Journal of Communication and Computer 13 (2016) 55-63
doi:10.17265/1548-7709/2016.02.001

Studies on the Auto-Tuning Variables in Auto-Cruise Vehicle

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Abstract: Tuning of the required torque and the shift pattern has been made in cruise driving manually by many engineers in the past. However, manual tuning has the disadvantages of high cost and time consumption for the operator. This paper studies the driving simulation and auto-tuning of the required torque and shift pattern. The target vehicle is a vehicle operated by an engine with the function of speed tracking. First, the power train simulator which was verified by the actual driving, was made in MATLAB. Then, driving simulation was conducted by the powertrain simulator and auto-tuning was also conducted by driving data. Tuning of the required torque means calibration of values of the required acceleration function, and tuning of shift pattern means the calibration of lines of up or downshift. The modified parameters are re-applied to the vehicle which is driven in the virtual environment. This process is repeated until the required performance has been achieved. It is a feedback process to get solutions of the parameters for a given vehicle load. Consequently, engineers can automatically tune parameters instead of manually tuning the parameters, which can satisfy vehicle performance, as well as increase the comfort feel for the driver.

Key words: Auto-cruise vehicle, virtual throttle opening, auto-tuning, shift pattern, required acceleration function.

1. Introduction

Vehicle drivers undergo various tough physical situations during a long-distance drive. There is a constant stress on the muscles to maintain an upright, balanced posture, especially long distance drivers feel the pain in their ankles while pressing brake and accelerator repeatedly. To overcome this situation, auto-cruise control was introduced to automotive manufacturing field. When a vehicle driver switches to set a desired constant speed, auto-cruise control system maintains its speed without the driver stepping on the accelerator [1]. This system, which has been an essential function for drivers, significantly reduces the fatigue of drivers' burden of long-distance driving. Recently, more advanced cruise control systems appeared one after another [2]. Fig. 1 shows the power train structure of the auto-cruise vehicle.

Those auto-cruise vehicles were tested to modify the required torque and the shift pattern to ensure the vehicle performance before mass production. The purpose of auto-tuning is two-fold. First, is the prevention of changing gear at the constant speed driving, and second is to maintain a target time at acceleration and deceleration while driving. Solutions of acceleration and shift pattern by auto-tuning on the part of engineers, should be determined by the vehicle load.

However, tuning of above mentioned parameters is currently done by handmade procedures consuming a lot of time and cost. Therefore, the manual tuning needs automation, and this study is to ensure vehicle performance associated with the automation process, and its consequences [3].

In general, studies of cruise driving have applied PID (proportional-integrated-derivative) control or fuzzy

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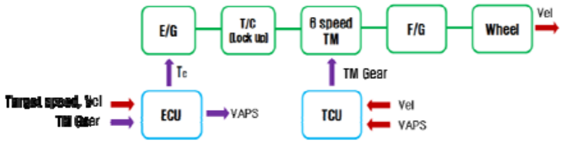

Fig. 1 Powertrain structure of Auto-cruise vehicle.

sets theory to follow the target speed. These studies adjust the throttle and tune the coefficients of the PID after target speed has been generated by switches. Such research has recently been carried out in many conventional vehicles as well as applied to hybrid vehicles [4].

However, to our knowledge, currently it is not easy to find studies which take into account the shift pattern. Some studies related to cruise driving considered shift pattern while fixing the number of transmission gear. They are researches which only considered required torque of cruise driving, and they introduced some control theories instead of reflecting tuning methods for engineers. This paper considers the shift pattern and the automation, unlike any other studies on cruise driving. These two characteristics are the originality of the study.

2. Target Vehicle

The target vehicle is a vehicle operated by an engine including a 6-speed automatic transmission. During the cruise mode, the required torque and the gear position are computed for accurate target speed. The vehicle is in lock-up state without any effect of the torque converter. In this state, the axle is in direct contact with the engine and the transmission, which improves fuel efficiency.

The simulator created by MATLAB Simulink consists of powertrain modules for simulating the existing hardware and the cruise logic to follow the target speed. This logic calculates the target speed, the required torque and the gear position, override signal, the speed unit, and the performance variables [5]. Power train modules and the cruise logic are separated from the auto-tuning program in the field of optimization. The auto-tuning program automates the manual tuning after the analyzing the driving data from simulation driving.

3. Overall Optimization Process

The overall progress of auto-tuning can be expressed as shown below, in Fig. 2 First, when driving data from the simulator consisting of the powertrain modules and the cruise logic is calculated, those parameters need to be determined that meet the target. Once the target is satisfied, the whole process is terminated. Otherwise, if the target is not satisfied, the required torque and shift pattern are modified through auto-tuning process.

