with passengers inside the vehicle, a comparison has been made between mode-stirred reverberation chambers and vehicle bodies. Based on this comparison, equivalently loaded $Q_{\max}$ measurements of the vehicles, with and without passengers, have been performed. Over the 1–6-GHz band, $Q_{\max}$ factors in the range of 100 to 1000 were obtained. In order to deduce an equivalent effect, passenger movements inside the vehicles have been evaluated in the way that a mechanical mode stirrer is characterized in a reverberation chamber. Stirring ratios in the order of 20 dB have been found for a typical automobile with four passengers onboard and ranging from 12 to 20 dB for a bus with 20 passengers onboard. It has been verified that the behavior of an antenna put inside a vehicle and its ability to couple with the EM environment depends on its property in free space. Finally, it has also been verified that only inside the automobile body, the real and imaginary parts of the scattering parameter, are almost independent Gaussian random variables with the same variances.

REFERENCES

[1] A. Bria, F. Gessler, O. Queseth, R. Stridh, M. Unbehaun, W. Jiang, J. Zander, and M. Flament, "4th-generation wireless infrastructures, scenarios and research challenges," *IEEE Pers. Commun.*, vol. 8, pp. 25–31, Dec. 2001.

[2] S. V. Bana and P. Varaya, "Space division multiple access (SDMA) for robust ad hoc vehicle communication networks," in *Proc. IEEE Intelligent Transportation System Conf.*, Oakland, CA, Aug. 25–29, 2001, pp. 964–969.

[3] K. Seki, T. Ogino, Y. Sato, R. Tsuchiya, and T. Watanabe, "Construction of future railway system utilizing information and telecommunication technologies," in *Proc. World Congr. Railway Research*, Germany, Nov. 25–29, 2001. Passenger Information session, CD-ROM.

[4] M. Heddebaut, J. Rioult, M. Klingler, A. Menhaj, and C. Gransart, "Microwave radio coverage for vehicle-to-vehicle and in-vehicle communication," in *Proc. 8th World Congr. Intelligent Transport Systems*, Sydney, New South Wales, Australia, Oct. 2001. Vision Enhancement session, CD-ROM.

[5] W. Stallings, *Wireless Communications and Networking*. Englewood Cliffs, NJ: Prentice-Hall, 2002, ch. 2, 4.

[6] R. Kronberger, H. K. Lindenmeier, J. F. Hopf, and L. M. Reiter, "Design method for antenna arrays on cars with electrically short elements under incorporation of the radiation properties of the car body," in *IEEE Antennas Propagation Soc. Int. Symp.*, vol. 1, July 13–18, 1997, pp. 418–421.

[7] A. Taflove and K. Umashankar, "A hybrid moment/finite time domain approach to electromagnetic coupling and aperture penetration into complex geometries," *IEEE Trans. Antennas Propagat.*, vol. AP-30, pp. 617–627, July 1982.

[8] D. S. Katz, M. J. Piket-May, A. Taflove, and K. R. Umashankar, "FDTD analysis of electromagnetic wave radiation from systems containing horn antennas," *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 1203–1212, Aug. 1991.

[9] D. A. Hill, "Spatial correlation function for fields in a reverberation chamber," *IEEE Trans. Electromagn. Compat.*, vol. 37, pp. 133–138, Feb. 1995.

[10] L. Cappetta, M. Feo, V. Fiumaro, V. Pierro, and I. Pinto, "Electromagnetic chaos in mode-stirred reverberation enclosures," *IEEE Trans. Electromagn. Compat.*, vol. 40, pp. 185–192, Aug. 1998.

[11] H. A. Wolfsberger, D. Jordan, and A. J. Schwab, "Automatic fields distribution measurement inside of enclosures," in *Proc. IEEE EMC Society 2000 Int. Symp.*, Washington, DC, Aug. 2000, pp. 237–240.

[12] P. Corona, G. Ferrara, and M. Miglaccio, "A spectral approach for the determination of the reverberation chamber quality factor," *IEEE Trans. Electromagn. Compat.*, vol. 40, pp. 143–153, May 1998.

[13] J. Perini and L. Cohen, "An alternative way to stir the fields in a mode stirred chamber," in *Proc. IEEE EMC Society 2000 Int. Symp.*, Washington, DC, Aug. 2000, pp. 633–637.

[14] O. Lundén and M. Backström, "Stirrer efficiency in FOA reverberation chambers. Evaluation of correlation coefficients and chi-squared tests," in *Proc. IEEE EMC Society 2000 Int. Symp.*, Washington, DC, Aug. 2000, pp. 11–16.

[15] I. Junqua, F. Issac, B. Michielsen, and C. Fiachetti, "Relation between variances of scattering parameters at an equipment port in a reverberation chamber," in *Proc. Conf. Rec. 2003 15th Int. Zurich Symp. Tech. Exhibit. Electromagnetic Compatibility*, Feb. 18–20, 2003, pp. 233–238.

