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주행 데이터를 활용한 오토 크루즈 차량의 변속 및 요구 토크 맵 자동 튜닝 기법에 관한 연구

Study on Auto-tuning of the Shift Pattern and Required Torque in the Auto Cruise Vehicle

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By

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ABSTRACT

Study on Auto−tuning of the Shift Pattern and Required Torque in the Auto Cruise Vehicle

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The operation to evaluate the performance of the vehicle and hence to tune the parameters is made by hand by an engineer in charge of the test vehicle. However, it has the disadvantage that is time consuming and expensive. To compensate for this, this paper studied the automated tuning of parameters. The target vehicle is a vehicle operated by an engine with auto cruise function for tracking a target speed. First, the power train simulator which was verified by the actual driving was made by MATLAB software. For calculating a target speed the power train simulator receives the switch signal and it calculates the required torque accompanying the speed change stage which is designated by calculation based application and also simplified map based application. The shift speed is generally the auto cruise function of parameters of the

vehicle wheel speed and the throttle opening degree. A new concept of the vehicle is introduced for the shift pattern, so it is important to keep tracking the target speed, the virtual throttle opening. When the simulation is performed, the target performance data of running the simulator are analyzed and it modifies the required torque and the shift map accordingly. The modified parameters are re−applied to the vehicle which is driven in the virtual environment. This process is repeated until satisfying the required performance. This iterative algorithm is built based on the theory of multi−disciplinary design optimization from the technology management theory. The theory is a feedback process to correct the input of design parameters of the system until the configured objective function satisfying the target performance or the output variable. Performance targets are sure to meet the target time during deceleration of the vehicle, constant torque fluctuation which is not severe, increase or decrease of fuel consumption, engine performance and drivability, such as, fuel efficiency, and the like. The correction of the required torque is determined according to the method applied constant speed, acceleration, From the data according to the running of the simulation, the constant speed drive range is applicable for strategies to fix the gear stage in order to minimize the fluctuation of the torque applied to the engine. For driving period of the acceleration and deceleration, required acceleration functions are adjusted to be applied to the calculated torque demand to meet the target time to reach the target speed. Correction of the transmission pattern is to extract a sample from the constant speed and acceleration data, the process proceeds to driving tuning for each sample. And selecting the first tuning target patterns in each sample and determine the number of stages accordingly. To review the correction, samples are investigated whether the traction-load and driving distance conditions are satisfied. It is not to proceed with the tuning for the sample if the target pattern does not meet the condition. Repeated analysis of the auto-tuning is conducted from the driving data. It can be seen that the vehicle meets the performance. Consequently, engineers automatically tune parameters from computers instead of manually tuning parameters which can be satisfied with vehicle performance expecting increase convenience as the good effect.

Key words : Auto Cruise Vehicle, Virtual Throttle Opening, Multidisciplinary Design Optimization Theory, Automatic Tuning, Shift Patterns, Required Acceleration Function.

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CHAPTER 1 INTRODUCTION

1.1 Motivation

Drivers of vehicle undergo various tough situations in approaching the long drive. It must bring a pain in muscles due to equivalent posture and drivers continue to feel the pain in the ankle while pressing brake and accelerator repeatedly. To overcome this situation, auto cruise control is introduced to automotive manufacturing field. Auto cruise control system means an electronic automatic cruise control system. When vehicle drivers operate switches to set the desired constant speed, auto cruise control system maintains its speed without stepping on the accelerator. [1] This system which has been essential function for drivers significantly reduces the fatigue of them who are burden for long-distance driving. Recently, more advanced cruise control system appeared one after another.

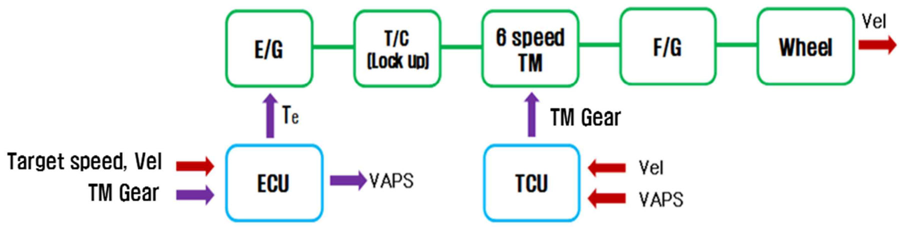

Figure 1.1 Powertrain structure of Auto-cruise vehicle.

The target vehicle of this study contains an engine and six-speed transmission as shown in the diagram above, the engine torque, the shift speed for tracking and maintaining the target speed are calculated from the controller. Unlike normal vehicles, it has a switch for setting a target speed and drivers can increase or reduce the target speed through the one. In general vehicle, if there is a desired speed, the driver can adjust throttle value in order to maintain. The required engine torque can be obtained through the engine map data, throttle and the engine speed, then this is applied to the engine. Since the shift map is a function of the driver throttle and vehicle speed, the transmission gear applied to the transmission is calculated by both of them. The normal engine vehicle follows and keeps the target speed manually through the throttle, which is the driver's will.

However, in the case of auto-cruise vehicle, transmission gear and required torque calculated by vehicle controller so as to follow the target speed are applied to the powertrain excluding intention of the driver. This is the system for maintaining and following target speed set by drivers in any of the road load. Therefore, there is no meaning of the engine data which is represented by the throttle and the engine speed in the cruise vehicle, the shift pattern is a function of the throttle of the cruise condition and not a function of the actual throttle. This will be described in further detail in Chapter 2. The figure below is an illustration comparing the general driving andcruise driving.

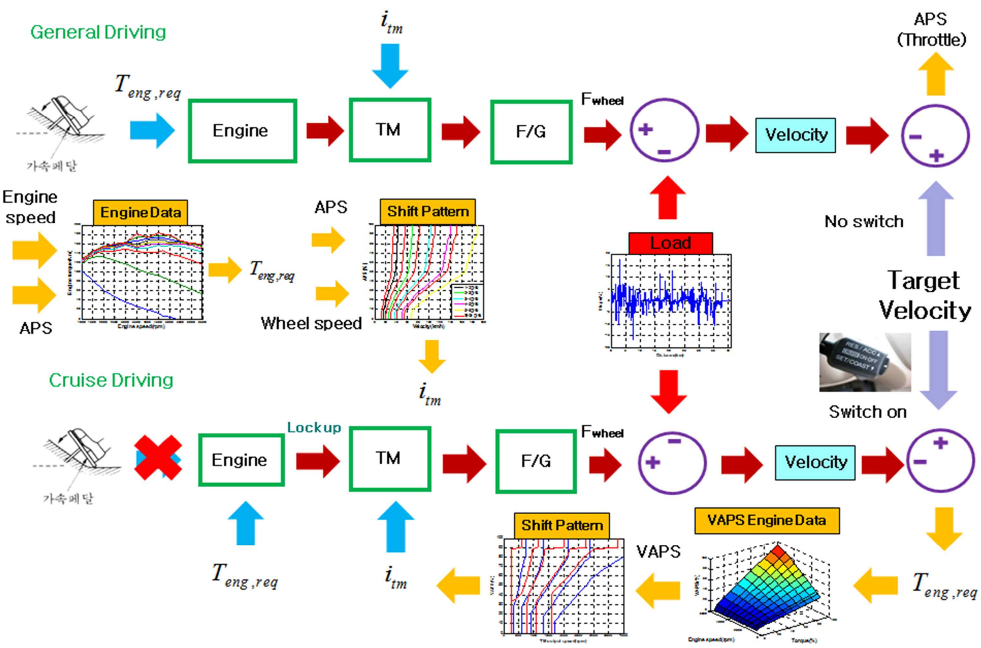

Figure 1.2 Comparison of General and Cruise Driving

Those auto cruise vehicles are tested to modify the applied torque and the shift schedule to ensure the power performance before the mass production. When confirming the driving data in the following figure, it is divided by the velocity data in the auto cruise vehicle such as acceleration, deceleration, constant speed section. First, an important requirement of the cruise driving is to maintain the target speed. Therefore, the transmission gear remains an important objective to maintain the target speed. In order to prevent the busy−shift or fix the gear number in the constant speed section, shift pattern needs to be tuned. And in the period of acceleration and deceleration, tuning the required torque is conducted. Tuning of the shift−pattern also needs to be conducted for the special case, because it is advantageous that when the torque of 100% or more of the required torque is calculated for driving acceleration. In this case the timing of up−shift must be later than tuning before. In the deceleration section, tuning of the required torque can satisfy target time with simulation time.

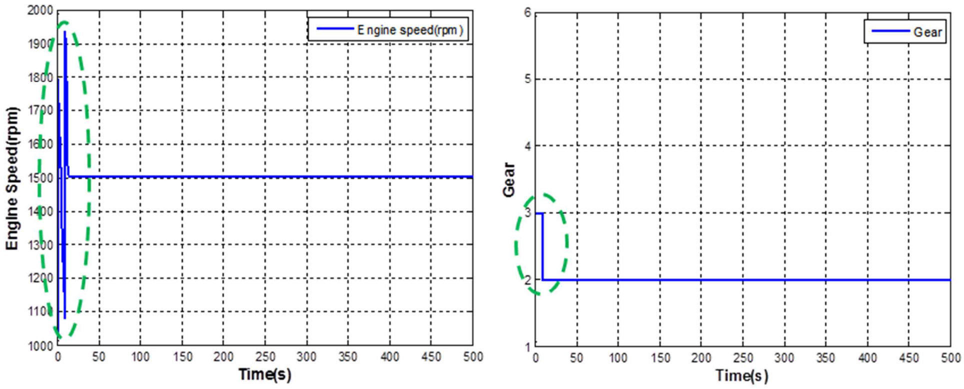

Figure 1.3 Situation of Auto−tuning Shift Pattern

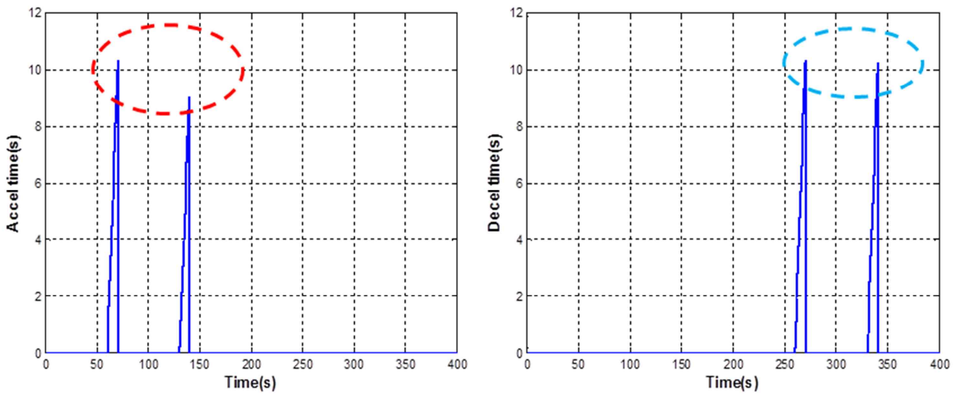

Figure 1.4 Situation of Auto−tuning Required Torque

There are three reasons of the purpose of tuning the parameters taken together the above figures. It follows the target speed by the switch setting and follow-up the target speed in the target time and eliminates the hunting or busy-shift phenomenon in the constant speed section.

However, this modification is currently done by handmade procedure consuming a lot of time and cost. It also accumulates fatigue of the engineers conducting the modification.

Switching from manual tuning to the automatic tuning is to solve this problem. In addition, to there are three effects of the automatic tuning as follows: This rapid response can be the first. When driving data has occurred computer analyzes it to implement the automatic tuning.

The second is quantitative solutions. Auto-tuning of those parameters has the purpose to get solutions for tracking and maintaining of the target speed. Finally, to save time and money is one of the advantages.

Therefore, the manual tuning needs automation and this study is to verify the time and cost savings associated with the automation process, the consequences.

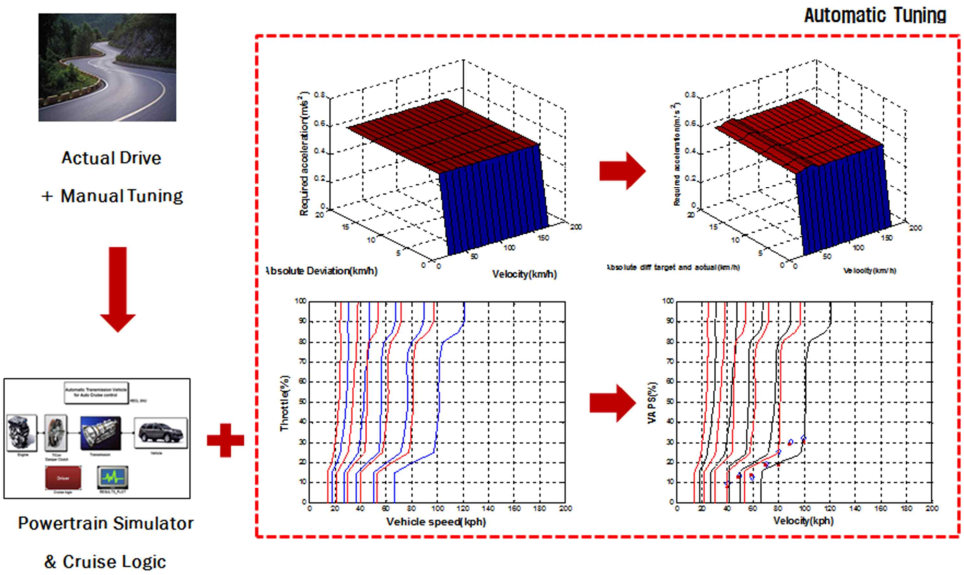

Figure 1.5 Conversion from Manual Tuning to Auto Tuning Process

In this study, conversion of the actual driving and manual tuning as shown in the figure to virtual drive with automatic tuning is major research.

1.2 Literature Review

The study using some control models to follow the target speed of the vehicle has been much progress all over the world. Typically PID model has to simulate the running of the auto cruise vehicle. [4] PID stands for proportional−integral−derivative, which refers to a control−loop feedback mechanism. It is widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point. This controller attempts to minimize the error by adjusting the process through use of a manipulated variable.[5]

In this vehicle it is a basic concept that the degree of throttle opening corresponding to the target data rate by the PID is calculated first and when it is input to the engine data, engine required torque which is the output is calculated. And by calculating the error between the target speed and the current vehicle speed throttle or brake signal is also calculated.

Recently, a study was carried out actively in the vehicle to recognize distance intervals of the car ahead. [6−7]This is called the smart cruise control and the basic concept of the vehicle is adjusted to the required torque, taking into account the distance to the car ahead while following the target speed. These days the auto cruise vehicle production is mostly smart cruise vehicle like this. This post−graduate study in laboratory has been actively conducted.

But because of expensive vehicle, testing environment which is not enough available for graduate students creating a model car study was conducted on behalf of the real driving.[8-9] The car model was also utilized by the stop and go strategy to be used in the power distribution required in the hybrid vehicle. [10]

Smart cruise function is closely related also with unmanned autonomous research. Recognizing the lane by using the sensor for measuring the distance to the car ahead has the ability to prevent it leaving the route. It is one of the study objects as the vehicle function.[11] It is also possible to improve the drivability. In addition, studies also can be performed by analyzing the driving tendency of the driver which is applied to the vehicle.[12-14] A virtual environment that can be played in the computer for driving the vehicle is created by the operator to analyze the drive-ability. This study on the basis of this analysis is conducted for a more efficient driving system, And some researches consider the characteristics of those cities which were carried traffic.[15] In this case, this study was conducted to consider the moment after the distance to the car ahead and replaced lane as well.

The ability to follow the target speed has been applied in green vehicles, such as hybrid vehicles, electric vehicles which are not applied only to the engine vehicle. The hybrid vehicle has an automatic cruise function which is implemented through the method of the convergence of the slide mode variables to zero for robust control.[16] And the target speed tracking simulation was conducted by PID control in electric vehicles.[17] Thus the auto cruise function for tracking and maintaining the target speed is applied all over the world and become a subject of study.

However, additional researches using other control models have been conducted to complement the PID which is visible weaknesses regarding the disturbance.

There is a speed change taking place in the constant speed during driving condition of the vehicle severely because of the characteristics of a PID. For this reason, some cases of using the model to compensate PID have been conducted while other studies were conducted by the completely alternative model. One of the typical models that complement the PID is the fuzzy theory. The basic concept of fuzzy logic theory from each of the target binary does belong to any meeting or part, each subject can be expressed mathematically by representing the function belonging to the extent that belong to that meeting(membership function).[18-19] It claims that everything is a matter of degree. Two or more principles of fuzzy probably indicate that the spectrum is no unlimited choice. This principle which is not in binary rather refers to the infinite density of gray between black and white. [20-22]

Learning control method for analyzing the driving data to take advantage of these characteristics have been utilized in an analog study.[23] In addition, many studies were carried out which can take the place of the PID.

Typically there is a follow-up study on the cruise and maintenance of the vehicle speed using linear quadratic model.[24-26] However, these studies did not look much progress to show the limitations applicable to the vehicle. Additionally, studies on tuning parameters closely to the topic of this study are increasingly conducted because such controllers do not fully guarantee the power performance and drivability to follow and maintain the target speed. About the subject of tuning parameters, studies on the throttle opening and the gain value of vehicle cruise controller have been much made.

Early 1990s, a lot of research was done on the adjustment of the throttle and the brakes, because the operation is required to adjust the torque to follow the target speed.[27] However, since the PID control models were introduced for following the target speed, this tuning method of those controllers has been utilized a lot. Throttle and brake compensation for Research in the 21st Century was held stepping Artificial Neural Networks(ANN).[28] And a lot of that research was conducted to calibrate the Gain value of the PID.[29-31] This was a great help in terms of reducing the speed fluctuation in target cruise speed. However, it had to take a different approach for reaching the target time of acceleration and deceleration, reducing torque fluctuation. The studies about fuzzy controller tuning out parameters were in progress,[32]the study about using the Karman filter which is one of the recursive filters tracking the state of a linear dynamical systems including noise also was performed to reduce the variations in the vehicle speed.[33] Similar research is a study on the introduction of a disturbance observer of the PID controller.[34-35] However, studies to follow the target speed by PID control models were validated with most simulations and the number of studies comparing torque applied to the power source of the actual vehicle test, the engine speed, the transmission gear stage is rare. It means that PID does not ensure exact information of the traction source. Thus, this study will be avoided by the introduction of a PID controller model which is not the power performance measurements of the performance variables. And the target of the tuning parameters is to introduce a required torque and the shift schedule. Two variables are also the manual tuning parameters by engineers. A lot of research has not been conducted about both tuning parameters. It means that the study to correct the engine torque and the shift schedule at the same time has not been built.