Cruise driving conditions are divided mainly into constant speed, acceleration, and deceleration. In constant speed situation, auto-tuning process has the objective to secure the transmission gear number. In the situation of acceleration and deceleration, the process has the aim of target time tracking. For this purpose, driving data of virtual driving can be analyzed by auto-tuning program [6]. After the auto-tuning process is complete, a solution of the shifting pattern, functions of the required acceleration and deceleration, are achieved.

4. Auto-Tuning Simulation

In order to follow the target speed of the vehicle, it is important to obtain the correct required torque of the engine in this paper, the PID control is avoided and vehicle dynamic equations are utilized to obtain

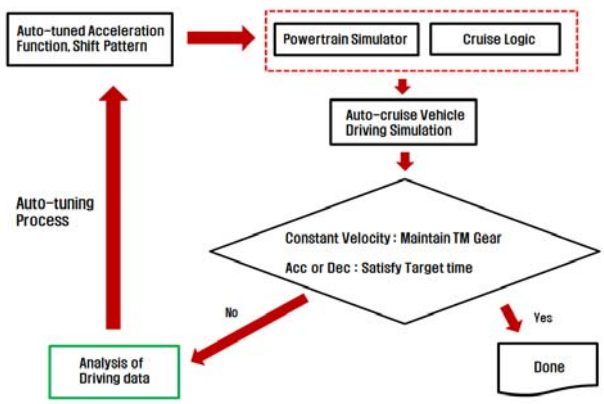

Fig. 2 Overall process.

the required wheel torque. Without any slip, the required engine torque can be calculated directly from wheel torque since lock-up state. The required acceleration and deceleration are generated by the function of deviation between current speed, target speed, and current vehicle speed after receiving a switch signal. In this way, the required torque based on the vehicle dynamics is calculated when generating the driving data and the system goes to the auto-tuning of itself.

4.1 Generation of the Required Acceleration and Deceleration Function

Target acceleration and deceleration needs are fed in the simulator to calculate the required torque. Figs. 3 and 4 show the two kinds of functions: Acceleration and Deceleration. The target acceleration and deceleration are a function of current wheel speed and

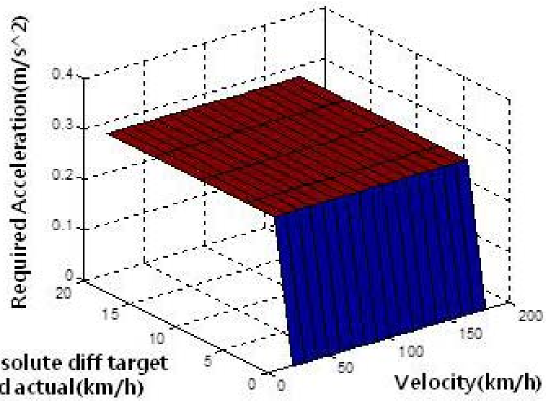

Fig. 3 Required acceleration function.

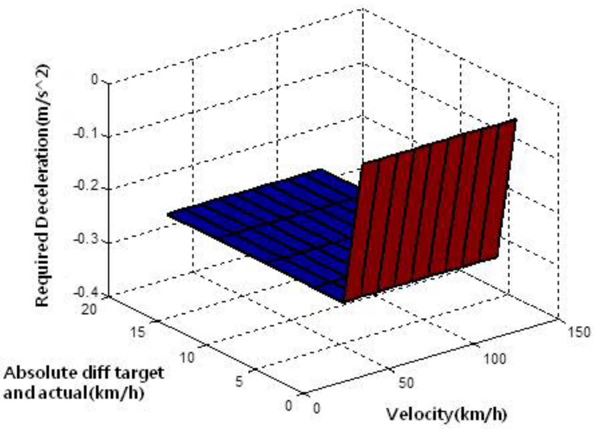

Fig. 4 Required deceleration function.

the absolute value of the difference between vehicle and target speed. These functions are subject to revision by the driving data after completion of one cycle of the simulation.

The above mentioned target acceleration or deceleration, is automatically generated if the target time is determined for two cases. Target time of acceleration means the time consumed by the vehicle to accelerate to 10kph. To obtain the required acceleration a formula is shown below, Eq. (1).

$$a_{req} = 20/3.6/t_{req} \tag{1}$$

Target required torque as a function of the required acceleration can be automatically tuned after generation of the driving data. Auto-tuning of the function of the required acceleration is made by comparing acceleration values of the driving data and required acceleration values.

4.2 Range of Vehicle Load for Auto-tuning

The affordable slope of the target vehicle, is calculated by vehicle dynamics required torque of the wheel. The value of the required acceleration generates the function of required acceleration.

The formula calculating the engine required torque from the wheel required torque makes use of the transmission gear ratios and the final gear ratio.

With formulas which are supposed to be solved for affordable slope, unknown parameter with putting the engine torque as maximum value according to engine speed [7]. Affordable driving slope is also calculated by the required acceleration of the vehicle to accelerate up to 10kph within 10seconds, and is obtained as shown in the Fig. 5.