[16] C. Fiachetti, "Modèles du champ électromagnétique aléatoire pour le calcul du couplage sur un équipement électronique en chambre réverbérante à brassage de mode et validation expérimentale," Ph.D. dissertation, IRCOM Dept., Commun. Res. Inst., Univ. Limoges, Limoges, France, 2002.

Knowledge-Based Gear-Position Decision

Guihe Qin, Anlin Ge, and Ju-Jang Lee

***Abstract*—Gear-position-decision (GPD) tactics strongly affect the performances of automatic transmissions (AT) and, therefore, the performance of the vehicle. Since the electronic control methods were introduced into ATs, many advanced techniques have been raised to make AT vehicles more human friendly and better in fuel economy and dynamic behaviors. As a type of emerging AT, the automated manual transmissions (AMT) are being researched and developed in all relevant technologies. In this paper, we proposed a driving knowledge-based GPD (KGPD) method for AMTs. The KGPD algorithm is composed of a driving environments and driver's intentions estimator, the shift schedules for each typical driving environment and driver's intention situations, and an inference logic to determine the most proper gear position for the present situation. The estimator identifies the driving environments and features of driver's intentions, which are divided into some typical patterns. Based on the identified results, the gear-position inference algorithm calculates the best gear position at the moment. In fact, the method just simulates the course of a driver's making gear-position decision when driving an automobile with manual transmission. The test results show that the AMT with the method gives less unnecessary shifting, conducts more proper gear positions, and behaves better in subjective assessment than that with the method that is directly based only on automotive state parameters.**

***Index Terms*—Automatic transmissions (AT), fuzzy logic, knowledge-based systems, road vehicle control.**

I. INTRODUCTION

In a road vehicle, the functions of transmission are to match the running state of engine to the motion states of the vehicle. The aims are to optimize the fuel economy and dynamic features, to keep the vehicle safe and controllable, and to make passengers more comfort. The ratio of transmission, which is determined with the gear positions, is changed according to engine states, vehicle states, and road situations. The transmissions are classified into automatic transmissions (AT) and manual transmissions (MT). A traditional AT is composed of a planetary gearbox and a torque converter. Shifting automatically, it is convenient to drive an AT vehicle. However, AT's transfer efficiency is low

Manuscript received July 22, 2003; revised February 9, 2004. This work was supported in part by the Excellent Young Teachers Program of the Ministry of Education (MOE), China, under Grant 1812. The Associate Editor for this paper was T. Fukuda.

G. Qin is with the Department of Computer Science and Technology, Jilin University, ChangChun 130025, China (e-mail: ghqin@jlu.edu.cn).

A. Ge is with College of Automobile Engineering, Jilin University, ChangChun 130025, China.

J.-J. Lee is with the Department of Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology, Deajeon 305–701, Korea.

Digital Object Identifier 10.1109/TITS.2004.828171

and it is more difficult to manufacture and maintain than MT. MT is composed of a gearbox and a dry clutch and has to be operated manually. However, it has the advantages of high efficiency and is easy to manufacture and maintain. automated MT (AMT) achieves automatic shifting function by electronic control of MT. AMT has the advantages of both MT and AT [1], [2]. To implement automatic shifting, AMT must have the ability to gear ratio selection automatically, i.e., gear-position decision (GPD) and the ability of automatic shifting control. Shifting control is a typical mechanical device-control problem. Many researches have sought to improve its performances [3]–[5]. GPD is involved in not only vehicle parameters, but also driver's intentions and road environments. In this paper, we focus the discussion on the GPD problem only.

GPD is one of the key technologies of AMT. Strongly affecting the performances of the AMT vehicle, GPD has been a most important research topic since AMT appeared in the 1980s [6], [7]. At the early time of AMT technology, GPD methods were mainly adopted from AT. The main tasks of the technology at the time were to implement the basic automatic shifting functions. The traditional GPD methods of AMT, the same as those used in AT, usually are based only on vehicle-state parameters such as speed, throttle opening degree, and acceleration [8], [9]. The GPD methods are very sensitive to the parameters and cannot adapt to variant road environments. They also cannot cater to driver's operating intentions [10], [11]. Because AMT is not as flexible as AT in mechanical characters, the defects derived from the drawbacks behave more seriously [8]. In the complex road environments, the drawbacks cause AMT to carry out many unnecessary gear changes and could not select proper gear positions. These may reduce the average driving force and fuel economy due to the interruption of power in shifting and decrease the life of mechanical parts because of more wearing. Ignorance of a driver's intentions causes more use of the brake or acceleration. These problems are initially studied for ATs. As the technology develops, some ideas have been presented, ranging from simple mechanical to software-based approaches. Among them, there exist the knowledge and fuzzy-logic-based tactics. Weil [11], Bastian [12], and Sakaguchi [13] proposed the ideas of introducing driving knowledge into shifting schedules of AT and, respectively, researched the "wind road," "slop road," and "load adaptation" situations. Graf [14], Shimizu [15], and Hayashi [16] presented neurofuzzy-based GPD concepts to make the control algorithms able to adapt to load variance and different driver types. As new powertrains are introduced and superpower microcontrollers are used in vehicles, more advanced control algorithms for AT systems are presented [17]. Most of the work focuses on one or several problems and are conceptualizing research. Little work has been found on general intelligent GPD models, especially the work direct for the AMT and practical methods.