Multi-disciplinary Design Optimization study was much conducted in the aviation sector.[36] Because of the various hardware design optimization theory was applied to the vehicle. MDO which is applied to the hyper cruise vehicle[37-38] has been also utilized to design vehicle doors.[39]Some studies were conducted as to minimize the noise and vibration of the vehicle. There is a study considering Noise, Vibration, Harshness (NVH)of the body design,[40]some studies also conducted a door designed considering crashes there were.[41] The suspension device study including a damper, spring or the like was also conducted by several researches on the design.[42-43] Mainly the design research has been conducted on the MDO in the automotive sector as well as the progress of the engine design.[44] A variety of vehicle types such as the passenger car has been studied by MDO showing much progress.[45] Thus, the present study came to be applied to the actual hardware, this study also applies it to the software to optimize the process of automatic tuning parameters because the feedback process of the MDO is similar to the process of the manual tuning and can be intuitively recognized by engineers for reaching an optimized results.

For the correction of the transmission gear position previously mentioned study has been in progress. A research analyzes the shifting trends based on probability theory and neural networks,[46-47] another study taking advantage of the Artificial Neural Network(ANN) used for throttle and brake control was conducted as an analysis of the shifting trends.[48]One of the optimal theories, dynamic programming which is not applicable to the vehicle also on the fuel consumption and the exhaust emission being set in the objective function of the vehicle was carried out.[49] The analysis of the dynamic programming from the driving data calculates the optimum gear range. However, optimal control, including dynamic programming and pontryagin's minimum principle is not applicable for real-time driving. It is used as a theoretical analysis when the travel data is output as a vehicle.

Other studies were conducted with Bi-variate process of two variables and utilizing ANN to analyze the shift pattern,[50] and a study of the fuzzy expert system utilizing a neural network structure was conducted to analyze the shift pattern.[51-52] There were also some researches on the automatic generation, this paper takes advantage of the vehicle free acceleration due to traction force and its wheel load.[53] The research which engineers supported to determine the shift point manually was conducted .

In addition studies selecting the optimum shift pattern through simulated vehicle driving simulation including the fuel, the acceleration performance tests were conducted,[54] a study considering the shift pattern for a hybrid vehicle as a power mode to consider the traction performance, fuel economy mode to consider fuel consumption quantity was conducted.[55] However, these studies are to determine the shift point in the current driving state of the vehicle in most cases. Research to modify lines of the shift pattern itself is not much progressed. In this paper, this study modifying shift pattern for leading to compensation lack of studies is conducted by extracting a sample of driving data and conducting other procedures.

The other study of auto cruise vehicles following the target speed considers the fuel consumption, [56] it is on the Lock-up clutch strategy considering the fuel efficiency.[57]And there is a study on Multi-Domain Modeling and Simulation of Clutch Actuation System,[58] also a study on the development of removing synchromesh elements, in addition to the two ring gears as shifting gears reduces shift shock.

1.3 Research Objectives and Expected Results

The aim of auto−tuning is reduced time and cost to overcome wasting them from the handmade procedure for tuning design parameters.

In addition, improving the power performance of the vehicle, as well as the fuel efficiency and drive−ability is the main goal of the auto−tuning. In the power performance of the vehicle acceleration the goal is to reduce the acceleration, deceleration time and during a constant speed within the target time, the goal is to minimize the torque variation. And the final goal is to maximize the overall drive−ability including reduction of fuel consumption at a constant speed through tuning of the shift.

Before the evaluation of automatic tuning performance, the powertrain simulator should check how well reflect the actual situation. Comparing the situation of the actual driving situation and driving simulator is to check the engine speed, torque, gear position, vehicle speed and etc. And it says that the results of the two situations are similar each other then the auto−tuning process should be introduced.

CHAPTER 2 ANALYSIS OF THE AUTO-CRUISE SYSTEM

A simulator of the auto cruise vehicle power train is divided into two parts. Powertrain modules that simulate the hardware, and Cruise logic simulation simulating software. Power train module is divided into four parts, those are engine, torque converter, the transmission, wheels. Cruise logic has a function of following and maintaining the vehicle the target speed. The role of the cruise logic calculates the target speed and the requested torque, the required gear stage through a switch signal. In addition also it has the function of the overriding signals and speed limiter functions. And power train simulator validation results are required in actual driving. This chapter will introduce features of the vehicle power train simulator and the results of the validation of the simulator with actual driving situation.

2.1 The Target System and Simulator Analysis

The target vehicle is a vehicle operated by an engine including a 6-speed automatic transmission. During the cruise mode the required torque and gear position tracking is computed for accurate target speed. The vehicle is on lock-up state without any effect of the torque converter. This state is the direct axle connection from the engine and to transmission which is advantageous in fuel efficiency improvement. The table 2.1 shows the specifications of the target vehicle.

Table 2.1 Target Vehicle Specifications

Specification	Value
Vehicle Mass (kg, +2 up)	1410
Frontal Area (m^2)	2.21
Final Gear Ratio	3.27
Tire Radius (m)	0.304
Gravity (m/s^2)	9.81
Air Density (kg/m^3)	1.204
Engine Inertia (kg m^2)	0.074
Turbine Inertia (kg m^2)	0.029
Impeller Inertia (kg m^2)	0.065
Air Drag Coefficient	0.292
Power-Train Efficiency(%)	90

Rolling resistance coefficient and the drag coefficient is to be obtained through the coasting down data of vehicle speed in Chapter 4.These two factors are the most accurate when it would be obtained through a vehicle testing. It is to accept that the reference value can recall a large error in obtaining the required torque values.

The simulator created by MATLAB Simulink consists of a power train model 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. Power train model and the cruise logic are design elements as separate systems against the automatic tuning program in the field of optimal design theory. The auto−tuning program automates the manual tuning after that engineers analyze the driving data.

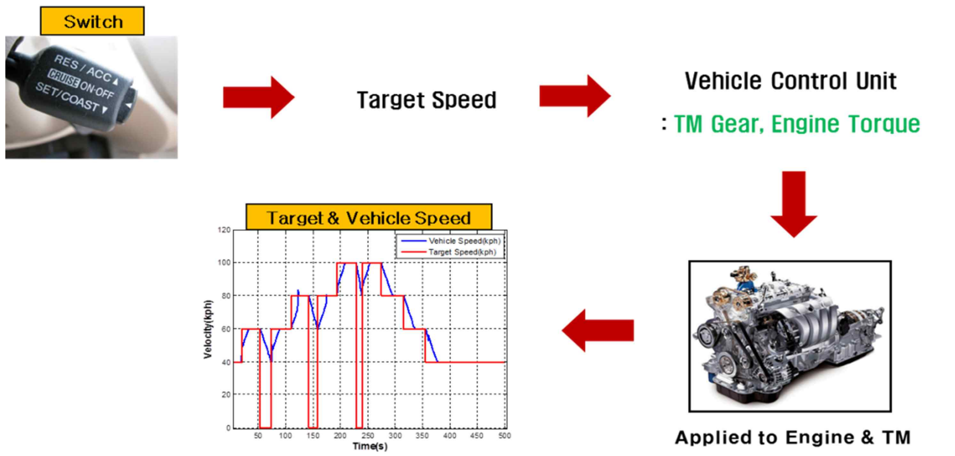

Figure 2.1 Operating Principle of Auto−cruise Vehicle Powertrain

2.2 Power Train Model

Power train of a vehicle simulator is divided into four modules largely that are the engine, the torque converter, transmission, tires. Engine module, which has the engine inertia value and required torque as the input has output parameters of the engine speed, transmitted torque to the torque converter module. Impeller and turbine inertia values are entered into torque converter module which has torque of the engine side as the input, a rotational speed and torque of the transmission side as outputs. For the correct calculation of the torque to follow the target speed the power train is on lock−up state, that is, the engine−side and transmission−side torque are the same. The transmission module has a 6−gear ratio values, which corresponds to a torque ratio. Torque from the torque converter side is as the input, and the torque and the rotational speed is transmitted to the wheel as outputs. The wheel module receives the torque transmitted from the transmission module, and wheel rotational speed, the linear speed are outputs. This module also calculates the load, which is considered to be accompanied by the engine required torque demand via the feedback. Cruise logic of the software and the vehicle powertrain model of the hardware for the powertrain simulator are shown in the figure below.

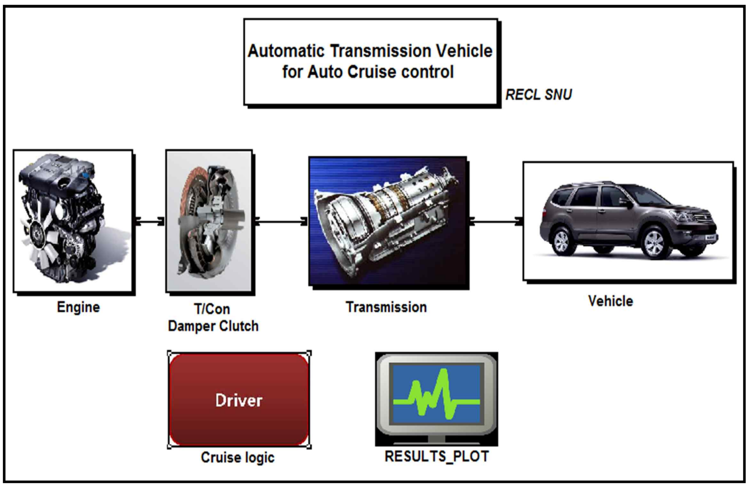

Figure 2.2Power Train Simulator of the Auto Cruise Vehicle

2.3 Cruise Logic

Cruise controller logic is an implementation of the software for the vehicle to follow and maintain the target speed of the target vehicle. It can calculate the throttle opening degree which is used for the shift pattern, the target speed, the required acceleration and the requested torque after receiving the switch signals. In addition, it is also possible to implement override signal and the speed limiter function.

2.3.1 Switch Operations

There are four types of buttons and switches that determine target speed for auto−cruise vehicles: Main switch, Resume/Acceleration, Cancel, and Set/Coast alternate among the main switch mode, vehicle acceleration, canceling acceleration, and deceleration. The figure 2.3 below shows target speed signal switches of the auto cruise vehicle.

Figure 2.3 Switch Buttons of the Auto Cruise Vehicle

If the main switch is on, the cruise mode to chase target speed is also on. The drivers need to press the Set/Coast button to make the target speed the current speed. Drivers also have options for setting the target speed between S/C and R/A. When a driver presses the S/C button for a short time, the target speed decreases by 1kph. In contrast, the target speed increases by 1kph when quickly pressing the R/A button. When the vehicle accelerates to the target speed, a driver can press the cancel button to cancel acceleration. However, it remembers the target speed of the acceleration. After cancellation, drivers have the option of pressing the R/A or S/C buttons again. If the drivers press the R/A button after cancellation, the vehicle remembers the target speed (Resume). However, if drivers press the S/C button after cancellation, the target speed is set as the current vehicle speed. Canceling does not mean the cruise mode is "off". The main switch set as 'off' means that the vehicle does not follow the target speed and that no target speed remains in the target speed mode algorithm.

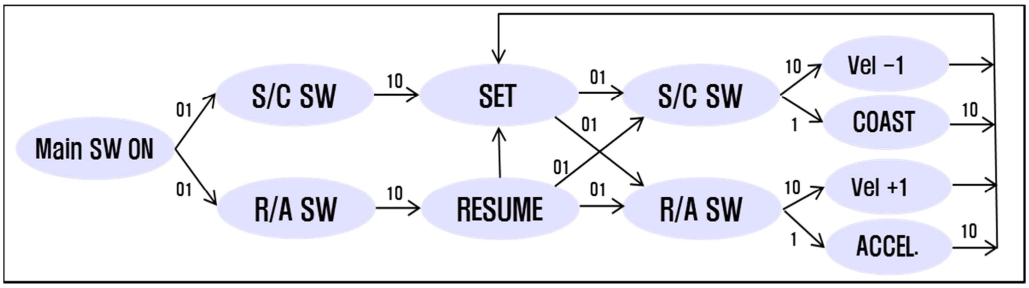

Figure 2.4 Flow Chart of the Switch Signals.

2.3.2 The Throttle Opening in the Auto Cruise Vehicle

Transmissiongear is configured as a function of the throttle opening and the vehicle speed. However, the throttle opening in the auto cruise vehicle has a different concept from a general vehicle. In general, the throttle opening degree is determined according to the accelerator pedal by the driver's request value, but the throttle opening in the auto cruise is determined by the engine required torque and engine speed calculated before. That is, only when the gear position is determined by the shift schedule the throttle opening is utilized. This is a concept introduced to the vehicle because of the characteristics to achieve the target speed in the target holding time. Auto cruise throttle map consisting of a function of the engine torque and speed are as follows. This is called a virtual throttle opening.

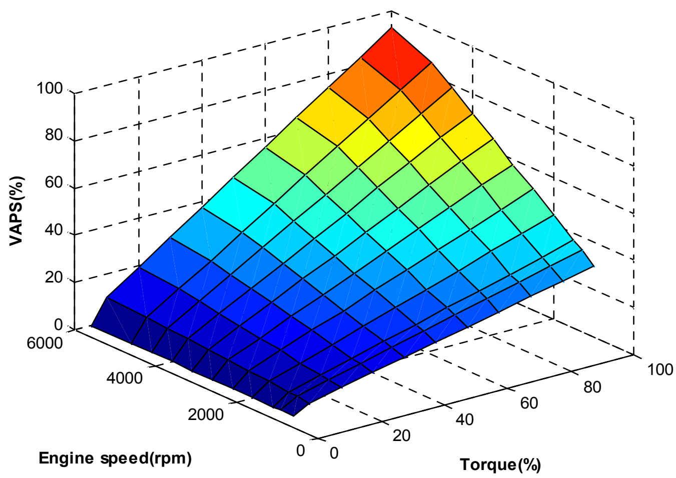

Figure 2.5 Virtual Throttle Data

Virtual throttle is usually shown as a function of engine speed and torque. Figure 2.5 is shown as a percentage torque relatively to the maximum torque for each engine speed instead of the unit Nm.

$$T_{eng,per} = \frac{T_{eng,req}}{T_{\max}} \times 100 \qquad (2.1)$$

Virtual throttle data is used upside down with the axis of the basic engine data. In this sense virtual throttle data is equal to the engine map. However, engineers may adjust the shift point by changing the number of virtual throttle after the vehicle is driving because it is a function of the transmission pattern. That is, the virtual throttle can be seen that only the function related to the transmission. This is different conception from throttle opening of the general vehicle.

$$Thr_{vir} = f(\omega_{eng}, T_{eng,per}) \tag{2.2}$$

$$i_{tm} = f(Thr_{vir}, v) \tag{2.3}$$

2.3.3 Over−ride Signal

Over−ride signal means that the cruise vehicle is under operated due to the drivers' demand torque. The required torque is supposed to be calculated by the simulator when chasing a target speed. However, if a driver steps on the acceleration pedal for a while to satisfy the condition between driver demand and calculated torque, the driver demand torque is actually applied to the engine.

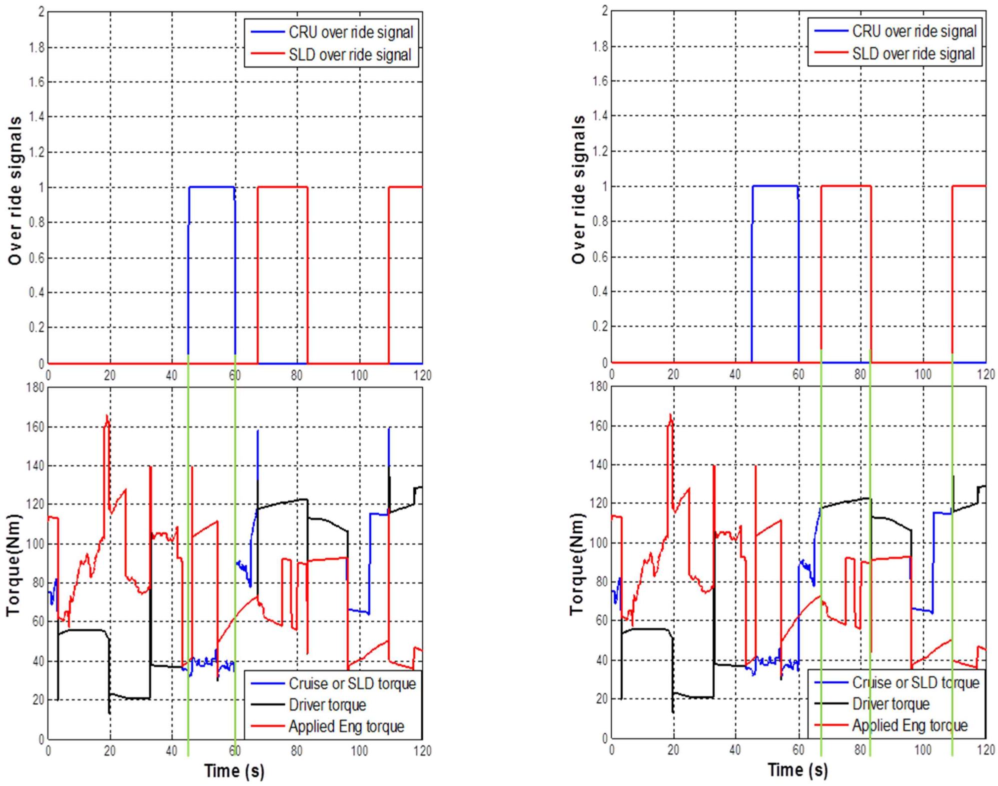

Figure 2.6 Over−ride signals

In the Figure 2.6over−ride signal simulation results are checked in the cruise mode following target speed and safe mode of the speed limiter functions. It compares the driver's requested torque and the required torque calculated by the computer and a signal is generated. And the formula is shown below.

$$T_{driver,req} >= T_{eng,req} + T_{eng,req} \times c_{hys} / 100 \qquad (2.4)$$

2.3.4 Speed Limiter Function

The speed limiter function limits the vehicle speed for safety. It is a governor used to limit the top speed of a vehicle. For some vehicle classes and in some jurisdictions, they are statutory requirement. For some other vehicles, the manufacturer provides a non-statutory system that can be fixed or programmed by the driver. Many countries now apply safety laws on vehicles to limit speeds, especially in Europe. The target speed setting of the speed limiter has equivalent target speed modes.

2.4 Verification of the Power Train Simulator

The required torque calculation needs to be compared to the actual applied engine torque. Figure 2.7 shows the actual driving test by the power train simulator of the auto cruise vehicle. It shows the actual driving results of cruise switch, engine torque, transmission gear, vehicle speed. When the vehicle speed data is to the reference it can be confirmed that the vehicle follows the target speed by the power train simulator very well.