Range of possible slope of the driving vehicle from 5th transmission gear is 4% to 5%. Therefore auto-tuning target slope is in the range of 0%~4%, and the auto-tuning of shift pattern makes the vehicle drive in 5th gear instead of 6th gear which means cruise driving of less than 4% of slope.

Slope information of the auto-tuning process is largest contributor to the required torque.

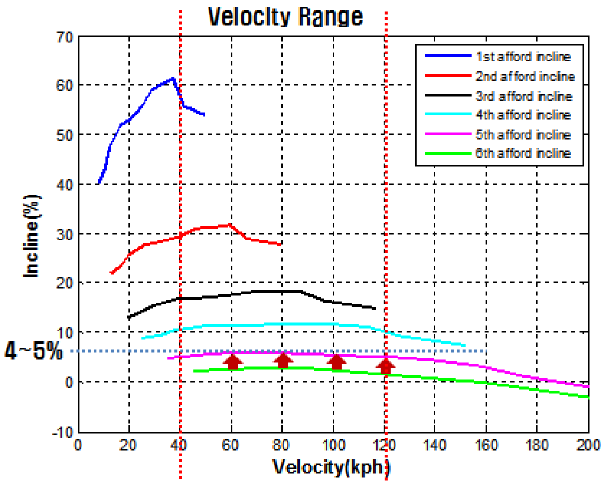

Fig. 5 Possible range of the slope.

5. Results and Conclusion

In this chapter the conclusion is explained by looking at the auto-tuning according to the simulation results.

Auto-tuning simulation was run in accordance with the scenario for acceleration, constant speed, and deceleration of the vehicle. The initial speed was 40kph and this is the minimum vehicle speed in a cruise mode of this target vehicle. The vehicle was accelerated up to 120 kph, which is considered to be the driving speed limit of cruise driving for this target vehicle.

5.1 Auto-tuning of the Shift Pattern

Auto-tuning of the shift pattern is divided into two cases which are situations of acceleration and constant speed. The situation of constant speed secures the transmission gear position and situation of acceleration has the aim to follow the target speed within the target time.

In particular, this means that 6th transmission gear driving of the large load is changed to 5th transmission gear driving.

5.1.1 Case of the Constant Velocity (Cycle 1)

Prior to auto-tuning of shift pattern, transmission gear number was changed in 50 kph speed section of constant velocity while after tuning shift pattern, gear number shifted in the range of 50kph -> 60kph acceleration in the Fig. 6. Operating points and tuned shift pattern are shown in the Fig. 7.

Target auto-tuning samples in blue dot lines are located in the area of 5th gear number before tuning shift-pattern, and 4th gear number after tuning target line. At the section of 50 kph constant speed, it prevents the shift to 5th gear in this manner. Target tuning pattern is a 4-5 Up-shift.

5.1.2 Acceleration (Cycle 2)

Acceleration of 100 kph -> 110 kph and then, 110 kph -> 120 kph, shows much longer acceleration time is needed than the reference time in the Fig. 8. Therefore, by tuning of the shift pattern for acceleration, the vehicle is able to be driven in 5th transmission gear.

Shift point timing is delayed from 5th gear to 6th gear as shown in the Fig. 9 after auto-tuning of shift pattern. Vehicle changed the transmission gear number

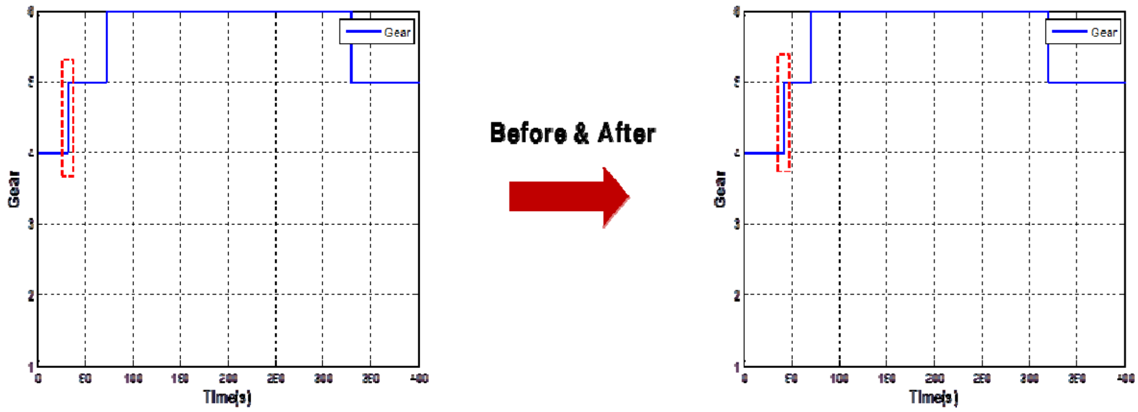

Fig. 6 Gear change through tuning of shift-pattern(Cycle 1).