In this paper, we present in detail a general knowledge-based GPD model for AMT and its realization. The driver's intentions as well as the road environments are introduced to improve the performances of AMT. It employs the information detected with the in-vehicle sensors. The principle to develop the algorithm is to improve the performances of the AMT as much as possible with little or no extra hardware additions. The basic idea is to fully use the available information and to mimic the GPD course of experienced drivers. The model is based on the driving knowledge. A three-layer intelligent-control structure of AMT is achieved from the analysis of experienced driver's shifting operation. In this paper, the topic is mainly focused on the top layer, i.e., GPD. The test results show that, compared with the traditional two-parameters GPD method [8], the presented method makes the test car conduct less unnecessary shifting, select gear position more properly, and obtain a higher subjective assessment score.

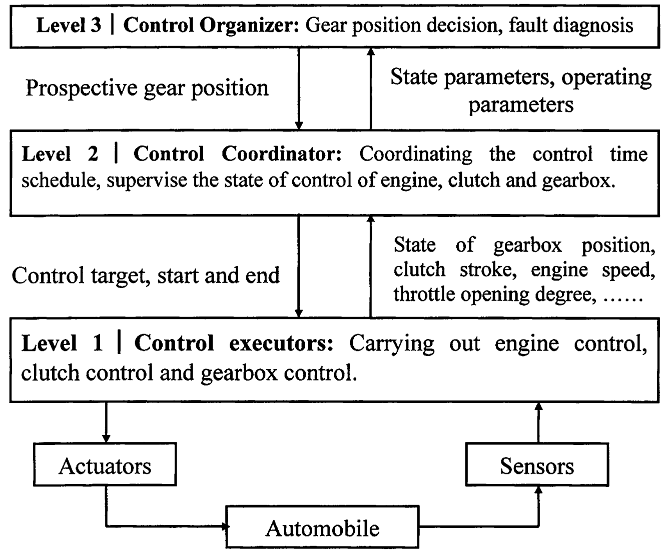

Fig. 1. AMT intelligent control architecture.

The rest of this paper consists of three sections. Section II is the formulation of the GPD and Section III illustrates experimental results. Section IV provides the conclusion and future work.

II. Knowledge-Based GPD (KGPD)

A. Basic Ideas

GPD is a very complex course. Essentially, it is an optimizing problem. Under different road environments and driving intentions, the optimum gear position is selected depending on different principles. It is very difficult to model the course with pure mathematical functions. In the other hand, an experienced driver can most properly select the gear positions in any driving situations when operating MT vehicles. Inspection of the driving process can provide us with useful ideas to design a more practical AMT control system. From the consultation of experienced drivers and vehicle experts as well as the driving handbook [18], we figure out the course of shifting as follows:

1) generating intentions of the interval based on the travel purpose, sensed road environments, and vehicle states;
2) making a GPD; if the present (GP) is not the same as the calculated one, shifting will be carried out;
3) figuring out the shifting operation-time sequences of the accelerator, clutch stroke, and gear-operating lever;
4) carrying out the operation of the accelerator, clutch stroke, and gear-operating lever, respectively, according to the time sequences.

To mimic the course, the control system of the AMT is adapted to a three-layer intelligent-control system structure [19], as shown in Fig. 1. This is the basic structure of the AMT control system. The top layer finishes the GP decision; the middle layer coordinates the engine, clutch, and gearbox controls; and the bottom layer carries out the control operations of engine (throttle opening), clutch stroke, and gearbox, respectively. The functions of the bottom two layers are shifting-control operations. In the AMT, the throttle opening is controlled with a stepper motor, the clutch with a cylinder, and the gearbox with two cross cylinders. Details of the parts can be found in [2] and [20]. In this paper, the top layer, i.e., GPD algorithm, is to be explained in the next sections.

The experienced driver's GPD can be summarized as follows:

1) sensing road environments and estimating vehicle states;
2) figuring out the features of the road environments and adjusting the vehicle according to driving knowledge and experiences;

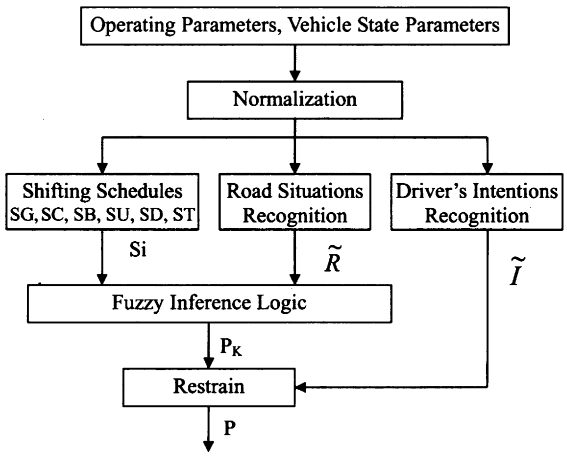

Fig. 2. General structure of the KGPD algorithm.