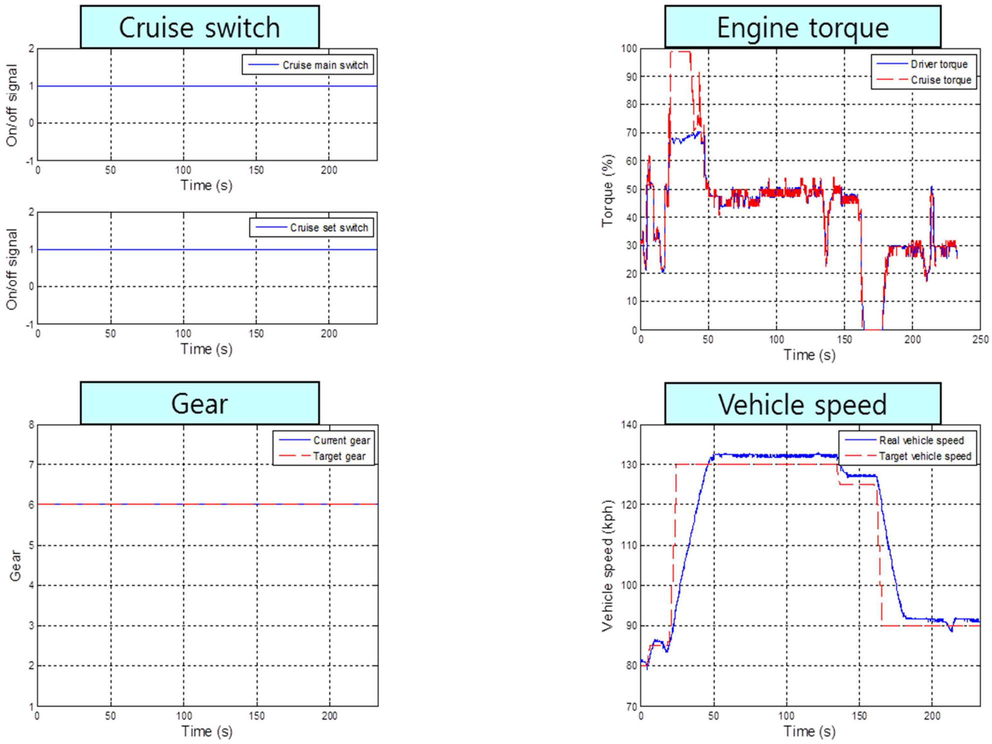

Figure 2.7 Actual Driving Test by the Power Train Simulator.

However, the applied engine torque is not measured directly in most cases so it must be from engine speed and throttle positioning data. The engine torque is to be obtained through the virtual throttle data. When engine torque of driving is applied to this power train simulator the engine speed and wheel speed are calculated. These values are compared to the results of actual driving condition. The powertrain simulator was verified by considering the situation of the vehicle acceleration and the constant speed. The verification process is shown in the figure below.

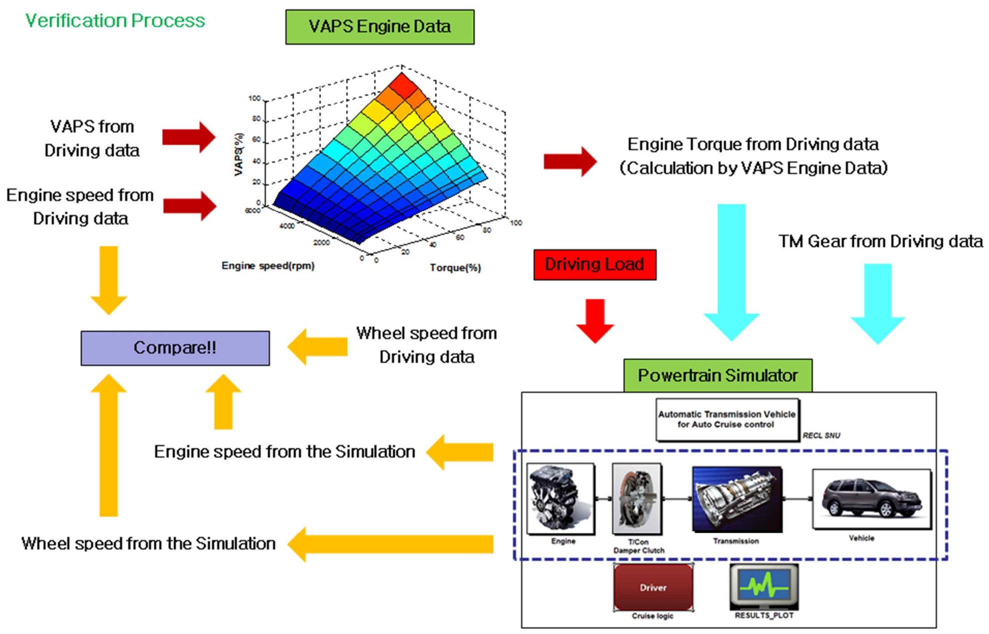

Figure 2.8 Verification Process

Road slope and measured VAPS in both situations of constant velocity and acceleration are shown in the figure below.

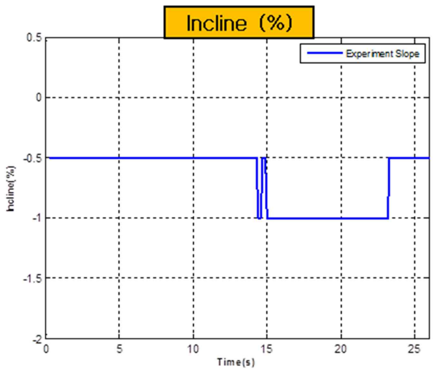

Figure 2.9 Incline of Constant Velocity Driving

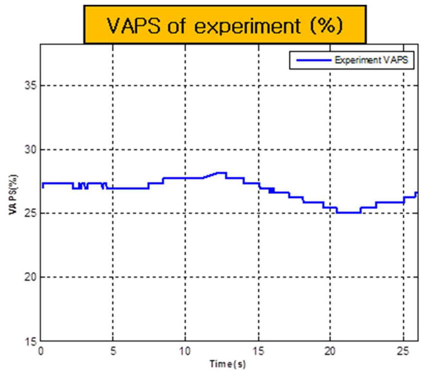

Figure 2.10 VAPS of Constant Velocity Driving

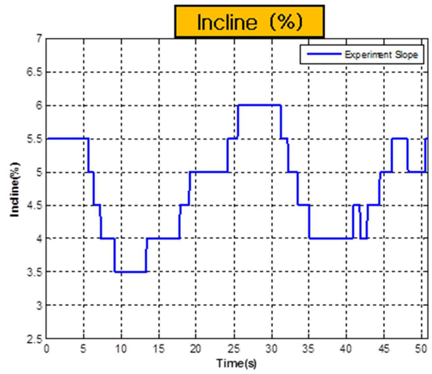

Figure 2.11 Incline of Acceleration

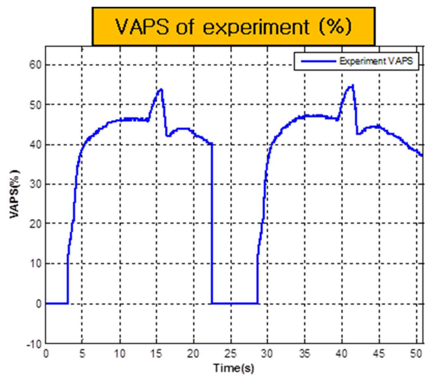

Figure 2.12 VAPS of Acceleration

VAPS has constant flow conditions in the constant speed while having a rapidly increasing current in an acceleration situation. This data can be converted into the engine torque by using VAPS engine data. As mentioned earlier, the VAPS engine data is a function of engine speed and torque.

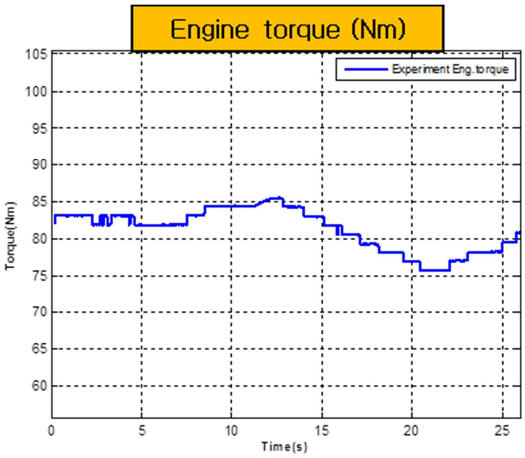

Figure 2.13 Engine Torque in the Case of Constant Velocity Driving

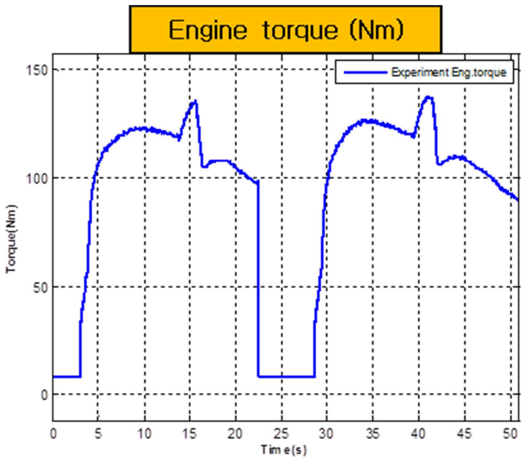

Figure 2.14 Engine Torque in the Case of Acceleration

Engine torque also has a similar flow as in the VAPS experiment result. VAPS and engine torque can be said to be proportional relationship due to the characteristic of the VAPS engine data. The powertrain simulator can be run by entering the calculated engine torque in the engine module. It is possible to obtain the following results for comparison :

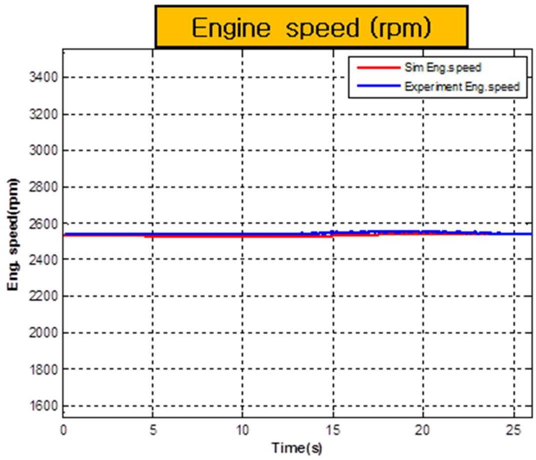

Figure 2.15 Engine Speed of Constant Velocity Driving

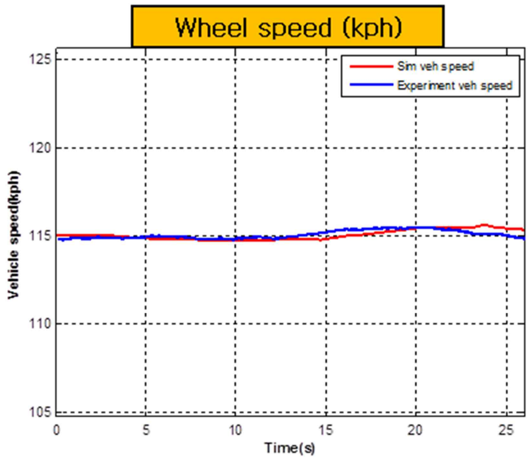

Figure 2.16 Vehicle Speed of Constant Velocity Driving

Engine speed and wheel speed are also confirmed to have a constant flow in the constant speed. Transmission gear is 6^{th} ratio value in driving. The result of the simulation result and the actual driving result are shown to be similar.

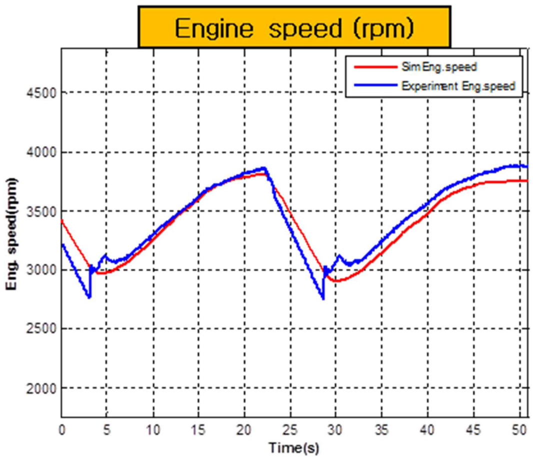

Figure 2.17 Engine Speed of Acceleration

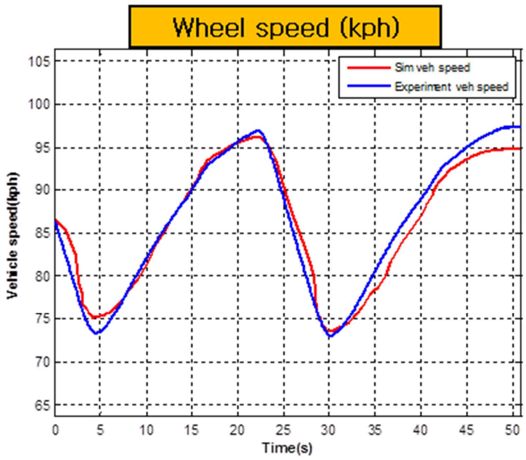

Figure 2.18 Vehicle Speed of Acceleration

It was confirmed that the wheel speed and engine speed show similar results between the case of running the simulator and the actual driving in the acceleration. Transmission gear is 4^{th} ratio value in driving. This makes the powertrain simulator reflecting on the situations of constant speed and acceleration proved to be verified in the auto−cruise vehicle.

The variable of auto−tuning by the power train simulator based on the MDO theory is configured. MDO is a theory of technology management field standing for Multi−Disciplinary Optimization. In this chapter, there is an explanation of the MDO problem definition and how to apply MDO for the automatic tuning. There is also the definition for design variables, output variables, the objective function. And it is necessary to explain some techniques of the optimization, how the whole process proceeds. MDO is currently and widely used in the aviation sector design, elements accompanying the various types are subdivided as Figure 3.1.MDO is also widely applicable to other fields.[59]

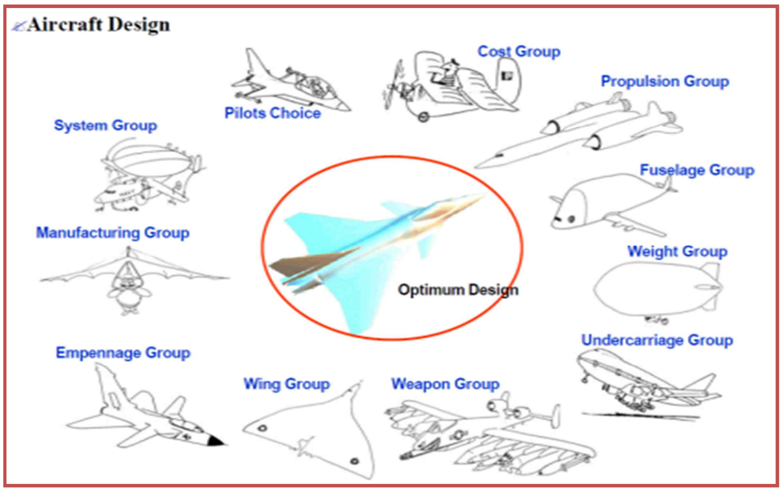

Figure 3.1 Aircraft Design Elements.

3.1 MDO Problem

The automated process is utilized to disciplinary Design Optimization Theory. This theory repeats the setting of the design parameters to satisfy the target performance to optimum design method for considering the design elements of the various fields affecting each other at the same time. MDO is very useful methodology to the design of electronic products, design of an independent system with rapid product manufacturing. The goal of MDO is seeking a reduction in speed and cost of the design time by applying the optimal design to the actual problem through the integration considerations.

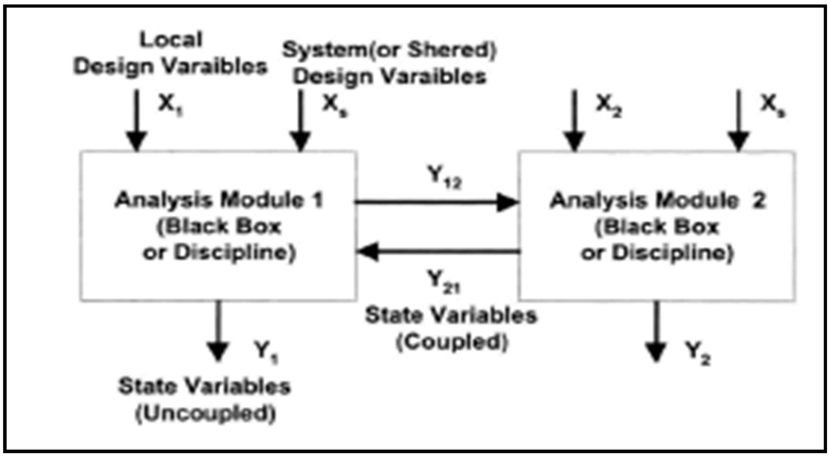

Figure 3.2The definition of the MDO problem

Design parameters are divided into system design that affects all the design elements and local variable design parameter. In the same way state parameters are divided into coupling variables and system outputs. In the case of vehicles in the auto cruise MDO problem is applied as shown in the following figure. Two-discipline coupled MDO problem, which has two design elements is simple way to resolve the situation. The purpose of solving the problem is to minimize the objective function of the design variables and the state variables satisfying the constraint.[60]

$$\text{Minimize} \qquad f(X,Y) \tag{3.1}$$

$$\text{Subject to} \qquad g(X,Y) \le 0 \tag{3.2}$$

$$h(X,Y) = 0$$

$$\text{Design Variables :} \qquad X = \{X_l, X_s\} \tag{3.3}$$

$$\text{State Variables :} \qquad Y = \{Y_c, Y_s\} \tag{3.4}$$

Figure 3.2 shows the situation of the Organization in Two-discipline coupled MDO problem. Similarly, this problem can also be applied to the automatic tuning of the auto cruise vehicle. Defining auto-tuning conditions as defined by the MDO problem is as follows.