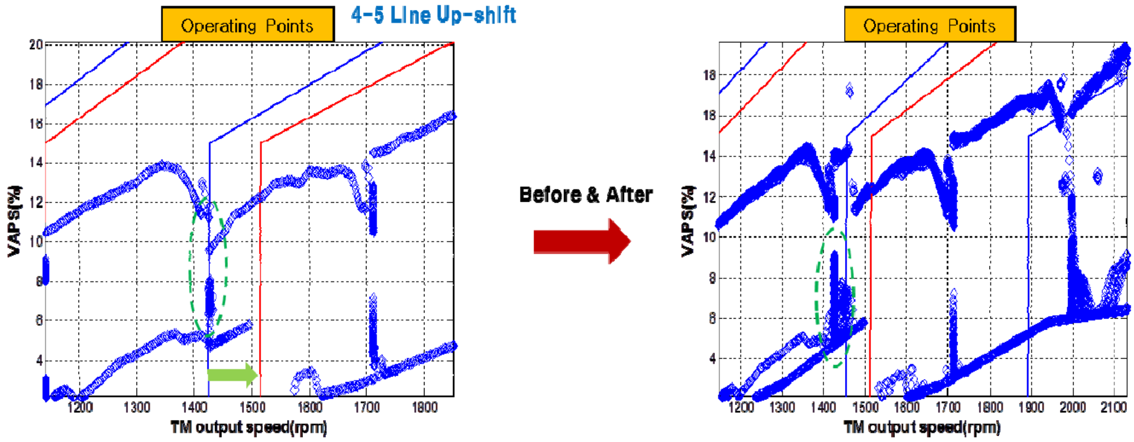

Fig. 7 Tuning of the shift pattern (Cycle 1).

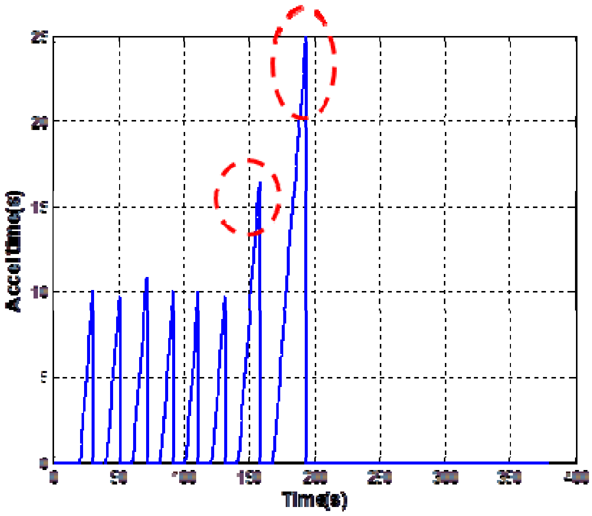

Fig. 8 Acceleration time before tuning (Cycle 2).

in the section of 90 kph -> 100 kph before tuning, while the vehicle changed the transmission gear number in the section of 110 kph -> 120 kph after auto-tuning.

The position of the target operating points in the red dot line of Fig. 10 is moved from 6th gear to 5th gear as a result of auto-tuning. It can be confirmed that the target tuning sample takes a large load in the acceleration at high speed by checking the engine torque and slope. The engine torque is applied to 100% of the engine speed and the engine speed exceeding the speed limit does not satisfy the reference time. It requires tuning of the transmission pattern. In other words, it is difficult section of acceleration to be driven as 6th gear number for 100 kph -> 120 kph.

5.2 Auto-tuning of the Required Acceleration

Fig. 11 shows acceleration time before auto-tuning of cycle 1. It means that acceleration time of simulation does not match for the reference time and auto-tuning process needs to be conducted. Auto-tuning of the required torque can be described as a modification of the required acceleration and deceleration values. After the virtual drive auto-tuning process increases the required acceleration in the interval corresponding to the higher acceleration time than the reference time by the end of iteration. In contrast, it decreases the required acceleration in the period in which the acceleration time is lower than the reference time. Fig. 12 shows the acceleration table of auto-tuning in cycle 1 and Fig. 13 is the acceleration time of simulation after auto-tuning.

5.3 Auto-Tuning of the Required Deceleration

It proceeds in the same manner as the auto-tuning of the required acceleration. Deceleration time before auto-tuning and deceleration table of after auto-tuning are shown in the Figs. 14 and 15.

Deceleration time after auto-tuning of cycle 1 and total simulation velocity are shown in the Figs. 16 and 17. It show both target speed and simulated vehicle speed in the cycle 1.