3) recalling gear-selection rules suitable for the road situations and intentions;
4) selecting a gear position according to operation rules and experiences;
5) carrying out the operation of shifting to the selected gear position if it is not same as the present one.

This course is modeled as Fig. 2, which is a KGPD algorithm that can synthetically use the information of road environment and driver's intentions as well as the automotive state parameters as an experienced driver behaves. The algorithm is composed of a road-environment estimator (E1), a driver's intention estimator (E2), a shift-schedule knowledge base (S) suited for every typical situation, an fuzzy-inference algorithm (I) to calculate the most suitable gear position, and the measure and normalization part to measure and normalize the vehicle-state parameters as well as the driver's operating parameters. The normalized data are sent to the estimators and every shift-schedule algorithm. The estimators E1 and E2 calculate the present road environments $(\tilde{R})$ and the driver's intentions $(\tilde{I})$ (refer to Section II-B). The estimated result $(\tilde{R})$ is used to select a gear position that is suitable for the road situation under the restraint of $\tilde{I}$. The basic meaning of the algorithm is "if the road environment is $\tilde{R}$ and the intention is $\tilde{I}$, then use schedule $S(\tilde{R})$ to calculate the optimum gear position with the restriction of $\tilde{I}$."

The basic idea of the method is that the optimal schedules for any situation are stored in the knowledge base and that the one used to calculate the gear position now is selected by the dynamically recognized situation. Every part of the model is to be depicted in the rest of this section.

B. Parameter Measurement and Normalization

The normalized measured parameters include the following.

1) Throttle opening $\alpha(i)$ degree ($\alpha(i)$ means that the normalized throttle-opening degree at t_i. "i" denotes the sampling time t_i. In the rest of this paper, the meaning of (i) is the same as in $\alpha(i)$): Detected with a potentiometer mounted to the throttle. The throttle-opening degree varies from 0% to 100%, correspondingly $\alpha(i)$ from 0 to 1.

2) Vehicle velocity $v(i)$: Derived from the speed of the output shaft of the transmission. The speed is measured with an encoder. The relation between real vehicle speed and $v(i)$ is

$$v(i) = \begin{cases} V(i)/(80\ \mathrm{km/h}); & V(i) \leq 80\ \mathrm{km/h} \\ 1; & V(i) > 80\ \mathrm{km/h} \end{cases} \tag{1}$$

where $V(i)$ is the directedly measured velocity. When $V(i)$ is bigger than 80 km/h, the gear position is the highest for any situation in the tested car, so $V(i)$ is normalized with 80 km/h.

3) Variation of throttle-opening degree $\alpha'(i)$: Calculated from $\alpha(i)$

$$\alpha'(i) = \begin{cases} (\alpha(i) - \alpha(i-2) + 1)/10; & |\alpha(i) - \alpha(i-2)| \leq 5 \\ 1; & |\alpha(i) - \alpha(i-2)| > 5. \end{cases} \tag{2}$$

4) Variation of vehicle velcity $v'(i)$: Calculated from $v(i)$

$$v'(i) = (v(i) - v(i-5) + 1)/2. \tag{3}$$

5) Braking frequency $B_f(i)$: Defined as the change times of the braking state in a time interval. To calculate $B_f(i)$, a variable $B(i)$ is introduced to count the braking action. At the sampling point, the braking state is inspected. If it is different from the last one, $B(i)$ is increased by 1

$$B_f(i) = \begin{cases} (B(i) - B(i-50))/5; & B(i) - B(i-50) \leq 5 \\ 1; & B(i) - B(i-50) > 5. \end{cases} \tag{4}$$

6) Frequency of $\alpha'(i)$ passing zero $\alpha_f(i)$: Defined as the times of $\alpha'(i)$ changing sign in a time interval and is the same as the method to compute $B_f(i)$; to calculate $\alpha_f(i)$, a variable $F(i)$ is introduced to count the sign change of $\alpha'(i)$. At the sampling point, the sign of $\alpha'(i)$ is inspected. If it is different from the last one, $F(i)$ is increased by 1

$$\alpha_f(i) = \begin{cases} (F(i) - F(i-30))/3; & F(i) - F(i-30) \leq 3 \\ 1; & F(i) - F(i-50) > 3. \end{cases} \tag{5}$$

7) Accumulation of braking time $B_t(i)$: Defined as the accumulated time of the braking state in an interval. To obtain $B_t(i)$, a clock is used to count the duration of each braking. Whenever the braking pedal is stamped down, the clock is reset. When the pedal is released, the clock is stopped and the recoded time is added to variable $C_t(i)$. At the sampling point, if the clock is counting, the counted time is added to $C_t(i)$ and then the clock is reset.

$$B_t(i) = \begin{cases} (C_t(i) - C_t(i-20))/2/20; & C_t(i) - C_t(i-20) \leq 40 \\ 1; & C_t(i) - C_t(i-20) > 40. \end{cases} \tag{6}$$

The parameters are selected because they can be measured with existing sensors and are sensitive to the road environments. The combination of $\alpha(i)$, $v(i)$, and $v'(i)$ reflect the vehicle dynamic fearures including road resistance at and before the moment. $\alpha'(i)$, $B_f(i)$, $\alpha_f(i)$, and $B_t(i)$ are sensitive to what the driver senses and what the driver wants [21].