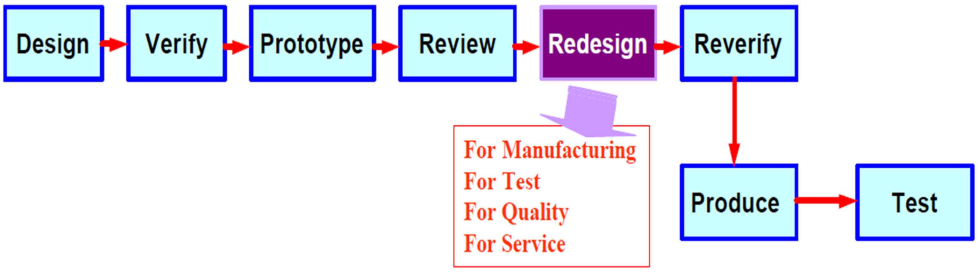

Figure 3.3 MDO Process

The design element is divided into hardware of the vehicle power train model and software of the vehicle controller. Powertrain models are switch signals and variable loads, auto cruise operating variables as input variables and driving data, switch signal as the output variables. The vehicle controller has automatically modified shift schedule, request acceleration function, the load variable, the switch signal and the driving data as the input variables, the output variable is the performance parameter.

Performance parameters include acceleration time, deceleration time, torque fluctuations during constant speed, fuel consumption which determine whether the automatic tuning conducted. The performance variables and the objective function are in the same concept. To be mathematically the difference of the acceleration, the deceleration time and the target time of the driving data should be minimized. Of course, the acceleration, the deceleration time of the driving data is less than the target time.[61]

Design variables are switch signals, load variables, auto-tuning result variables and the state variables can be defined as a switch signal, driving data, variables featuring cruise mode, performance evaluation parameters.

$$\text{Minimize} \quad |t_{acc} - t_{tar,acc}|, |t_{dec} - t_{tar,dec}|, T_{con,eng,fluc} \tag{3.5}$$

$$\text{Subject to} \quad t_{acc} - t_{tar,acc} \leq 0, t_{dec} - t_{tar,dec} \leq 0 \tag{3.6}$$

$$\text{Convergence} \quad F_c, T_{ft} \tag{3.7}$$

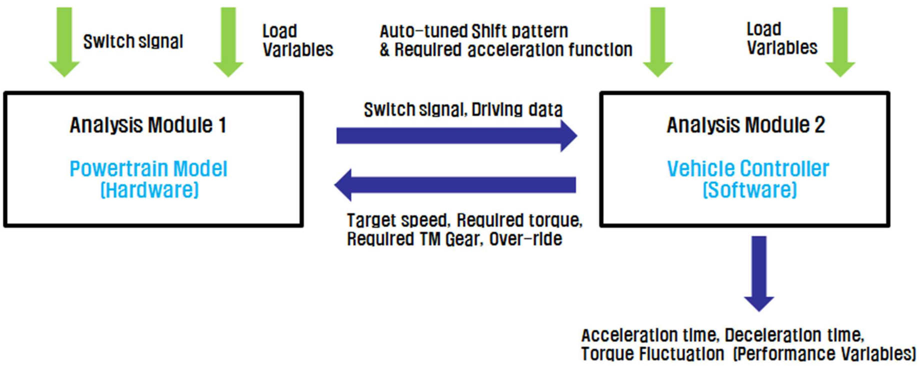

Figure 3.4 MDO Definition of the Auto Cruise Vehicle

3.2 System Fragmentation and Optimization

The MDF (Multi-Disciplinary Feasible) scheme performs directly to the flexible multi-field analysis with respect to the current design point.Since the configurations are not intended to modify the optimization problem by applying separate techniques but formulate the problem in the same way, a major characteristic of MDF is intuitive and simple optimization problem.

However, MDF techniques to deal directly with respect to the current design points of multi−circulation period in each of the optimization problem requires considerable time and cost analysis over the entire field in the case of the close relationship between various fields. Moreover, MDF further required for the number of iterations of the optimization of the each circulation period generate an inefficient problem despite the useful configuration problems of MDF techniques practical for the engineering optimization problem.

Application also to the distributed parallel processing environment to reduce the analysis time, it is difficult to the additional problem. Therefore, in the complex field of MDO problem which requires distributed processing environments and has the number of analysis and design parameters increased fragmentation technique needs to be applied to the system instead of applying directly MDF.[62]

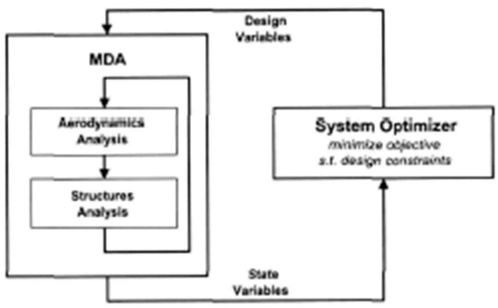

Figure 3.5 Multi−Disciplinary Feasible (MDF)

MDF formulation needs to satisfy the availability for all the areas after a repetition of one of the system design cases, while IDF (Individual Discipline Feasible), one of the segmentation technique methods is set to satisfy only the constraints on each of the unit areas. It is the analysis to determine the feasibility of a self-contained system optimization phase for the analysis of each step. In the system optimization module, suitable constraints are additional conditions for the determination of the violation of the other fields in the specific field with existing design parameters and constraints.

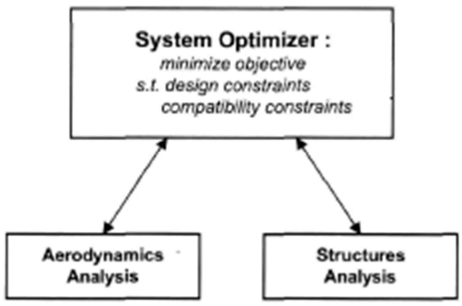

Figure 3.6 Individual Discipline Feasible (IDF)

Therefore, MDF process is applied to the automatic tuning of the auto cruise vehicle but the whole process is to perform the simulation by fragmentation to meet the optimization constraints between each sub- field.[63]

3.3 Full Optimization Process

As the overall progress of MDF system it can be expressed as shown below, Figure 3.7. First, when performance parameters from the simulator consisting of the power train model and the vehicle controller are calculated, those parameters needs to be determined that meets the target. If the target is satisfied whole process is terminated. Otherwise, if the target not satisfied, required acceleration and shift patterns are modified through auto-tuning process.

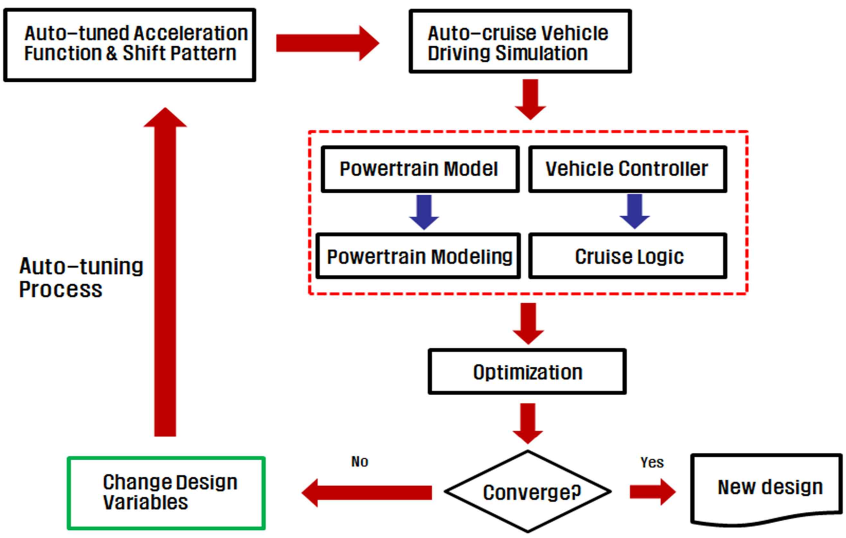

Figure 3.7 Optimization Process of Auto-Tuning Parameters.

As mentioned earlier, the whole process is configured by the MDF scheme, but constraints are added to one of the details, the power train model. It is just the engine performance, which means the engine torque, engine maximum power. It means that the engine performance can be exerted over the vehicle driving force when the auto cruise follow and maintain a target speed itself.

This study leads to Power train Model Vehicle Controller and the effect of the automatic tuning program applied in a real vehicle to verify how well they reflect the actual driving situation. Comparison and analysis of the actual driving results and powertrain simulator can be found in Chapter 2. And the automatic tuning program is analyzed by using the information of the actual driving road, the results and the effect of the auto-tuning.

CHAPTER 4 Automatic Generation and Tuning of the Required Engine Torque

In order to follow the target speed of the vehicle, it is important to obtain the correct required torque of the power source. In this paper, the PID method is avoided and vehicle dynamic equations are utilized to obtain the required wheel torque. Without any slip, the engine torque demand can be calculated directly from wheel torque since lock–up state. However, the rolling resistance coefficient and the drag coefficient of the vehicle dynamics equation recall error of the engine torque demand if the reference values of them are used for calculation. Thus, the coasting down data is needed to get exact values of the target vehicle. The data indicates the deceleration data of the transmission stage which is the neutral one. And the required acceleration generated by the function of the deviation between current speed and the target speed, 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 go to the automatic tuning of itself. Auto–tuning process is divided into three cases, there are the constant–speed driving, the acceleration, the deceleration driving. Different strategies are applied in each case.

4.1 Coasting Down Data

Friction and aero dynamic coefficients are unknown parameters for the required engine torque. Engineers also measured two unknown parameters after the test because the literature values differ by a little bit each target vehicle. Coasting down data, which is the decreased velocity data without-gear, standing for neutral transmission solves the unknown parameter, friction coefficient. Figure4.1 shows the coasting down data of 0% incline starting at 112kph.

To solve the unknown parameter, an equation is set by consisting of vehicle dynamics. From the vehicle dynamic equation, simultaneous equations from coating down data can calculate the friction coefficient.[64]

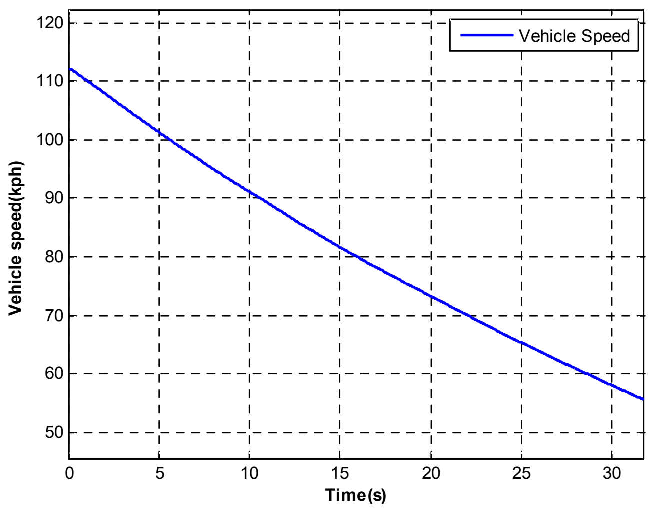

Figure 4.1 Coasting Down Velocity.

The following formula is used to determine the unknown rolling resistance coefficient of the vehicle dynamics equations. The acceleration value is a derivative of the applicable point. Because the transmission is in the neutral position the wheel driving force is zero.

$$F_{t1} = Mg\,f_r\cos\theta + \frac{1}{2}\rho_{air}C_d A_f V_1^2 + Mg\sin\theta + Ma_1 \qquad (4.1)$$

$$F_{t2} = Mg\,f_r\cos\theta + \frac{1}{2}\rho_{air}C_d A_f V_2^{\,2} + Mg\sin\theta + Ma_2 \qquad (4.2)$$

Since the driving force is zero, rolling resistance coefficient can be expressed as polynomial on the vehicle speed. The rolling resistance coefficient is obtained by utilizing the acceleration data in accordance with the vehicle speed. Acceleration points and the second interpolated formula appear as shown below. When velocity is zero, the rolling resistance coefficient can be obtained by substituting y-intercept value above the equation. The effective vehicle mass is assumed to be equivalent to vehicle mass, due to the neutral condition of transmission.

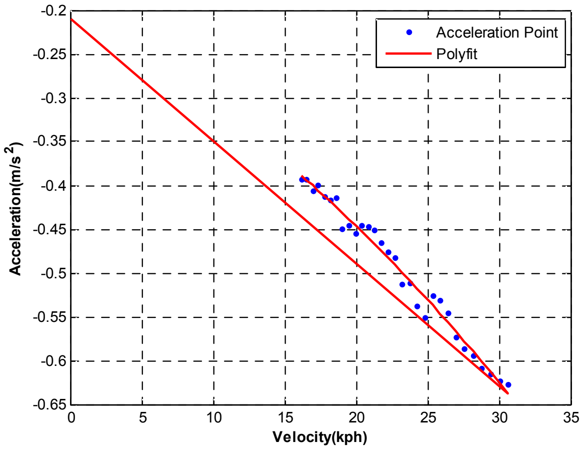

Figure 4.2Acceleration Points and the Interpolation Line

Since the y−intercept value is−0.2104, rolling resistance coefficient is 0.0204, and the drag coefficient is 0.292.Air resistance coefficient is determined through wind tunnel tests. Those values are used for obtaining the required torque of the engine.

4.2 Auto−Generation of the Demand Acceleration Map

Target acceleration needs to be put in the simulator to calculate the required torque. Figs. 4.3~5 show the acceleration values in three cases: accelerated, decelerated, and constant speed driving. The target acceleration has parameters like vehicle velocity and the absolute value of the difference between vehicle and target speed. These are subject to revision by the driving data after terminating the simulation.

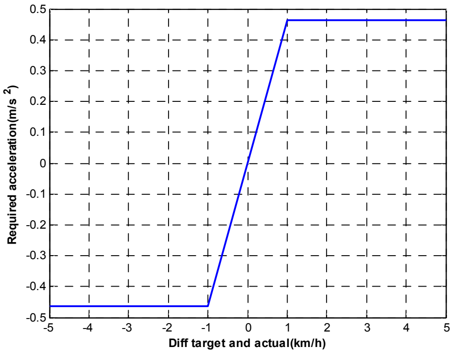

Figure 4.3Acceleration values of Constant Driving

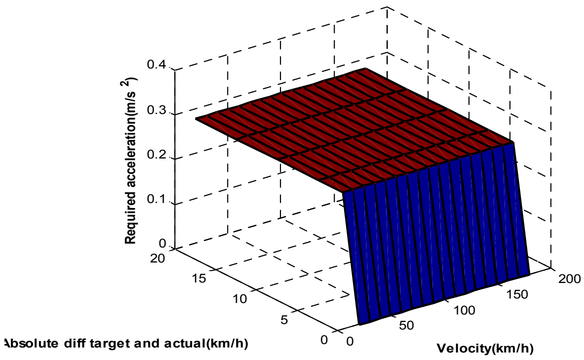

Figure 4.4Required Acceleration Function

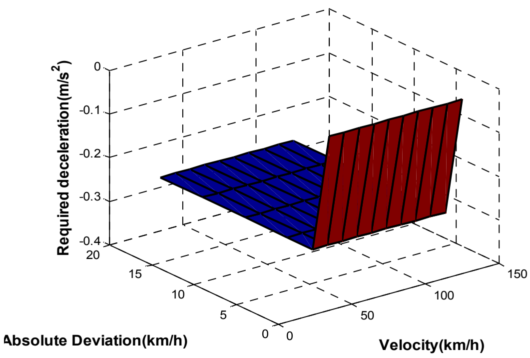

Figure 4.5Required Deceleration Function

Mentioned above is automatically generated if the target time is determined for constant, acceleration, deceleration situations considering vehicle, speed, the difference between the vehicle speed and the target speed. To obtain the required acceleration a formula is shown below.

$$a_{req} = 20 / 3.6 / t_{req} \quad (v_{target} - v > 1) \tag{4.3}$$

$$a_{req} = (v_{target} - v) / 3.6 / t_{req} \quad (v_{target} - v \leq 1) \tag{4.4}$$

Acceleration time means the time consumed when the vehicle speed is accelerated 20kph. Therefore, the target acceleration time is defined by different values accordance with applied transmission gear to the vehicle. Target time is 20s for 20kph acceleration or deceleration.

4.3 Calculation of the Required Torque

The required engine torque is calculated by calculating the required torque to the wheel with a gear ratio and power train efficiency. The wheel required torque consists of slope resistance, rolling resistance, air resistance, acceleration resistance which is based on vehicle dynamics theory. Rolling resistance coefficient and drag coefficient are calculated from the coasting down data and the required value of acceleration resistance is used in the required acceleration function. The formula for the wheel requested torque and the engine required torque is as follows.

$$T_{wheel,req} = R_{wheel}(Mg\sin\theta + \frac{1}{2}\rho_{air}C_d A_f V^2 + Mg f_r \cos\theta + Ma_{req}) \qquad (4.5)$$

$$T_{eng,req} = T_{wheel,req} / i_{tm} / i_f / s_{eff} \qquad (4.6)$$

In the above formula, i_m is the transmission gear ratio, i_f the final ratio, S_{eff} means a power train efficiency. The calculated engine torque demand is input to the tracking or maintaining the target speed.

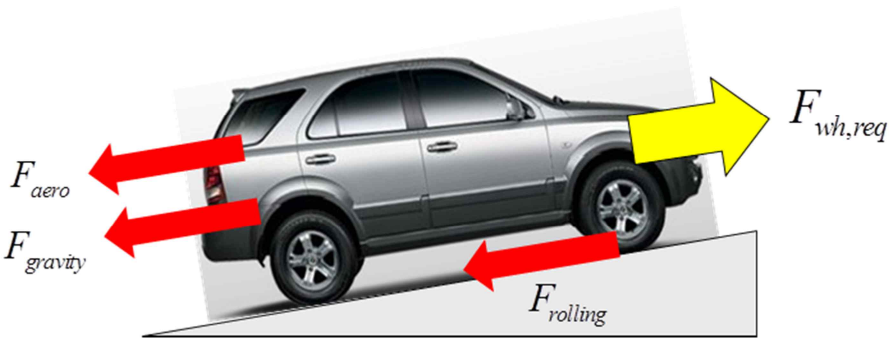

Figure 4.6 Traction and Load of Vehicle Dynamics

4.4 Automatic Tuning of the Required Torque

4.4.1 Sample Extraction of the Driving Data

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

In the beginning, samples for the engine torque calibration are extracted from driving data. Figure4.7shows the actual and target vehicle speed divided into three cases: acceleration, deceleration, and constant driving.

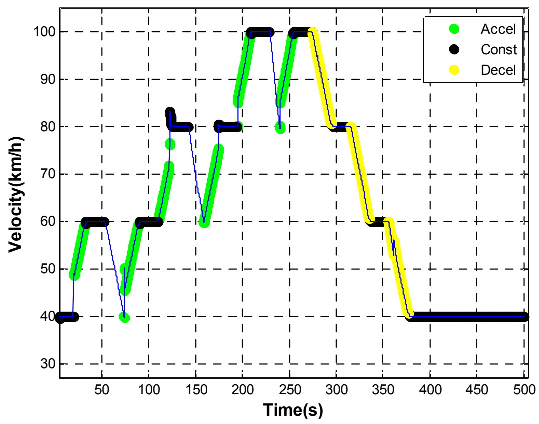

Figure 4.7Extracted samples of driving data

Samples are extracted corresponding to a frame of the functions of the required acceleration after classifying the samples in driving data. A constant speed required acceleration is a function of vehicle speed and a target speed difference. Acceleration, the deceleration required acceleration is a function of the vehicle speed and the target speed, the vehicle speed difference. Thus the driving data samples extracted for the respective variable of the function are compared to the required acceleration tables.