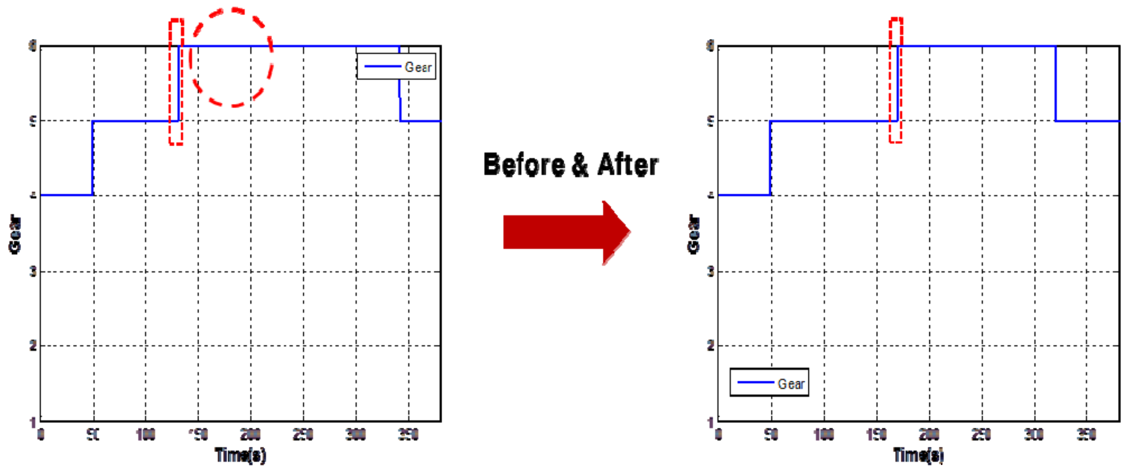

Fig. 9 Gear change through tuning of shift-pattern (Cycle 2).

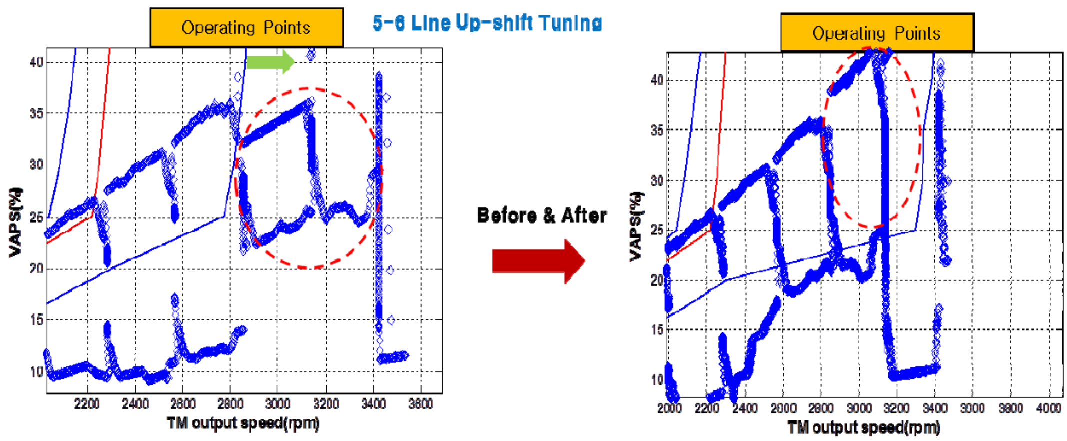

Fig. 10 Change of operating points (Cycle 2).

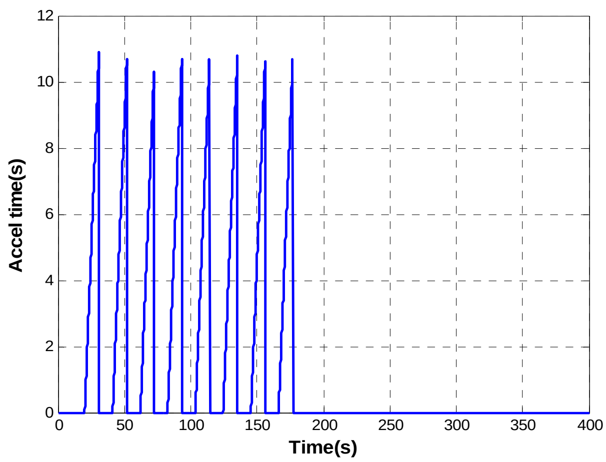

Fig. 11 Acceleration time before auto-tuning(Cycle 1).