C. Road Environment and Driver's Intention Recognition

According to the need of GPD [20], road environments are divided into the typical patterns, as follows:

- "good road" (G), i.e., flat, straight, and spacious;
- "complex road" (C), i.e., jam, narrow, or winding;
- "bump road"(B);
- "sharp-up road" (U);
- "sharp-down road"(D).

To recognize them, we consider them as patterns defined by space $(\alpha, v, \alpha', v', \alpha_t, B_f, B_t)$. The pattern set is

$$\psi = \{G, C, B, U, D, T\}. \tag{7}$$

The pattern vector is defined with the measured parameters as

$$X_j = (\alpha_j, v_j, \alpha'_j, v'_j, \alpha_{tj}, B_{fj}, B_{tj}), \quad j \in \psi. \tag{8}$$

Unknown vector at time t_i is

$$X(i) = (\alpha(i), v(i), \alpha'(i), v'(i), \alpha_t(i), B_f(i), B_t(i)). \quad (9)$$

For all the data of the parameters that are normalized (refer to Section II-A), the pattern vector is of the form of a fuzzy set defined by the universe of discourse $\{\alpha, v, \alpha', v', \alpha_t, B_f, B_t\}$. With an experienced driver driving the vehicle, we sample the data in every situation. For situation $j, j \in \psi$, a group of vectors are obtained. The center of the vectors is taken as X_j.

Define a measure of distance of two vector points (Y and Z) in the space of $(\alpha, v, \alpha', v', \alpha_t, B_f, B_t)$ as

$$\delta(y, z) = 1 - \frac{1}{\sum_{k \in p} \omega_k} \cdot \sum_{j \in p} |y(j) - z(j)| \cdot \omega_j \quad (10)$$

where p represents the set $\{\alpha, v, \alpha', v', \alpha_t, B_f, B_t\}$ and $\omega_k \in [0, 1]$ is the weight attached to the element k of vector y and z. It is added to adjust the significance of the corresponding parameter. Evidently, $\delta(y, z)$ is of the properties

1) being a map of $X \times X \to [0, 1]$;
2) if $y = z, \delta(y, z) = 1$;
3) $\delta(y, z) = \delta(z, y)$;
4) if $y \subset A \subset z$ or $y \supset A \supset z$, $\delta(y, A) \geq \delta(y, z)$. (11)

According to Wang [22], $\delta(y, z)$ defines a measure of a near grade of two fuzzy sets and can be used to describe the degree of difference of fuzzy sets. The value of $\delta(X(i), X_j)$, i.e., the near grade between $X(i)$ and X_j, describes the grade that the present situation belongs to pattern j. Construct a set $\tilde{R}$ as

$$\tilde{R} = \{\tilde{R}(j)\}; \quad \tilde{R}(j) = \delta(X(i), X_j), \quad j \in \psi. \quad (12)$$

For $\delta(X(i), X_j) \in [0, 1], \tilde{R}$ is a fuzzy set defined by ψ and its membership, i.e., the near degree between $X(i)$ and X_j, describes how much the mode j belongs to the present situation. Therefore, $\tilde{R}(j)$ provides the information regarding to what mode the road now belongs.

Driver's intentions are divided into three patterns: "acceleration" (A), "keeping the state" (K), and "slowing down"(S). A fuzzy set defined by $\{A, K, S\}$ is employed to describe patterns

$$\tilde{I}(i) = \{\tilde{I}(j) \,|\, j \in \{A, K, S\}\} \quad (13)$$

where

$$\begin{aligned} \tilde{I}_i(A) &= \max((\alpha'(i) - 0.5), 0)/0.5 \\ \tilde{I}_i(K) &= (1 - |\alpha'(i) - 0.5)/0.5|) \cap (1 - B_t(i)) \\ \tilde{I}_i(S) &= (1 - \alpha'(i)) \cup B_i(i). \end{aligned} \quad (14)$$

They are derived directly from the driving knowledge. The meaning of the definition is that if $\alpha'(i)$ is bigger than 0.5 (throttle opening is increased), the driver want to accelerate; if $\alpha'(i)$ is about at 0.5 (unchanged) and $B_t(i)$ is small, the driver wants to keep the speed; and if $\alpha'(i)$ small or $B_t(i)$ is big, the driver wants to decrease the speed.