4.4.2 Acceleration Case

Target acceleration needed to get the target speed are made bigger if a driver wants to decrease the acceleration time. The acceleration samples of driving data are compared to acceleration values of function.

4.4.3 Deceleration Case

In contrast, the target deceleration needed to get the target speed are made smaller if a driver wants to decrease the deceleration time. The deceleration samples of driving data are compared to deceleration values of function.

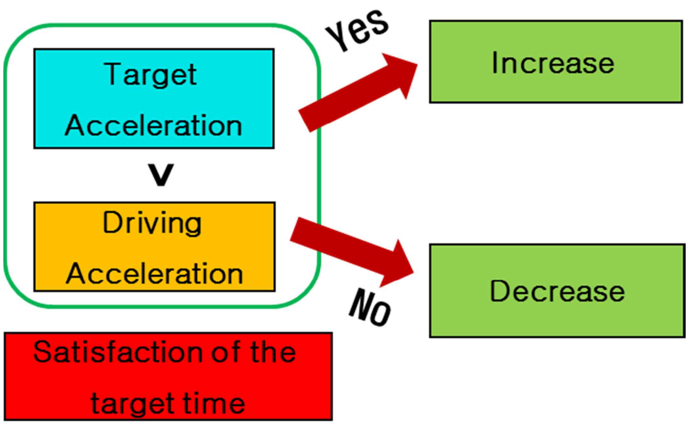

Figure 4.8 The Situation of Acceleration or Deceleration

4.4.4 Constant Velocity Driving

For constant velocity driving, the vehicle needs to reduce the torque fluctuation, which causes drivers to feel uncomfortable. In this case, the number of transmission gears does not need to be changed instead of changing the acceleration values. If the vehicle speed is outside the target speed range, the gear number follows the shift strategy by engine torque and speed.

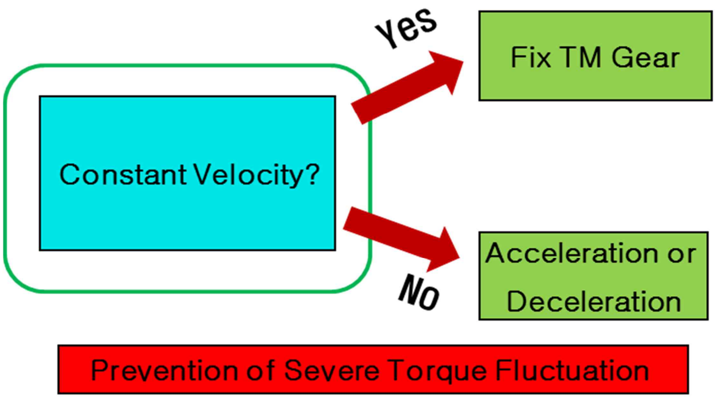

Figure 4.9 The Situation of Constant Velocity

There is a method to secure the torque during the constant speed drive for the stability of the torque. However, when the engine torque is the fixed wheel speed of the vehicle goes out of the constant−speed range easier. It is beyond the constant speed range, entering the acceleration or deceleration state. This causes instability of the constant speed vehicle increased, because the vehicle turns the acceleration or deceleration state. Acceleration values applied for calculating engine torque could be changed frequently by each changed state. Since the controller adjusts the engine torque of the vehicle, it is possible to reduce the fluctuation rate in fixing the transmission gear stage.

CHAPTER 5 Automatic Generation and Tuning of the Shift Pattern

For following of the desired speed of the vehicle selection of the torque demand as well as appropriate transmission gear stage is also important. Auto−tuning of the shift pattern in these dimensions can be described as the process which is also necessary. At this chapter the automatic creation of shift schedules were added to the contents. Auto−generation method of Up−shift and Down−shift, the lower limit of line settings, etc. were introduced. Automatic generation of the transmission pattern based on the vehicle dynamics equation is also calculated. There are utilized virtual throttle as the previously described concept. If driving data of the simulator or an actual vehicle is generated tuning the transmission pattern is started automatically. Automatic tuning samples extracted from the driving data, the tuning target patterns of the samples are selected. The sample is extracted in the deceleration and acceleration period. And the pattern of distance and comparative load conditions will decide whether the following auto−tuning process is proceeding. Distance condition means that even if the automatic tuning is in progress the interference between lines of the pattern is not allowed. The other condition, traction−load condition means that even if the automatic tuning is in progress the traction force of the sample is bigger than the wheel load. The method of auto−tuning process has two strategies by directions to increase the transmission gear stage of the sample or decrease it.

5.1 Automatic Generation of the Shift Pattern

5.1.1 Auto Generation of the Up-Shift

Engineers determine the shift pattern under the driving directly and subjective judgment in calculating the shift timing of the vehicle. However, this needs to be done as an automated auto-tuning since the time-consuming and expensive. Automatic generation of the transmission pattern is started from obtaining the required torque from the engine and the wheel. When the object vehicle driving ahead follows target speed, the engine torque demand can be calculated directly by using the transmission gear ratios since lock-up condition referred to the section of introduction part is applied.

The engine torque demand for generation shift pattern is divided into two cases, the acceleration and constant speed driving. By default, required torque for generating up-shift is calculated in the constant speed driving of the vehicle.

However, the shift pattern based on the power performance is not calculated in the engine data of the target vehicle. In this study, using the engine fuel consumption data the shift pattern is automatically calculated and utilized in driving. Fuel consumption data is as follows.

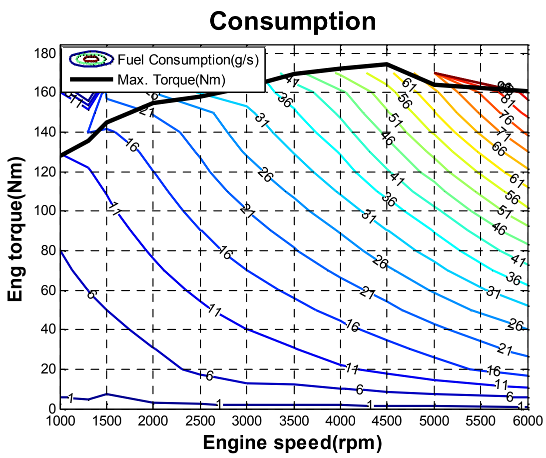

Figure 5.1 Fuel Consumption Map

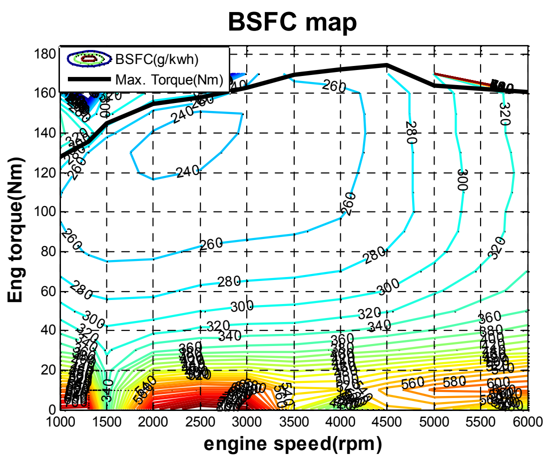

Figure 5.2 Engine BSFC Map

Engine BSFC map is calculated by converting the unit from fuel consumption map. And the BSFC map can be converted into the BSFC accordance with vehicle speed and transmission gear ratios. Since the transmission has 6 gears, BSFC converted by wheel speed is as follows.

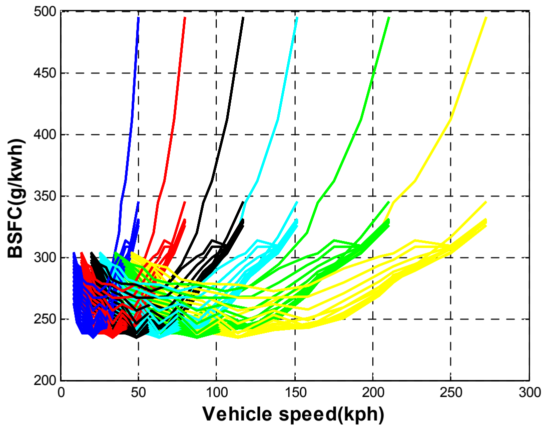

Figure 5.3 BSFC in accordance with Wheel Speed

Engine torque demand by the aforementioned VAPS map data may be converted into the VAPS. Interpolation is used for converting after replacing the basic unit, Nm of the engine demand torque as a percentage. Interpolation is a technique of numerical analysis.

Next, VAPS offset shall be applied to calculate the shift point or timing. This is the line of the transmission pattern to be calculated sequentially. To yield the up-shift, required torque lines of 2 ~ 6 transmission gear ratio only for the constant speed driving are used. This is because the vehicle needs to afford to required driving force of the applicable transmission gear ratio for increasing the number of gears.

5.1.2 Auto Generation of the Down-Shift

Automatic generation of the down-shift also begins from calculating the engine torque demand, as up-shift. It is different from the engine required torque considering the required acceleration. To obtain the required wheel torque in accordance with the required acceleration time mentioned in section 4 above then the engine torque demand is determined according to the transmission gear ratio.

VAPS off-set is applied to calculate shift points of down-shift as the equivalent strategy of up-shift. However, in the case of down-shift, required torque lines of 1 ~ 5 transmission gear ratio are used for calculating. That is, the remaining four lines, VAPS lines of 1 ~ 4 transmission gear ratio need to move symmetry based on the fifth VAPS line.

However, traction performance is not taken into account for calculating down-shift because of up-shift not calculated by considering the engine power. Instead of considering power performance, up-shift lines move parallel with a wheel speed difference of 70 to 80 % to complete the down-shift.

Since the transmission has 6 gears, down-shift has 5 lines according to vehicle speed and VAPS.

5.1.3 The setting of the higher and lower limit speed

The upper and lower limit speed of the up, down−shift is determined from the driving force of the vehicle or the off−set set by the user by default. The upper limit of speed of up, down−shift is determined mainly by the maximum traction force.

There are three strategies determining lower limit speed from the off−set, user−defined. It compares the previously determined difference of lower limit speeds of up, down−shift line and a lower limit speed difference in the user off−set.

The lower limit speed of down−shift needs to be changed according to that of up−shift relatively if the lower speed difference of both shift pattern is greater than the user off−set. If they are same, nothing is changed. If smaller, the lower limit speed of up−shift needs to be changed according to that of down−shift relatively.

Consequences are: This is the target shift pattern of auto−tuning process set by the user after driving data generated from actual or simulated driving.

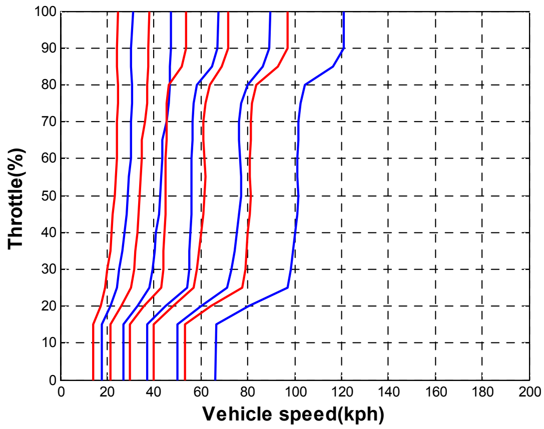

Figure 5.4 Automatically Generated Shift Pattern

5.2 Automatic Tuning of the Shift Pattern

5.2.1 Samples of the Driving Data

Driving data including road grade, velocity, throttle opening accordance with time needs to conduct calibration of shift pattern. Original shift pattern is supposed to be changed by selected samples of driving cycle. That is, it is necessary to view the correction of the shift pattern for the driving conditions.

Constant velocity section is not consideration of calibration. Sampling of the speed section is not required because the transmission strategy in the constant speed section is fixed to the shift speed. In the case of constant driving, the torque demand only focuses the target acceleration time of auto-tuning process.Samples of decreased and increased velocity sections are extracted from driving cycle. Figure 5.7 shows driving data of the object vehicle. VAPS and Cruise signal data is also used for extracting samples. Especially samples are extracted when cruise signal is 1 which means that object vehicle is following to target speed. When cruise signal is 0, it is cancel mode that engine torque is 0. But Vehicle memorizes acceleration target speed. Users can determine velocity range where samples are extracted. It is about 10km/h from 40km/h. Each velocity range has both samples for calibration.Figures below show the VAPS data, cruise signal, wheel speed data over time.

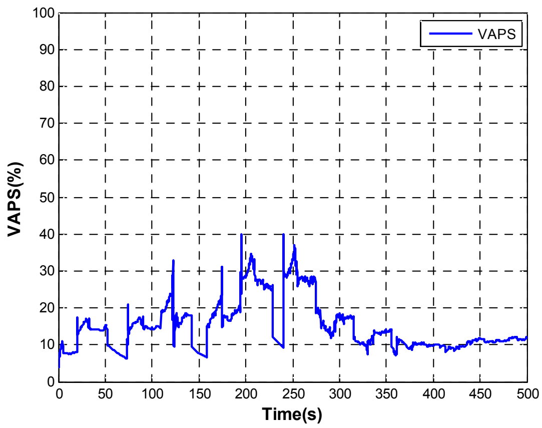

Figure 5.5 VAPS data

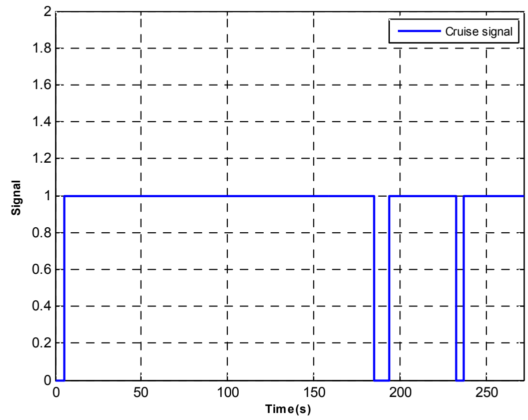

Figure 5.6 Cruise Signal

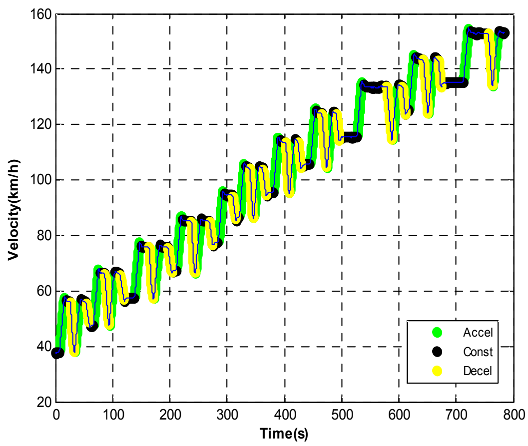

Figure 5.7 The example of the driving data.

The above data based on the acceleration, constant speed and deceleration extracts samples. And it also extracts a representative sample for the average value of VAPS for each speed. These are the auto −tuning target samples.

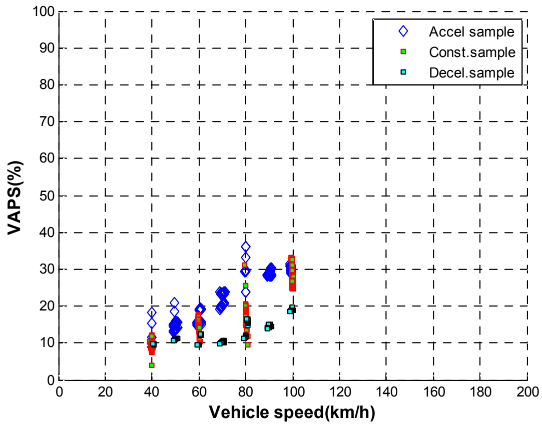

Figure 5.8Samples extracted on driving data

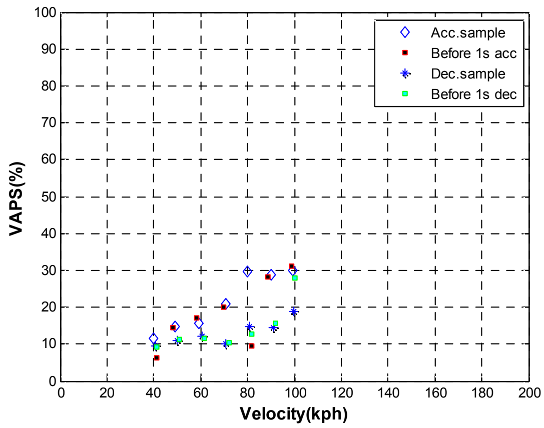

Figure 5.9 Extracted Samples of Average VAPS

However, all samples are not used for calibration. One constant and one increased velocity samples are extracted for one section. Criteria is average throttle signal, that means a sample which is related to medium traction force among samples of a section needs to be used for shift pattern calibration. It is pointed that calibration for shift pattern plays a role to find out appropriate engine operating points. Figure 5.9 shows extracted samples of average VAPS for calibration. Decelerated velocity and acceleration samples are used in calibration of lines of shift pattern. Samples which are located 1s before on driving cycle are used in calculating values of acceleration samples. Acceleration values determine calibration method for acceleration samples. It will be discussed in calibration chapter.

5.2.2 Selection of the Target Tuning Pattern

Each sample is supposed to be used for calibration. Object calibrated line should be assigned to each sample because vehicle shift situation is supposed to be up or down shift. Figure 5.10 shows cases of object calibrated line of vehicle situation. For example, if velocity is increased and throttle signal value is decreased between a sample and 1s before sample, object line is up−shift line. In contrast, if velocity is decreased and throttle signal value is increased, object is down−shift line. It means that if vehicle shift situation is up−shift situation, object calibrated line should be up−shift line.

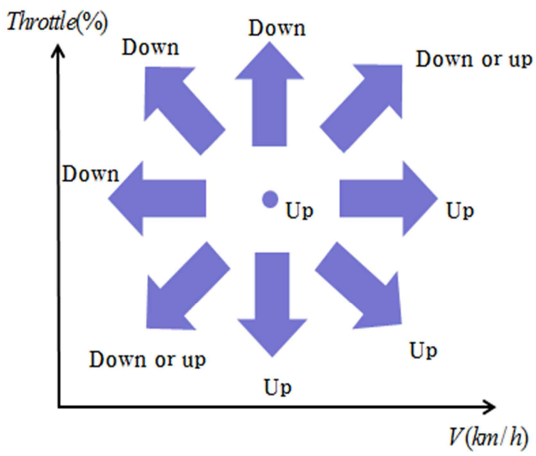

Figure 5.10Auto-tuning Pattern Selection.