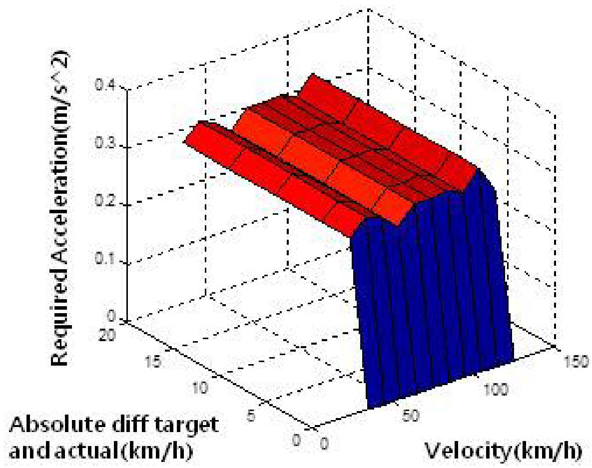

Fig. 12 Acceleration table of auto-tuning (Cycle 1).

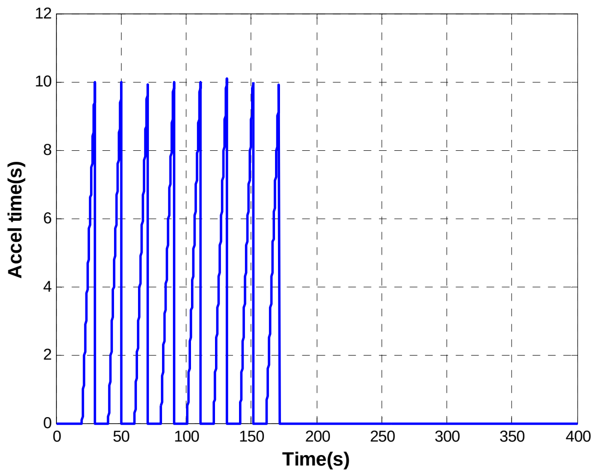

Fig. 13 Acceleration time after auto-tuning (Cycle 1).

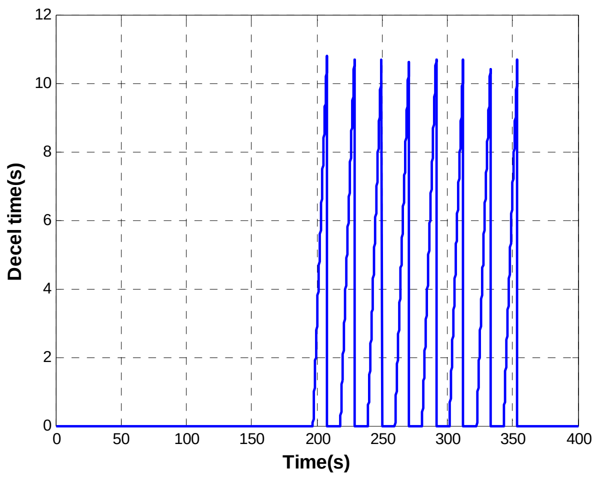

Fig. 14 Deceleration time before auto-tuning (Cycle 1).

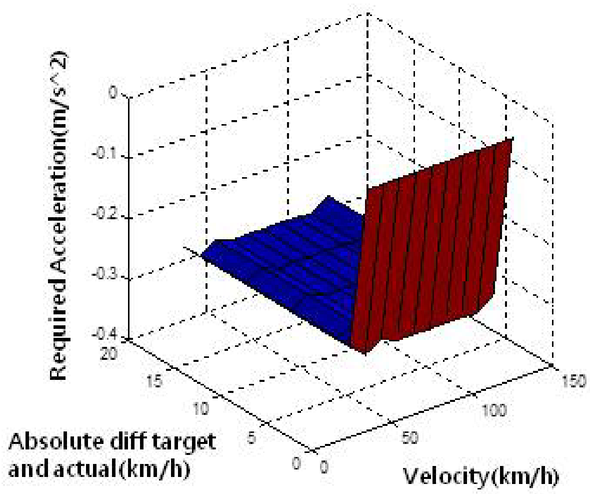

Fig. 15 Deceleration table of auto-tuning (Cycle 1).

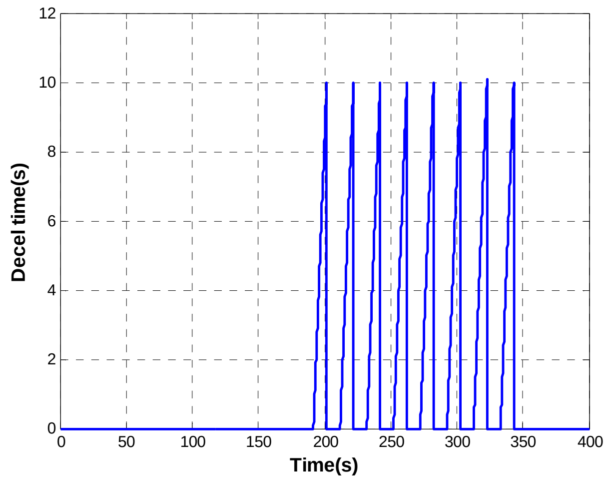

Fig. 16 Deceleration time after auto-tuning (Cycle 1).