D. Shift Schedules

Shift schedules are functions of vehicle-state parameters to calculate the optimum gear position. There are two types of methods to obtain the shift schedules. One is the optimization method, whose principle of determining the shift points is to make the fuel economy or dynamic performance best. This is the traditional method for obtaining the shifting schedules and is relatively perfect. Here, the shift schedules S_G, S_U, which are, respectively, used at situations G and U, are obtained with the method. The detailed process to calculate the schedules can be found in [8]. The other method is to determine the shift points according to the operating rules and the experienced driver's knowledge. The shift schedules S_C, S_B, S_D, and S_T, which are, respectively, used in situations C, B, D, and T, are obtained with the method, which are as follows:

1) listing all the operating rules in a situation;
2) sorting out all the control variants;
3) defining the fuzzy subsets of the variants;
4) inducing the fuzzy rules of GPD in the situation according 1)–3);
5) quantizing the control variants and calculating the shift-schedule tables.

More details and the calculation of other schedules can be found in [20] and [21].

All the shift schedules are expressed with datum tables and are stored in the electronic control unit (ECU) of the AMT as a knowledge base. The output P_j of shift schedule S_j can be calculated with the corresponding table.

E. Gear-Position Calculation

Based on the road-environment information and intentions, with the shifting schedule knowledge, the GPD becomes a problem such as "If road situation $R = j$, then gear position $P = P_j$. The road situation $R = \tilde{R}(i)$ and the gear position $P = ?$ (Crisp form)."

This is a fuzzy inference in which the rules are in crisp form. To correspondingly extend the membership of fuzzy set $R = \tilde{R}(i)$ to the

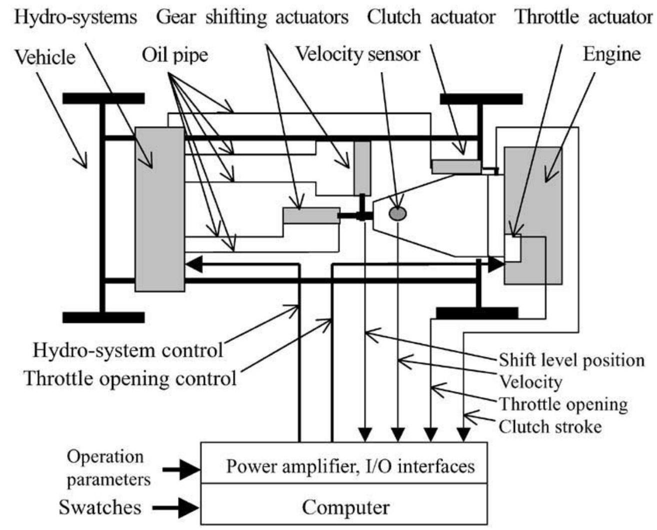

Fig. 3. Experimental system.

TABLE I
SUBJECTIVE ASSESSMENT RESULTS

Drivers	Round1 (DTP)		Round2 (KGPD)		Round3 (DTP)		Round4 (KGPD)	
	Score	Shift	Score	Shift	Score	Shift	Score	Shift
1	75	37	85	34	70	35	75	35
2	80	40	85	36	80	37	90	35
3	75	38	75	36	80	39	85	37
4	70	35	75	34	75	36	75	34
5	75	38	80	37	70	37	80	35
6	80	39	90	36	80	37	85	37
7	85	36	90	36	80	38	90	36
8	85	40	90	37	85	39	85	35
9	80	38	80	35	75	40	85	36
10	70	37	85	36	75	38	80	35
Average	77.5	37.8	83.5	35.7	77	37.6	83	35.5