Table 5.1 shows target tuning pattern of each sample according to the relationship between the sample and 1s before in paragraph.

Table 5.1Target Tuning Pattern

VAPS \ Velocity	Increase	Decrease
Increase	Down or Up	Down
No change	Up	Down
Decrease	Up	Down or Up

However, object calibrated line is possible to be both up and down shift line if both velocity and throttle signal value are increased. In this situation, acceleration of the samples by up-shift needs to be considered. Figure 5.11 shows object samples and samples located 1 second before on driving cycle. If acceleration makes object samples located lower gear number, object calibrated line should not be up−shift line. It means that crossing up−shift does not allow samples lower gear number. Object calibrated line can be up−shift if acceleration makes samples having higher gear number.

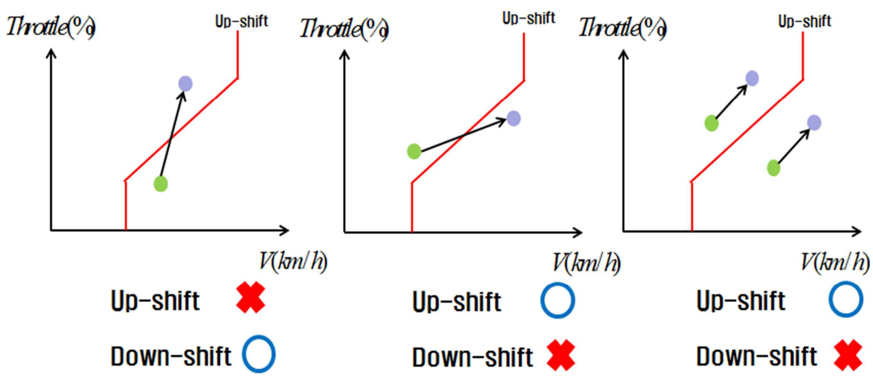

Figure 5.11Object calibrated line selection

The description above is applied to the case of the deceleration samples. If both VAPS and wheel speed decrease for one second, the automatic tuning target pattern can be that all the up, down−shift. Therefore, it can determine the auto−tuning target pattern comparing the shift gear ratio of a second before samples and representative samples in this case. Method is the same as described above.

5.2.3 Line Distance Condition

Calibration only can happen around samples which satisfy some conditions. There are two conditions, First line distance condition is about the interval of shift lines. Second, traction-load comparison is to compare vehicle traction and load around samples. Object lines should satisfy both conditions for one sample. Line distance condition is about interval of shift lines. Each up-shift line should have interval with other lines, and crossing each other is not allowed. Each down-shift line also is not allowed to do. Moreover, one up-shift line and one down-shift line which have equivalent order are prohibited from crossing. Figure 5.12 shows line distance condition. It means that location order of shift pattern lines should not be changed even though shift pattern around samples are calibrated.

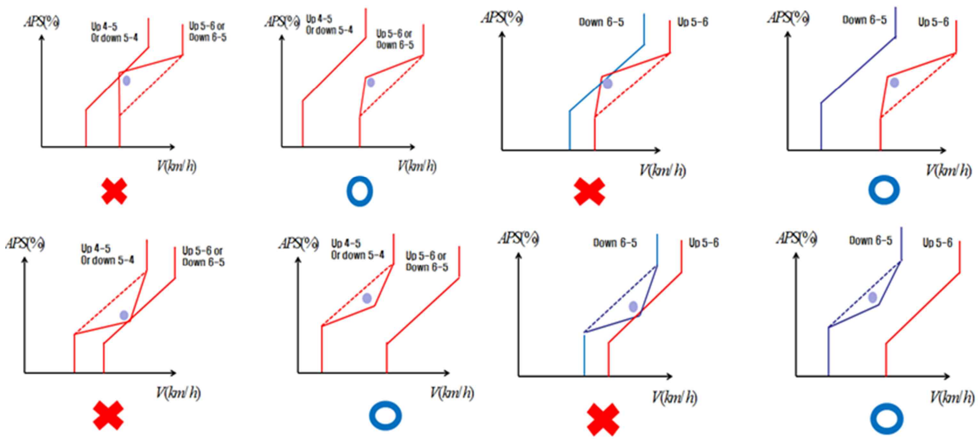

Figure 5.12 Line Distance Condition

5.2.4 Traction−Load Comparison

Vehicle traction of object samples should be bigger than vehicle load even though shift patterns are calibrated. Torque, speed ratio, capacity factor of the torque converter are considered when wheel traction force is calculated. Equation shown below stands for traction−load comparison, traction force Ft should be larger than vehicle load including rolling resistance, aerodynamic drag, grading resistance even though shift patterns are calibrated.

Comparison of vehicle traction and load needs to be conducted after calculation of vehicle load. Figure.5.13 shows torque converter data including capacity factor and torque ratio for the vehicle load calculation.

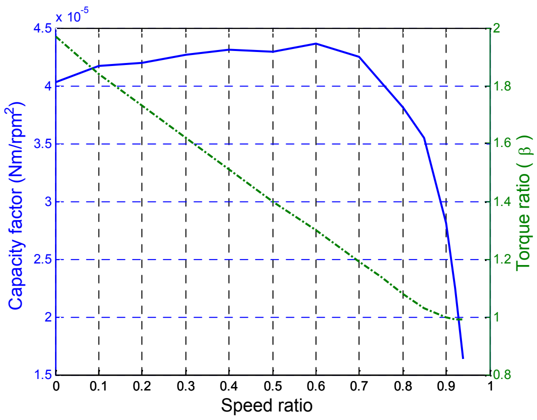

Figure 5.13 Torque Converter Map

5.2.5 Calibration of Lines

Object lines nearing constant samples are supposed to have lower gear ratio and those nearing samples of increased velocity are supposed to have both lower and higher gear ratio. In the case of lines nearing samples of increased and decreased velocity, calibration is dependent on target acceleration.

In case of acceleration and deceleration samples, there are two cases for calibration. If acceleration values are bigger than target acceleration, object lines of the acceleration samples are calibrated for higher gear number.

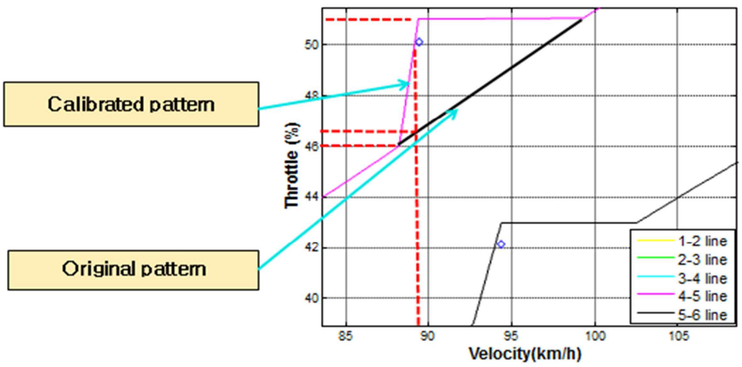

Figure 5.14Calibration for higher gear number

Object lines nearing acceleration and deceleration samples are changed to make the samples having higher gear ratio and lower gear number. In contrast, if acceleration or deceleration values are less than target acceleration, object lines of the samples are calibrated for lower gear number. Constant velocity samples are not accustomed to having lower gear number.

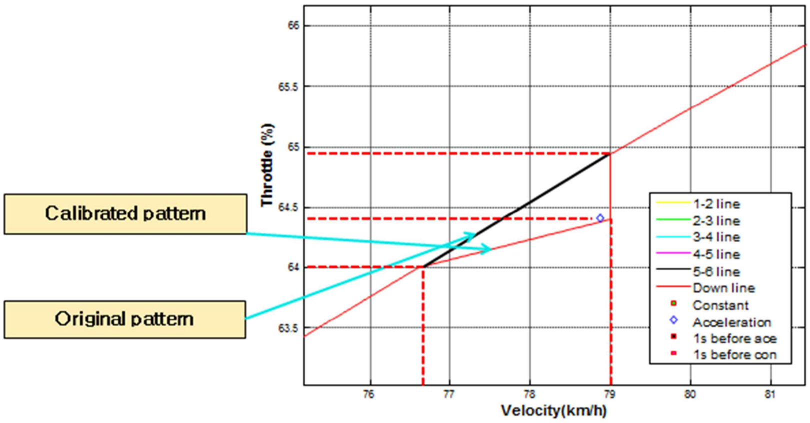

Figure5.15Calibration for lower gear number.

The calibration simulator which changes shift pattern after driving cycle is generated is shown below. It shows both original, calibrated pattern and driving cycle. Users can check original pattern first then check the calibrated pattern after calibration. Driving cycle show velocity in accordance with time, road grade, pedal signal information. Data can be saved by excel format.

The picture above, Figure 5.8 shows the shift pattern of the automatic tuning of higher point shift. It is undergone by accelerated samples meaning that the simulated acceleration in the applicable driving speed and VAPS is measured above the target acceleration. It is possible to adjust the correction amount of the line according to the user's will.

In this Chapter the conclusion is explained by looking at the auto-tuning according to the simulation results accordingly. And the study content to be made in the future is introduced.

Auto-tuning simulation was run in accordance with the scenario for acceleration, resume mode, constant speed and deceleration. The initial speed is 40kph and this is the minimum value of a cruise mode, the vehicle speed of the target vehicle. This was accelerated up to 120kph, which was considered to be driving the speed limit. Incline information which is largest contributor to the required torque is as follows. It performs a virtual drive through a total of five of the driving load.

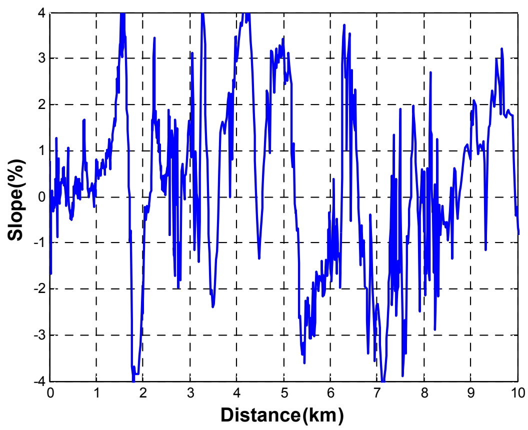

Figure 6.1 Incline Information1 (Namyang-Suwon Road)

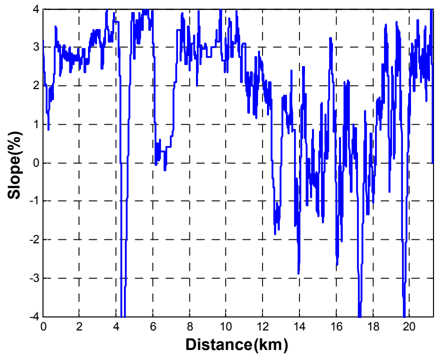

Figure 6.2 Incline Information 2 (Cycle 1)

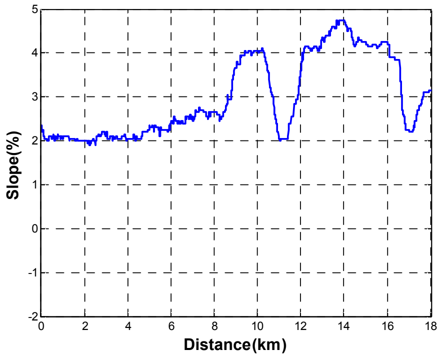

Figure 6.3 Incline Information 3 (Cycle 2)

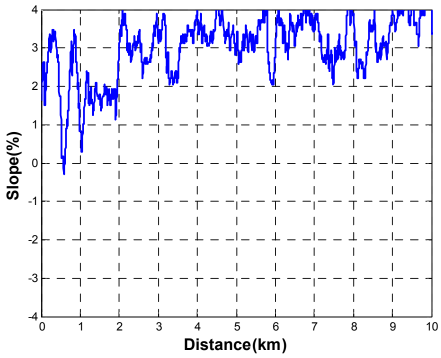

Figure 6.4 Incline Information 4 (Cycle 3)

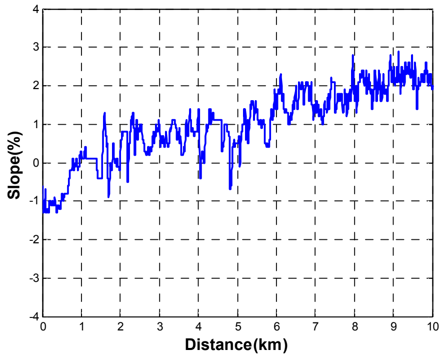

Figure 6.5 Incline Information 5 (Cycle 4)

Initially, virtual driving and automatic tuning over a wide range of road load is conducted and change of road load becomes smaller gradually according to each driving cycle. These repeats show the convergence of required acceleration functions and change of the shift pattern.

6.1 Simulation Results

The most important task of the auto– cruise vehicle is maintaining target speed with appropriate transmission gear with auto tuning of the shift pattern and required engine torque. Figure shown below is Namyang–Suwon vehicle speed data which is driving for 400 seconds starting at 40kph.

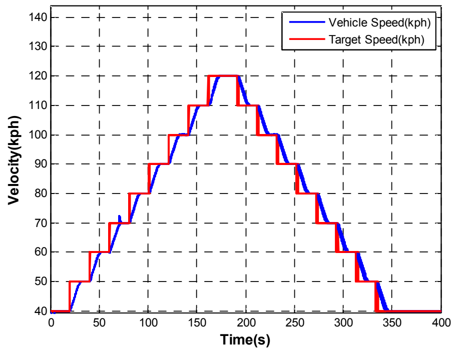

Figure 6.6Vehicle Speed data (Namyang-Suwon)

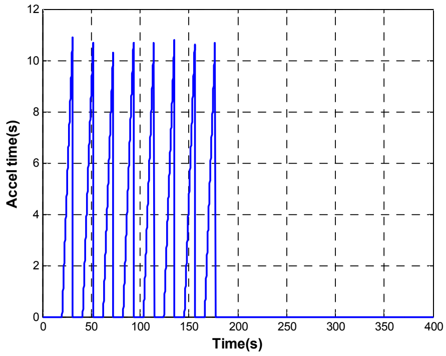

Figure 6.7 Acceleration Time before Auto-tuning (Namyang-Suwon)

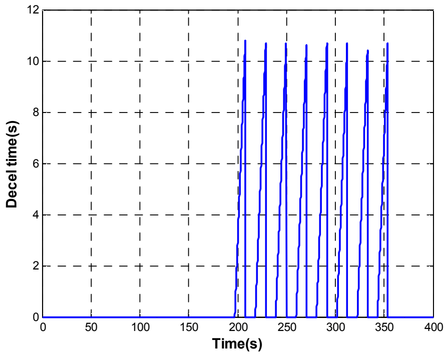

Figure 6.8 Deceleration Time before Auto-tuning (Namyang-Suwon)

The acceleration and deceleration time previous automatic tuning can be seen that does not satisfy the reference time. Hence it implemented the automatic tuning of the required torque. And shift-pattern nearing the shift point of constant velocity must be tuned to prevent hunting or shifting gear. Section of constant velocity does not consider shifting gears for drivability.

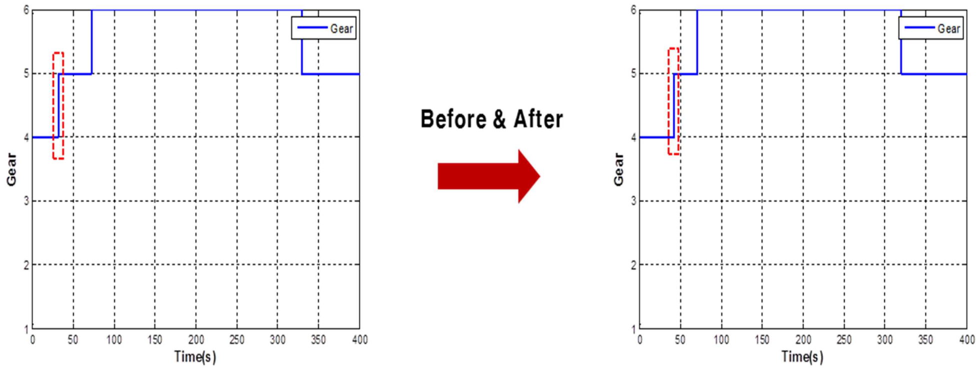

Figure 6.9Gear Change through tuning Shift-Pattern (Namyang-Suwon)

Prior to tuning transmission gear number was changed in 50kph speed section of constant velocity while gear number shifted in 50-> 60kphacceleration after tuning shift pattern. Operating points and shift pattern are shown in the figure below.

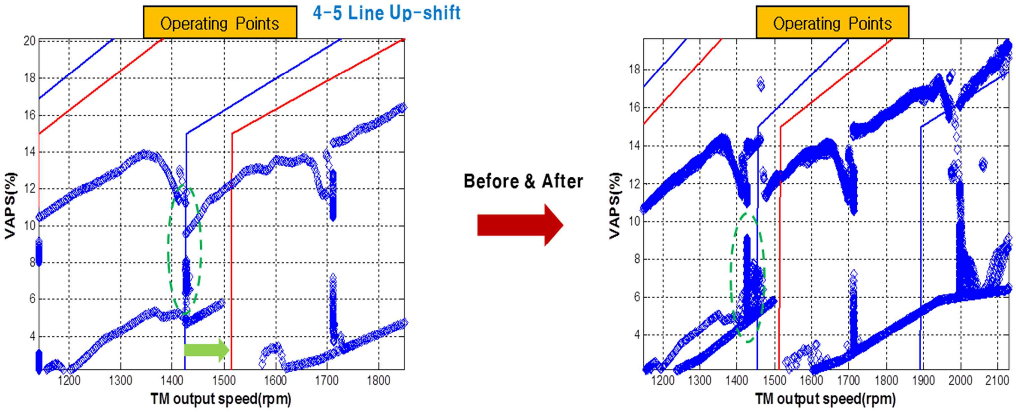

Figure 6.10Shift-Pattern tuning (Suwon-Namyang)

Target tuning samples in a green line are located in the area of 5^{th} gear number before tuning shift-pattern, while in the area of 4^{th} gear number after tuning target line. At the section of 50kph constant speed, it prevents the shift to 5^{th} gear in this manner. Target tuning pattern is a 4-5 Up-shift. The results of the automatic tuning required torque after tuning shift-pattern are as shown below.

