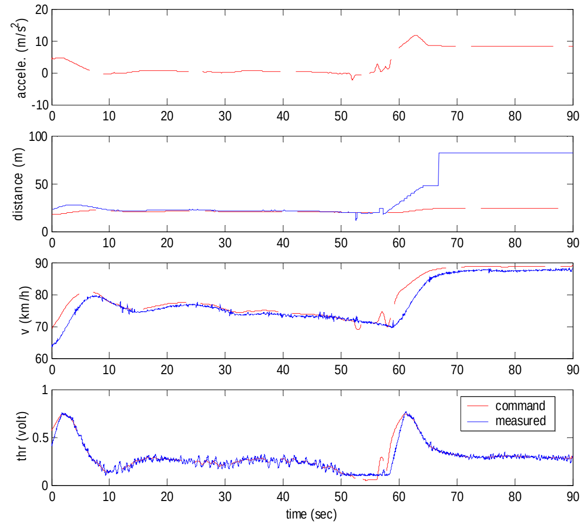

Fig. 7. The experimental scenario on the real road environment.

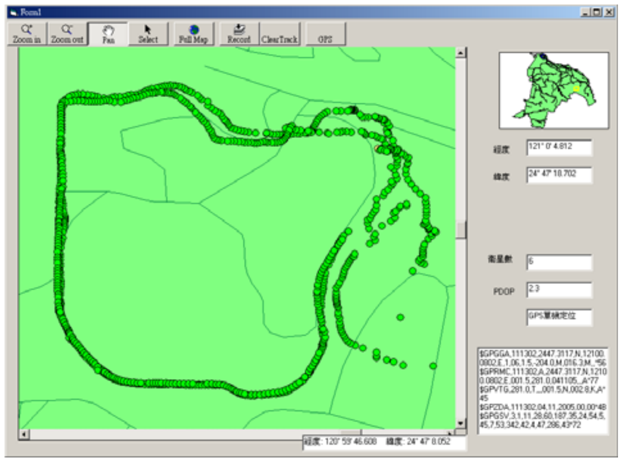

Fig. 8. GPS information and interface.

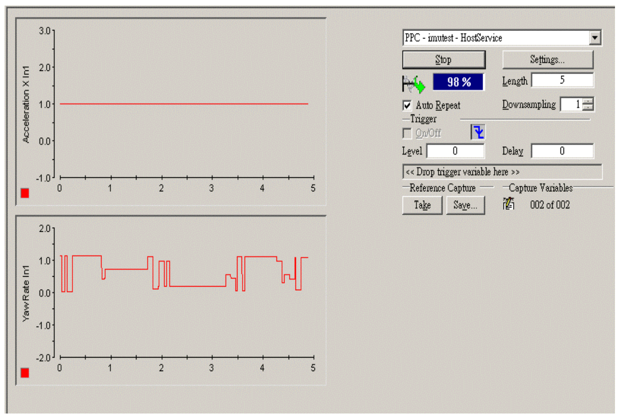

Fig. 9. IMU measurement.

km/h upward) can also be handled by the regulation control against gear changes and torque converter of the vehicle engine.

On the other hand, the GPS receiver provides orbital data for calculating the position and velocity values for the GPS satellites. The interface of GPS system is setup and shown in Fig. 8. The information including latitude, longitude, altitude, time-of–fix, data-of-fix, number of satellites seen, heading data, etc., of vehicle can be obtained from GPS receiver through an additional RS232 port. The onboard sensing components consist of gyros and accelerometers together with other electronics comprise the IMU. The IMU along with software and hardware implements the navigation solution for the INS. Fig. 9 shows the data acquirement from IMU sensor through RS232 port.

VI. Conclusion

In this project, the overall system is successfully implemented on a passenger vehicle tested in real road environments. The longitudinal automation system is composed of the adaptive sensory processor, the supervisory control, and the regulation control. The system safety is improved by inclusion of adaptive sensory scheme to prevent the missing detection of the preceding vehicle on curved roads. The supervisory control is designed to switch between different modes automatically and operate within the bound acceleration constraint without v-v communication need. The regulation control is to execute the desired velocity tracking commanded from the supervisory control. The proposed automation system is to assist the human driver in the velocity and inter-vehicle space control such as to yield the workload reduction of driving. Finally, the experimental results in real road environments verify the validness of the longitudinal automation system. In the future, the information from the integrated GPS/INS will also be applied to enhance the stability and performance of the vehicle control system.

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計畫成果自評

本研究內容與原計畫所提之主要研究方向與目標是相符的。研究成果建立台灣第一輛具有自動跟車系統之智慧車。不僅能保持安全車距也能符合行車舒適性。目前已初步在快速道路上完成實車驗證。未來將藉由GPS與INS之整合設計，可以進一步提高行車控制器之安全性及效能。

研究成果將兼具學術與商用價值。除了部分成果已投稿至國際研討會IEEE SMC2006。而完整的成果也將投稿至IEEE著名期刊。

Appendix

$$
\begin{bmatrix} \delta\dot{r}_N \\ \delta\dot{r}_E \\ \delta\dot{r}_D \\ \delta\dot{v}_N \\ \delta\dot{v}_E \\ \delta\dot{v}_D \\ \delta\dot{\theta}_N \\ \delta\dot{\theta}_E \\ \delta\dot{\theta}_D \end{bmatrix}
=
\begin{bmatrix}
0 & -\dot{\lambda}\sin L & \dot{L} & 1 & 0 & 0 & 0 & 0 & 0 \\
\dot{\lambda}\sin L & 0 & \dot{\lambda}\cos L & 0 & 1 & 0 & 0 & 0 & 0 \\
-\dot{L} & -\dot{\lambda}\cos L & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
-\frac{g}{R} & 0 & 0 & 0 & -\left(2\Omega+\dot{\lambda}\right)\sin L & \dot{L} & 0 & -f_D & f_E \\
0 & -\frac{g}{R} & 0 & \left(2\Omega+\dot{\lambda}\right)\sin L & 0 & \left(2\Omega+\dot{\lambda}\right)\cos L & f_D & 0 & -f_N \\
0 & 0 & 2\frac{g}{R} & -\dot{L} & -\left(2\Omega+\dot{\lambda}\right)\cos L & 0 & -f_E & f_N & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\left(\Omega+\dot{\lambda}\right)\sin L & \dot{L} \\
0 & 0 & 0 & 0 & 0 & 0 & \left(\Omega+\dot{\lambda}\right)\sin L & 0 & \left(\Omega+\dot{\lambda}\right)\cos L \\
0 & 0 & 0 & 0 & 0 & 0 & -\dot{L} & -\left(\Omega+\dot{\lambda}\right)\cos L & 0
\end{bmatrix}
\begin{bmatrix} \delta r_N \\ \delta r_E \\ \delta r_D \\ \delta v_N \\ \delta v_E \\ \delta v_D \\ \delta\theta_N \\ \delta\theta_E \\ \delta\theta_D \end{bmatrix}
$$