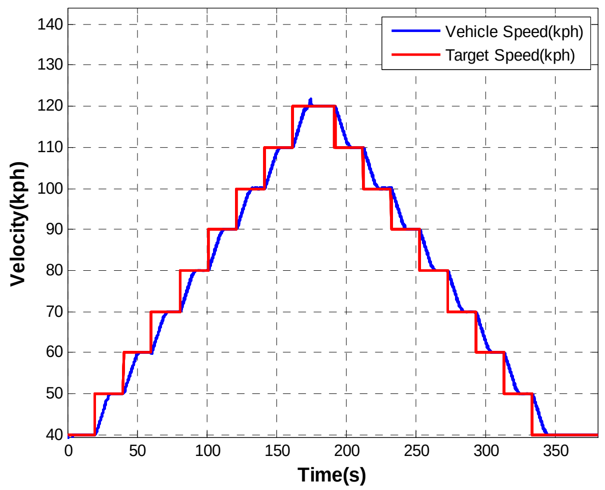

Fig. 17 Target and simulated velocity in the simulation (Cycle 1).

5.4 Solutions of Auto-Tuning

Change in the required acceleration table according to the driving data is as follows (Fig. 18). It can be seen that different driving cycles and auto-tuning in progress make the acceleration table converged. Drastical change in the driving environment is not detected.

Change in the required deceleration in accordance with the driving cycle are shown in the Fig. 19. It can also be seen that different driving cycles and auto-tuning process make the deceleration table converged. Even it shows less change compared to the acceleration

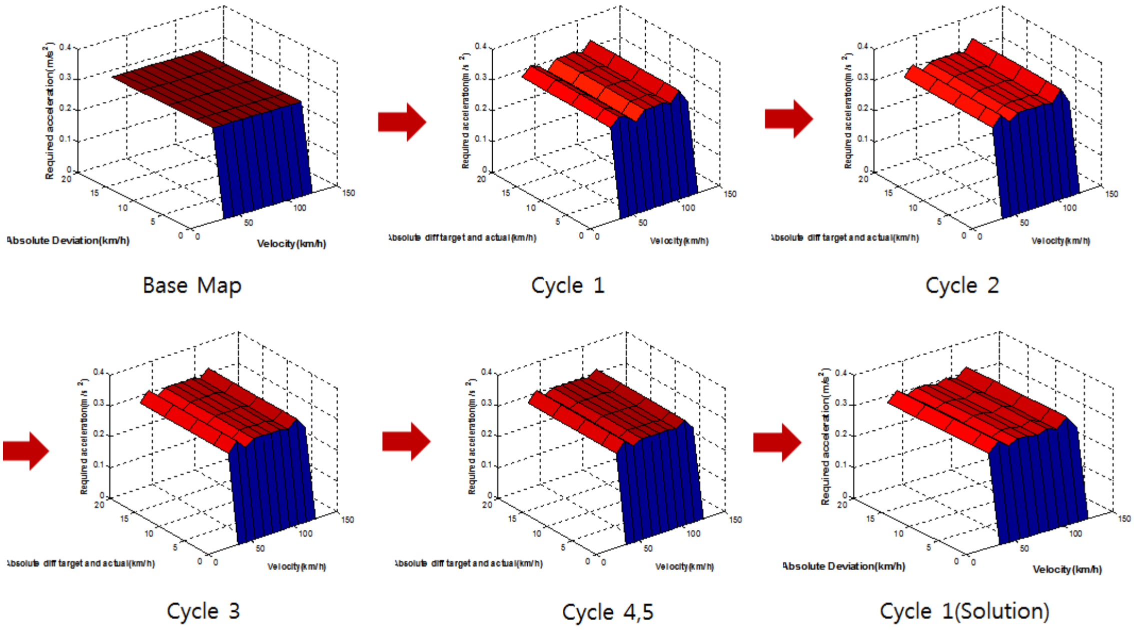

Fig. 18 Change of the required acceleration.