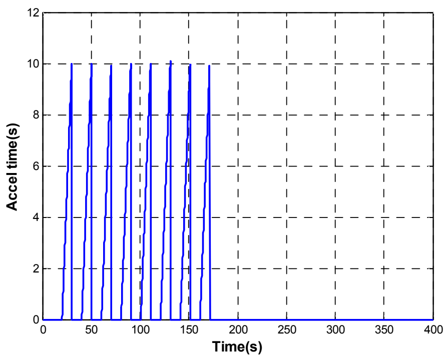

Figure 6.11 Acceleration time after Auto-tuning (Namyang-Suwon)

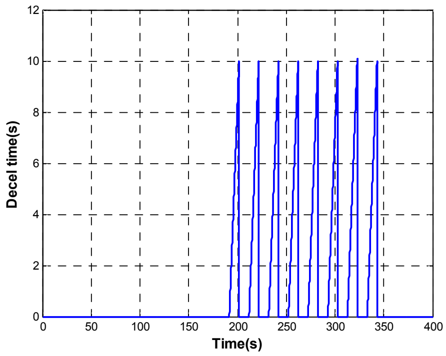

Figure 6.12 Deceleration time after Auto−tuning (Namyang−Suwon)

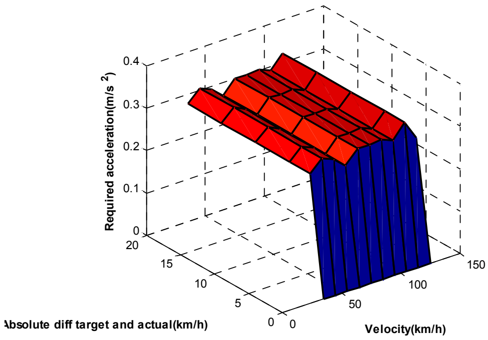

Figure 6.13 Acceleration Table after Auto−tuning (Namyang−Suwon)

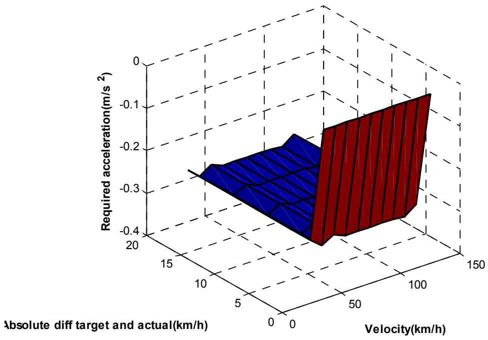

Figure 6.14Deceleration Table after Auto−tuning (Namyang−Suwon)

In addition, the vehicle driving data results are as follows .

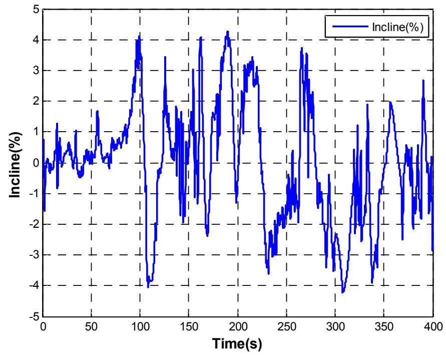

Figure 6.15 Slope according to Time (Namyang–Suwon)

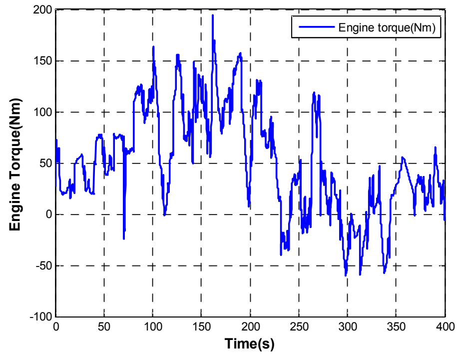

Figure 6.16 Engine Torque according to Time (Namyang–Suwon)

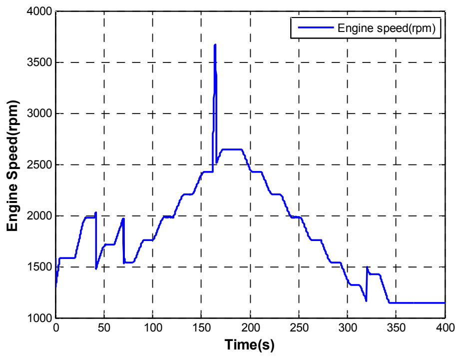

Figure 6.17 Engine Speed according to Time (Namyang–Suwon)

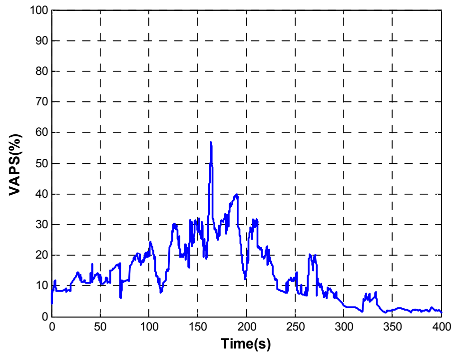

Figure 6.18VAPS according to Time (Namyang-Suwon)

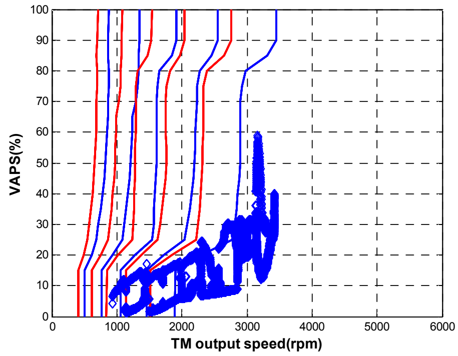

Figure 6.19 Operating Points (Namyang-Suwon)

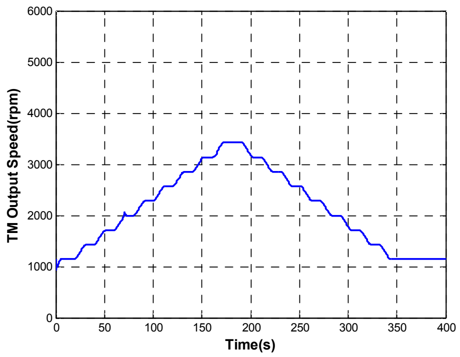

Figure 6.20 Vehicle Speed according to Time (Namyang-Suwon)

Auto−tuned required torque and shift pattern are applied in the following driving cycle. Simulation results of virtual driving before conducting auto−tuning applied in Cycle 1 are as follows.

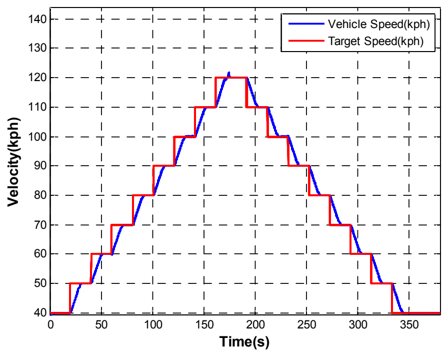

Figure 6.21Vehicle Speed data (Cycle 1)

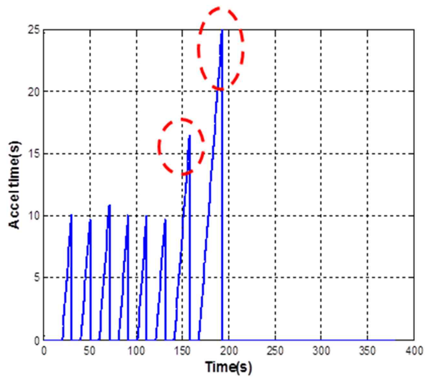

Figure 6.22 Acceleration Time before Auto−tuning (Cycle 1)

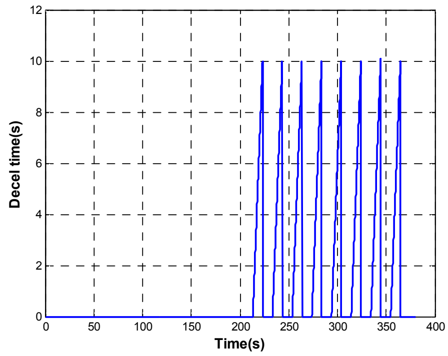

Figure 6.23 Deceleration Time before Auto−tuning (Cycle 1)

Acceleration of 100 −> 110, 110−> 120shows much short of the acceleration time to the reference time. Therefore, by tuning the shift pattern for the acceleration the vehicle is able to be driven in 5th gear number.

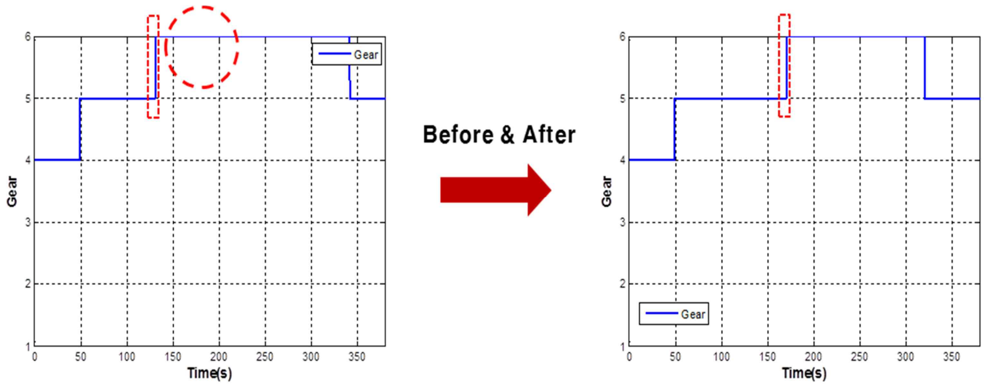

Figure 6.24Gear Change through tuning Shift−Pattern (Cycle 1)

Shift point is delayed from 5th gear to 6th gear as shown in the figure above by tuning shift−pattern. Vehicle changed transmission gear number in the section of 90 −> 100before tuning while performing a shift in the section of 110−> 120 after auto−tuning.

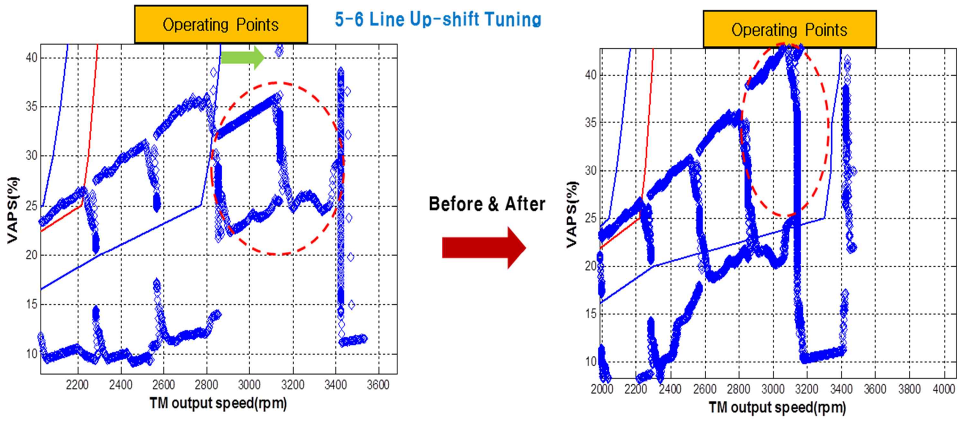

Figure 6.25Change of Operating Points (Cycle 1)

The position of the target sample in the red line is moved from 6^{th} gear to 5^{th} gear due to 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 inclination. The engine torque is applied to 100% of the engine speed and engine speed exceeding the speed limit does not satisfy the reference time. It require tuning of the transmission pattern. It is difficult section of acceleration to be driven as 6^{th} gear number for 100 -> 120.

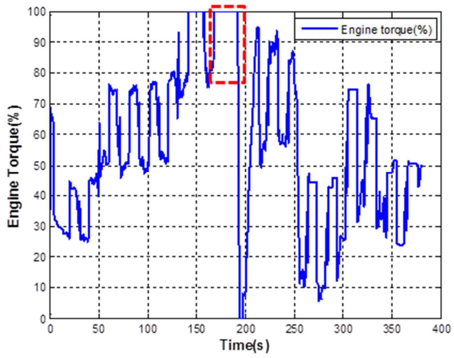

Figure 6.26 Period of 100% Torque Used (Cycle 1)

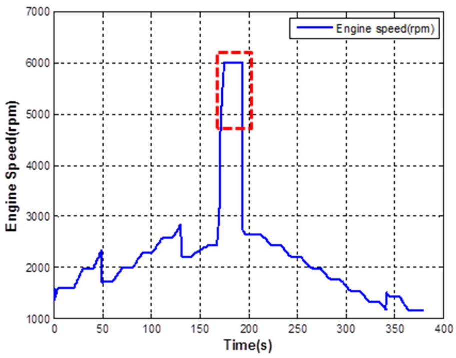

Figure 6.27 Period of Excessive Engine Speed (Cycle 1)

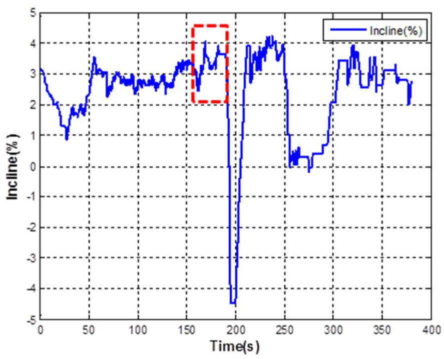

Figure 6.28Period of Heavy Load for Acceleration (Cycle 1)

The driving results of auto−tuning required torque after tuning shift−pattern done are as follow : It can be seen that driving time of the acceleration, deceleration satisfies the reference time.

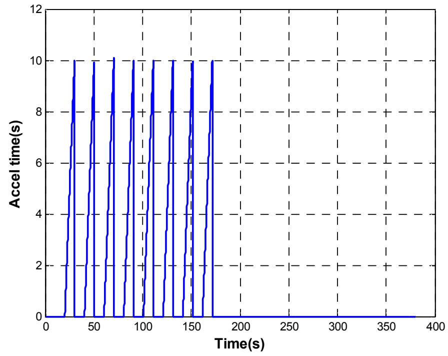

Figure 6.29 Acceleration Time after Auto−tuning (Cycle 1)

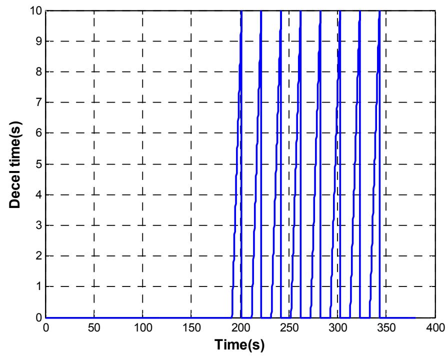

Figure 6.30Deceleration Time after Auto−tuning (Cycle 1)

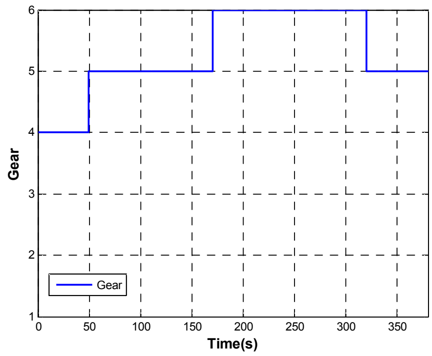

Figure 6.31 Gear Change after Auto−tuning (Cycle 1)

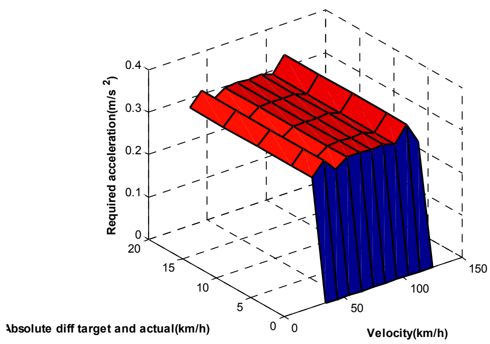

Figure 6.32 Acceleration Table after Auto−tuning (Cycle 1)

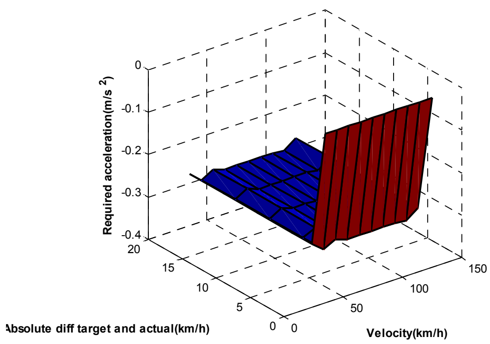

Figure 6.33 Deceleration Table after Auto−tuning (Cycle 1)

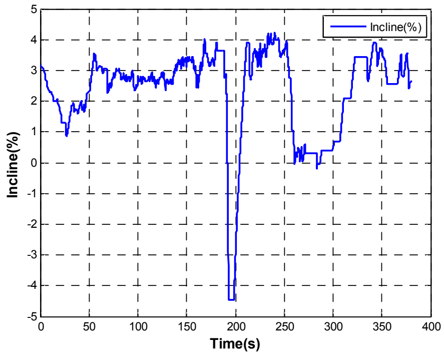

Figure 6.34 Slope according to Time (Cycle 1)

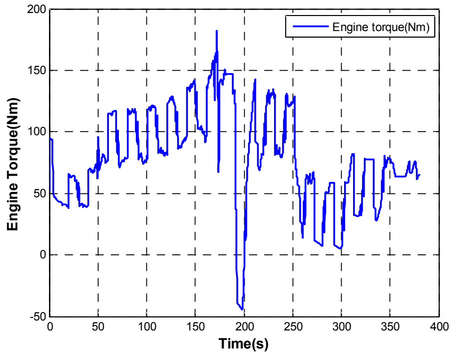

Figure 6.35 Engine Torque according to Time (Cycle 1)

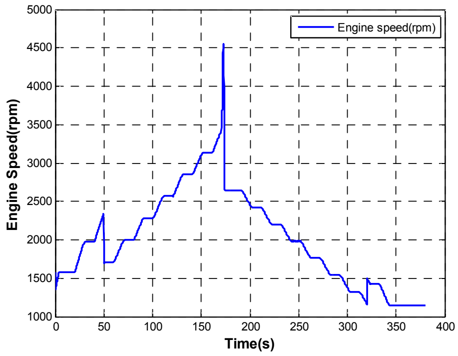

Figure 6.36 Engine Speed according to Time (Cycle 1)

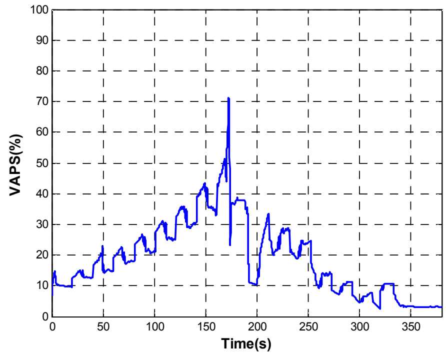

Figure 6.37 VAPS according to Time (Cycle 1)

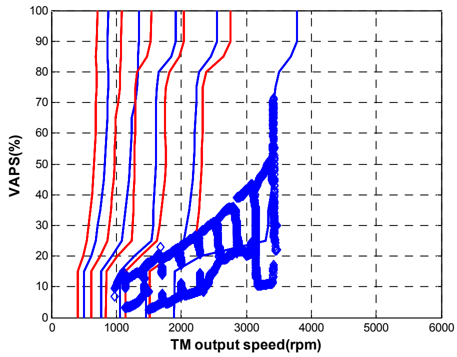

Figure 6.38 Operating Points (Cycle 1)

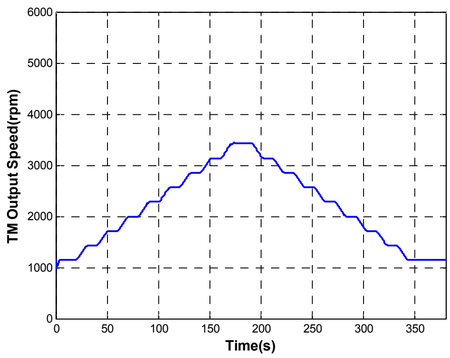

Figure 6.39 Vehicle Speed according to Time (Cycle 1)

Auto−tuned required torque and shift pattern are applied in the following driving cycle, Cycle 2. Auto−tuning of the required torque is performed only. Simulation results of virtual driving after conducting auto−tuning applied in Cycle 2are as follows.