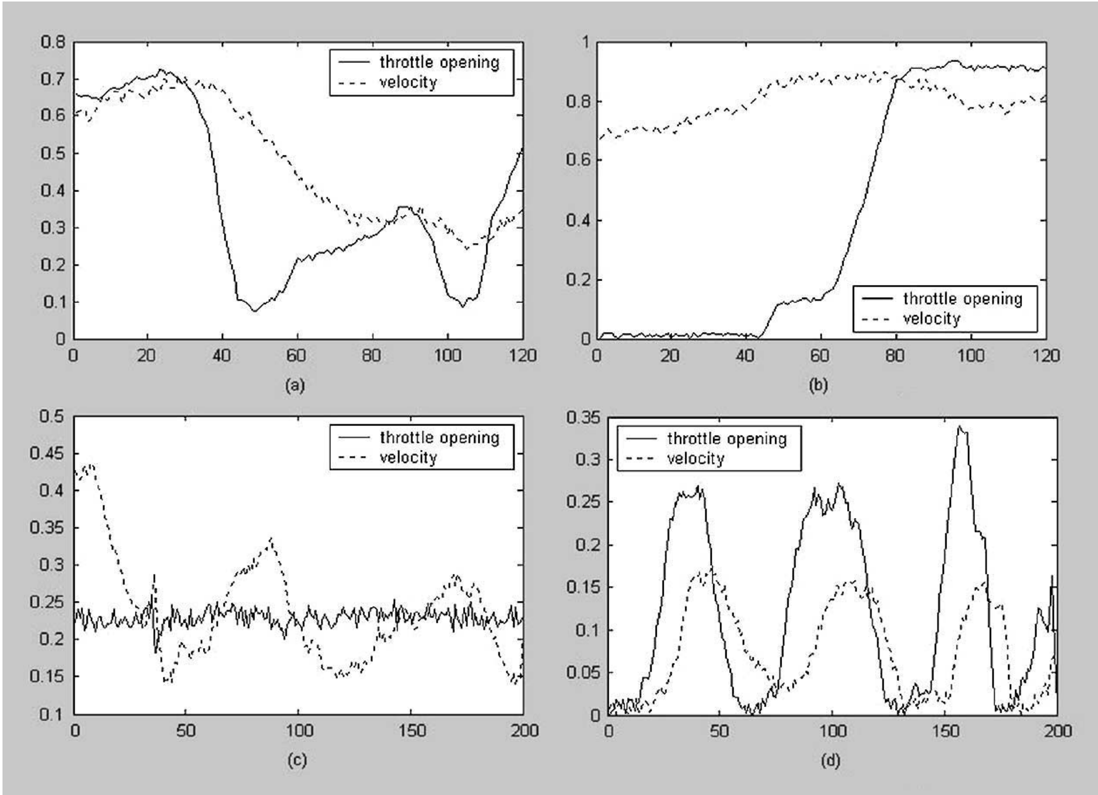

Fig. 4. Test at different road situations.

universe of discourse of $\{P_j \mid j \in \psi\}$, we obtain the fuzzy-set gear position

$$\tilde{P}(i) = \{(\tilde{R}_j(i), P_j)\}. \tag{15}$$

With the "first-of-maxims" defuzzification method, the most possible road situation can be obtained as

$$P_k = \inf_{i=\psi}\{P_j \mid j \in \text{Con},\ \tilde{R}(j) = \max_{l\in\psi}(\tilde{R}(l))\}. \tag{16}$$

Then, P_k is taken as the candidated gear position. At last, the output gear position is determined with constrain of $\tilde{I}(i)$ as

$$\begin{aligned}
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\}\\
&\quad = A \cap P_0 > P_k,\\
&\text{then } P = P_k;\ P_0 \text{ is the geared position;}\\
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\}\\
&\quad = A \cap P_0 < P_k,\\
&\text{then } P = P_k \text{ (with a delay);}\\
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\}\\
&\quad = A \cap P_0 = P_k,\\
&\text{then } P = P_0;\\
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\} = K,\\
&\text{then } P = P_i;\\
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\}\\
&\quad = S \cap P_0 \le P_k,\\
&\text{then } P = P_0;\\
&\text{If } \inf_{i=\{A,K,S\}}\{i \in \text{Con} \mid I(i) = \max_{j\in\{A,K,S\}}(I(j))\}\\
&\quad = S \cap P_0 > P_k,\\
&\text{then } P = P_i.
\end{aligned} \tag{17}$$

III. Experiment Test

The KGPD model was tested on the AMT mounted on a Shanghai Santana 2000 car with a five forward one backward gearbox transmission. The control was carried out with an in-car PC powered with uninterupted power supply (UPS). The basic structure of the system is illustrated in Fig. 3. The test was conducted in downtown Changchun and on rural roads. The experiment was carried out as follows:

Ten drivers drove the car in turn. Each drove on the same road four times (starting from Jilin University, ChangChun, China, to rural, then back to the university). Among the four tests of each driver, the KGPD was used two times while dynamic three parameters schedule (DTP) was used in another two times. The drivers were not informed of the difference and each time the driver evaluated the shifting performance of the car. The results included a subjective assessment of the drivers and of the recorded data. Table I shows the results.

The AMT With the KGPD was evaluated to be higher than with DTP and the average shifting times were evidently lower. From the recorded data, we found that the decrease mainly appeared on "turn," "bump," "down-and-up," or "up-and-down" roads, as well as "deceleration" and "acceleration" situations. On other situations, the shifting times with the two methods were about the same. Fig. 4 illustrates the typical situations. In the situations with KGPD the AMT, no shifting was carried out. However, if DTP was used, an unnecessary shifting would occur. In Fig. 4(a), the AMT held the gear-position 3 in the case, but if the DTP was used, the gear position would rise up to 4, then decrease to 3, according to the throttle opening and motion speed.

IV. Conclusion

The road test data show that the AMT gives out less unnecessary shift and that the gear position in "turn road," "sharp down," "deceleration," and "bump road" are more proper than the one using the common two-parameter shift schedule in all the situations. These prove that the method improves the adaptation of AMT to the road. In the assessment, the AMT obtained a higher score than that with traditional shift schedules. The subject assessment of functions is very important to cars. Generally, with the structure, the road environment and intention information can be introduced into GPD and the performance of the AMT with the GPD are improved. The GPD model is general and practical.

Our future work will focus on the self-adjusting ability of GPD, i.e., the ability to adapt to vehicle character change and different drivers.