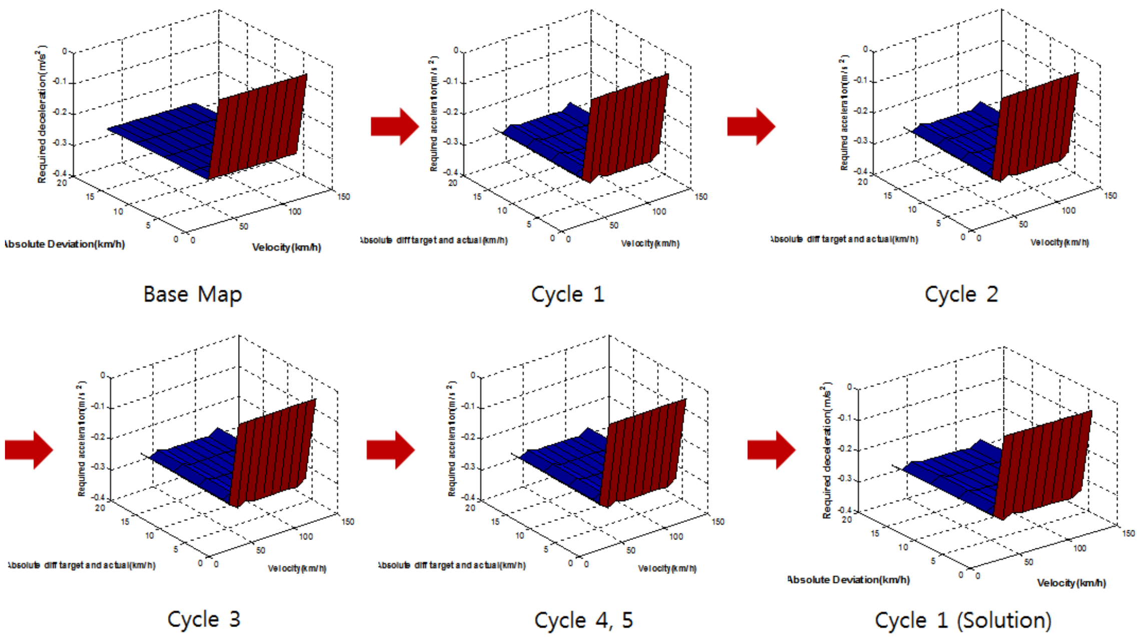

Fig. 19 Change of the required deceleration.

table. Drastical change in the driving cycle is not detected here either.

Change in the shift pattern in accordance with the driving cycle is as follows. There is tuning of 5-6 Up-shift line for the acceleration of high speed above 100kph in cycle 2 and cycle 4, also tuning of 4-5 Up-shift line for preventing shift in the section of constant velocity. The results reflected on shift pattern are shown below, Fig. 20.

Thus required acceleration, deceleration and the shift pattern applied to the cruise range of 0 ~ 4 % uphill can be obtained. The significance of this paper

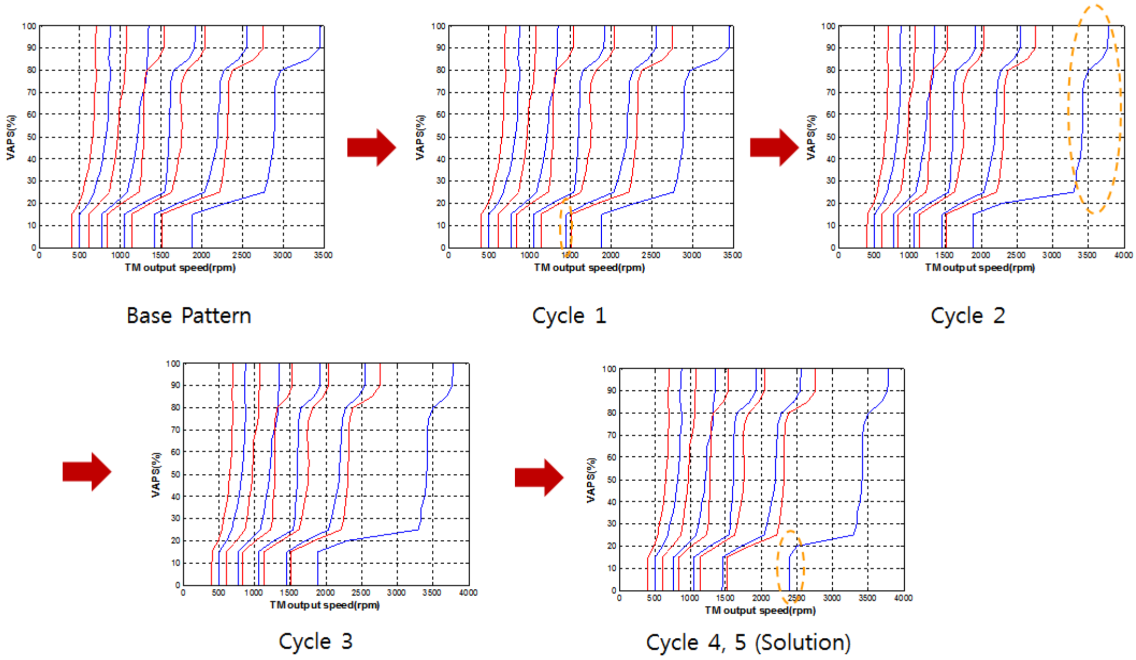

Fig. 20 Change of the shift pattern.

can be said to ensure the performance of the auto cruise vehicle driving over a virtual driving and automatic tuning thereof.

Acknowledgement

This research was financially supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science, ICT & Future Planning (MSIP) (No. 2009-0083495).

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