References

[1] H. Yashimura and A. Hirako, "Automated mechanical transmission control," in *Proc. Int. Congr. Transportation Electronics*, Dearborn, MI, 1986, pp. 179–189.

[2] G. Qin, J. Fan, H. Zhang, and A. Ge, "Microcomputer control system of automated mechanical transmission," *Qiche Gongcheng/Chinese Autom. Eng.*, vol. 21, no. 1, pp. 21–25, 1999.

[3] H. S. Jo, S. T. Jo, J. M. Lee, and Y. I. Park, "Analysis of the shift characteristics of a automated manual transmission in the parallel type hybrid drive train system of a transit bus," *Heavy Veh. Syst.*, vol. 8, no. 1, pp. 60–82, 2001.

[4] J. Fredriksson and B. Egardt, "Nonlinear control applied to gear shifting in automated manual transmissions," in *Proc. IEEE Conf. Decision Contr.*, vol. 1, Sydney, Australia, 2000, pp. 444–449.

[5] H. Tanaka and H. Wada, "Fuzzy control of clutch engagement for automated manual transmission," *Veh. Syst. Dynamics*, vol. 24, pp. 4–5, 1995.

[6] R. C. Holmes, R. R. Smyth, and D. Speranza, "Automation of mechanical transmissions," in *Proc. Int. Congr. Transportation Electronics*, Dearborn, MI, 1984, pp. 11–23.

[7] ——, "Manual transmission converted to automatic," *Automot. Eng.*, vol. 92, no. 1, pp. 67–74, 1984.

[8] A. Ge, *Vehicle Automatic Transmission Theory and Design*. Beijing, China: Mechanical Industry, 1993, ch. 4.

[9] A. Ge, J. Jiang, W. Wu, and J. Chen, "Research on dynamic 3-parameter shift schedule of automatic transmission," in *Proc. 6th Int. Pacific Conf. Automotive Engineering*, Seoul, Korea, 1991, pp. 303–312.

[10] H. Yamaguchi *et al.*, Automatic Transmission Shift Schedule Control Using Fuzzy Logic, SAE paper 930 674, 1993.

[11] H. G. Weil, G. Probst, and F. Graf, "Fuzzy expert system for automatic transmission control control applications," in *Proc. 1st IEEE Conf. Fuzzy Systems*, vol. 2, 1992, pp. 716–721.

[12] A. Bastian, S. Tano, T. Oyama, and T. Arnould, "FATE: Fuzzy logic automatic transmission expert system," in *Proc. IEEE Int. Conf. Fuzzy Syst. 2nd Int. Fuzzy Engineering Symp.*, vol. 5, 1995, pp. 5–6.

[13] S. Sakaguchi, I. Sakai, and T. Haga, "Application of fuzzy logic to shift scheduling method for automatic transmission," in *Proc. 2nd IEEE Int. Conf. Fuzzy Systems*, vol. 1, 1993, pp. 52–58.

[14] F. Graf and W. Hauptmann, "Automotive powertrain control with fuzzy logic," in *Applications of Fuzzy Logic: Toward High Machine Intelligence Quotient Systems*, M. Jamshidi, A. Titli, L. A. Zadeh, and S. Boverie, Eds. Englewood Cliffs, NJ: Prentice-Hall, 1997, ch. 6, pp. 109–129.

[15] Y. Shimizu, S. D. Taniguti, Y. Kondo, A. Hayasi, and K. Hirako, "Neuro-fuzzy optimal down hill driving control for automated gear shift system," in *Proc. Artificial Neural Networks Engineering (ANNIE)'95*, St. Louis, MO, 1995, pp. 563–568.

[16] K. Hayashi, Y. Shimizu, T. Yasuhiko, and A. A. Hirako, "Neuro-fuzzy transmission control for automobile with variable loads," *IEEE Trans. Contr. Syst. Technol.*, vol. 3, pp. 49–52, Mar. 1995.

[17] H.-S. Jo, Y.-I. Park, and J.-M. Lee, "Development of an advanced shift control algorithm for a hybrid vehicles with automated manual transmission," *Heavy Veh. Syst.*, vol. 7, no. 4, 2000.

[18] *Automotive Driver Handbook*, Renmin Transportation, Beijing, China, 1989. Y. Zhao.

[19] C. J. Harris, C. G. Moore, and M. Brown, *Intelligent Control: Aspects of Fuzzy Logic and Neural Nets*. Singapore: World Scientific, ch. 1.

[20] G. Qin, "Study on the control technology and development of control system of automated manual transmission," Ph.D. Dissertation, Jilin Univ. Technol., ChangChun, China, 1997.

[21] G. Qin, H. Zhang, Y. Lei, and A. Ge, "Gear position decision method of automated mechanical transmission based on fuzzy inference," *Chinese J. Mech. Eng. (English ed.)*, vol. 12, no. 1, pp. 76–80, 1999.

[22] P. Wang and H. Li, *Fuzzy System: Theory and Fuzzy Computer*. Beijing, China: Science, 1996, ch. 3.