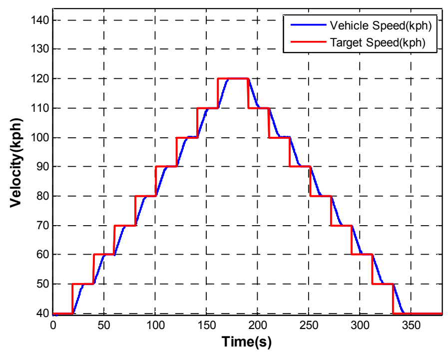

Figure 6.40Vehicle Speed Data (Cycle 2)

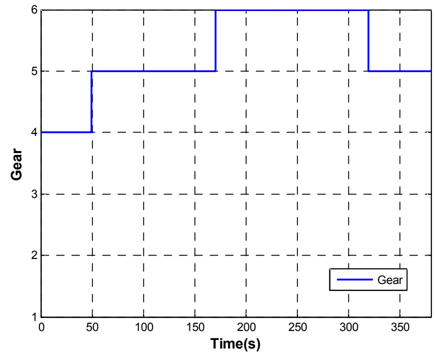

Figure 6.41 Gear Change according to Time (Cycle 2)

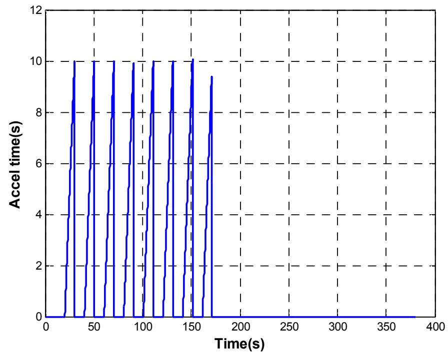

Figure 6.42 Acceleration Time according to Time (Cycle 2)

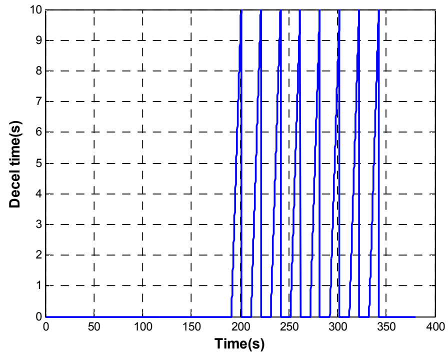

Figure 6.43 Deceleration Time according to Time (Cycle 2)

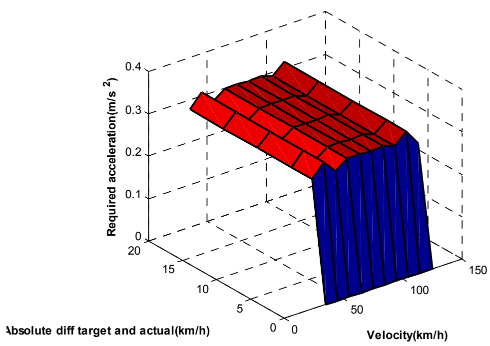

Figure 6.44 Acceleration Table after Auto−tuning (Cycle 2)

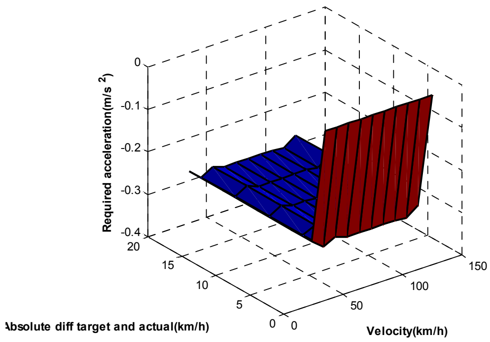

Figure 6.45 Deceleration Table after Auto−tuning (Cycle 2)

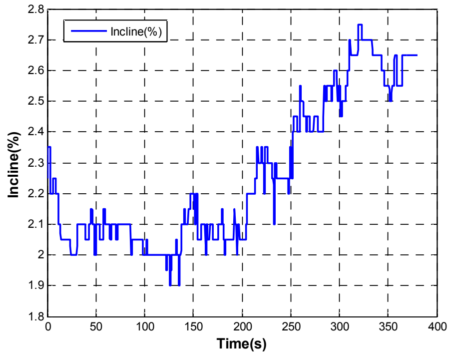

Figure 6.46 Slope according to Time (Cycle 2)

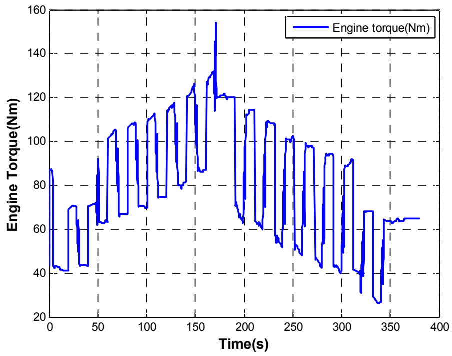

Figure 6.47 Engine Torque according to Time (Cycle 2)

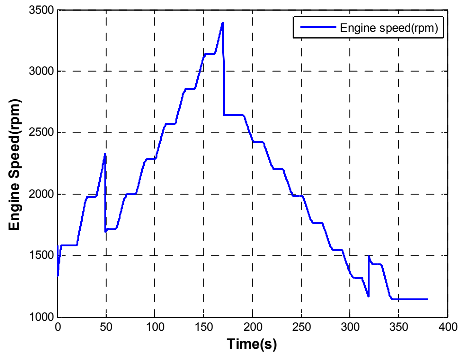

Figure 6.48 Engine Speed according to Time (Cycle 2)

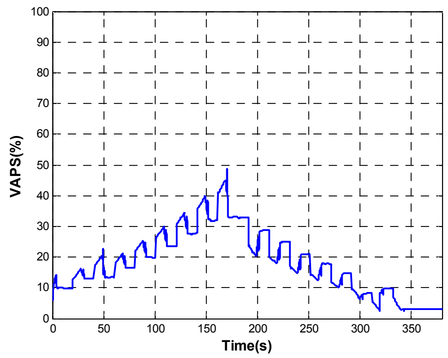

Figure 6.49VAPS according to Time (Cycle 2)

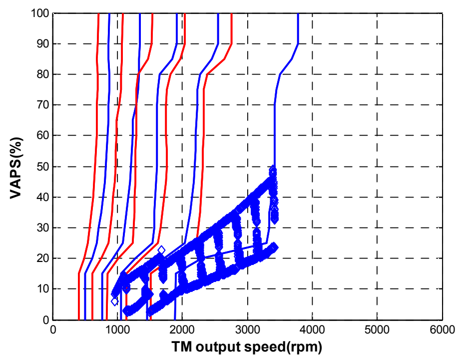

Figure 6.50 Operating Points (Cycle 2)

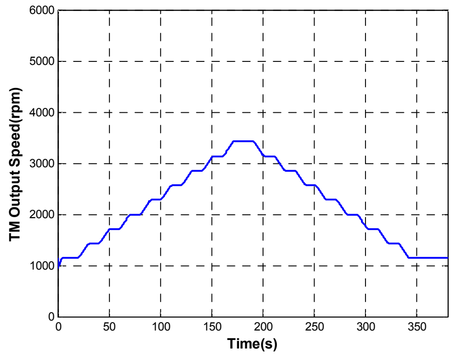

Figure 6.51Vehicle Speed according to Time (Cycle 2)

Next, auto−tuned required torque and shift pattern are applied in the following cycle, Cycle 3.The tuning of shift−pattern is conducted as Cycle 1 again. 5−6 Up−shift line is tuned by target samples in order to match the reference time with acceleration time of section 100 −> 110, 110 −> 120. Driving results before auto−tuning are as follows :

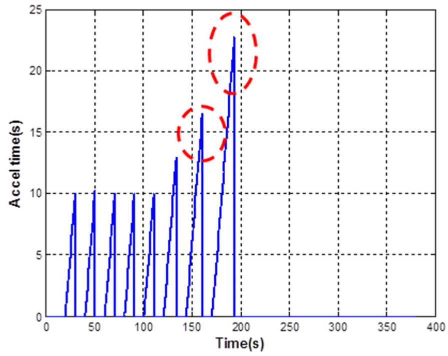

Figure 6.52 Acceleration Time before Auto−tuning (Cycle 3)

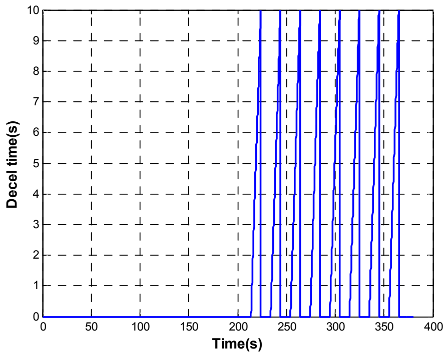

Figure 6.53Deceleration Time before Auto−tuning (Cycle 3)

Some acceleration periods have problem of matching reference time during high speed, especially above 100kph. Acceleration of high speed also needs driving of 5th gear number as cycle 1 in order to delay timing of shifting gear.

Before tuning shift−pattern, shifting to 6th is performed in the section of 60 −> 70kph, while being performed in the section of 110 −> 120kph after tuning shift−pattern.

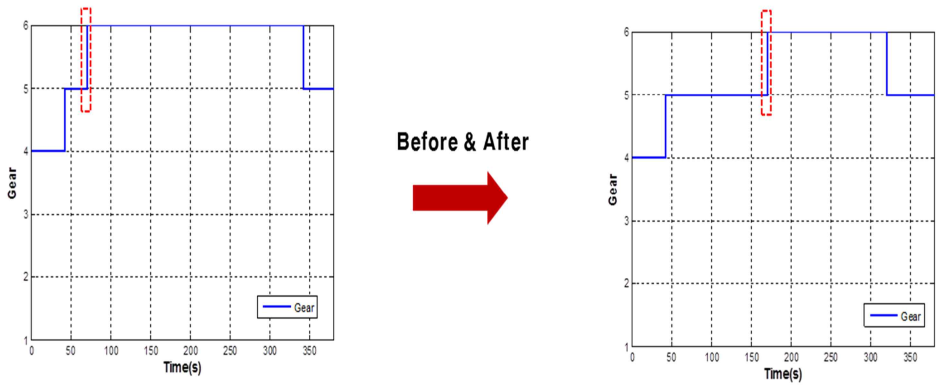

Figure 6.54Gear Change through tuning Shift−Pattern (Cycle 3)

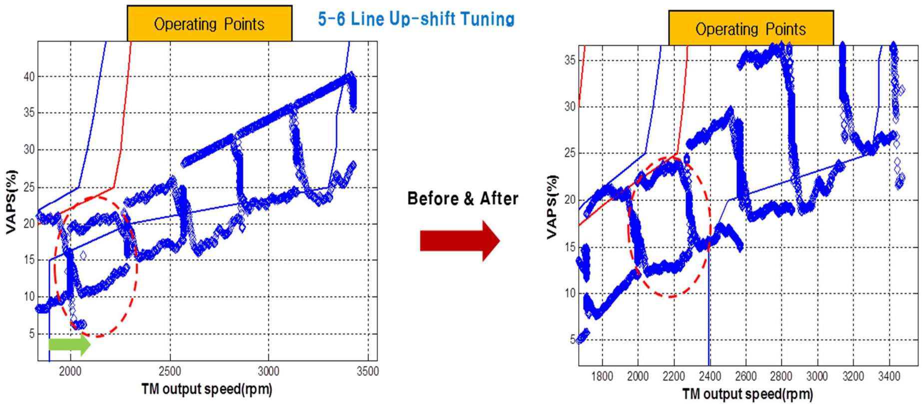

Figure 6.55Change of Operating Points (Cycle 3)

It moves the shifting points of the target tuning samples again. Shifting points of samples are moved from 6th to 5th to prevention shifting gear in the section of 60 -> 70kph by tuning the target line. Torque change due to the tuning of the transmission pattern is as follows. Less torque was used after tuning shift-pattern in acceleration periods of high speed.

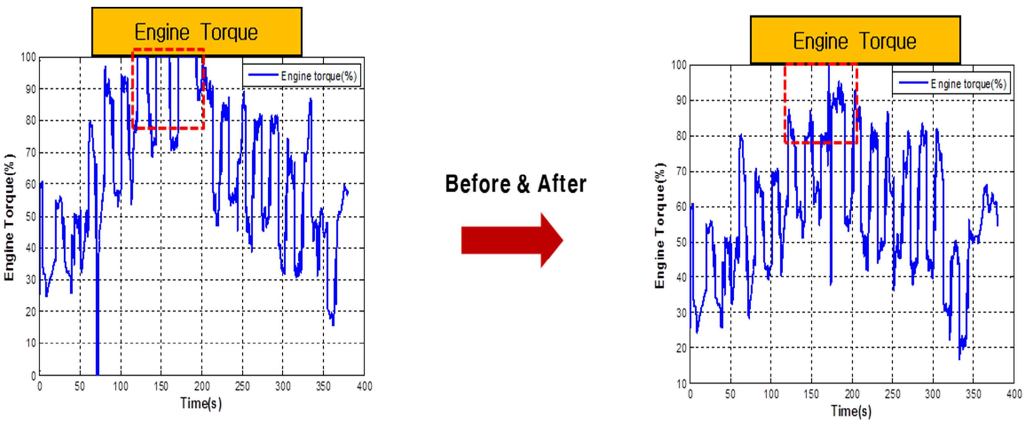

Figure 6.56Change of Engine Torque (Cycle 3)

The driving results of auto−tuning required torque after tuning of shift−pattern are as follows.

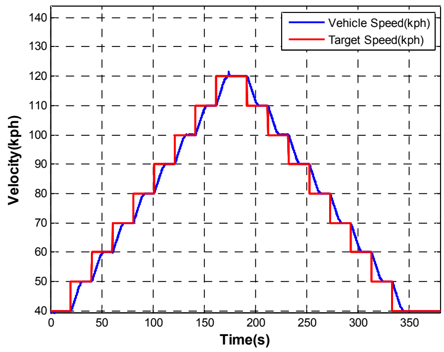

Figure 6.57 Vehicle Speed Data (Cycle 3)

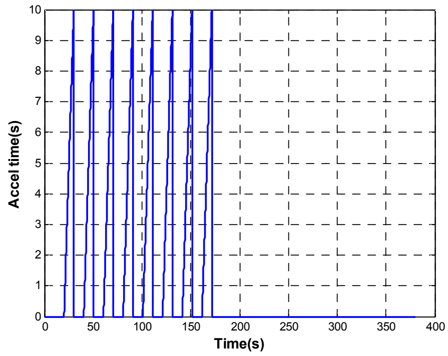

Figure 6.58 Acceleration Time according to Time (Cycle 3)

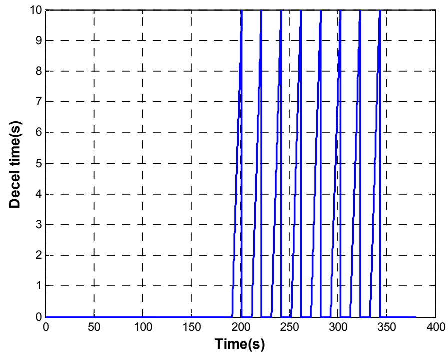

Figure 6.59 Deceleration Time according to Time (Cycle 3)

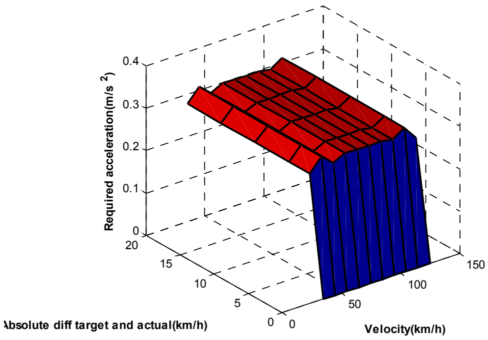

Figure 6.60 Acceleration Table after Auto-tuning (Cycle 3)

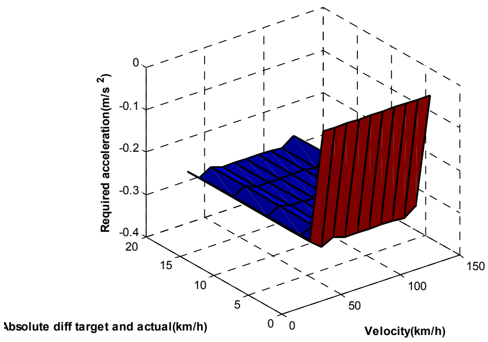

Figure 6.61 Deceleration Table after Auto-tuning (Cycle 3)

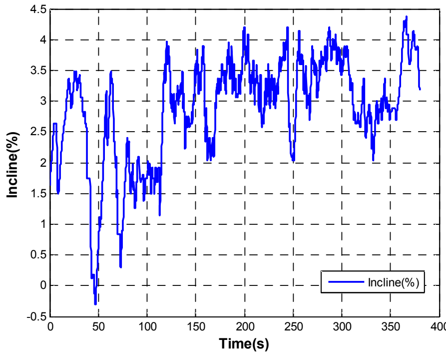

Figure 6.62 Slope according to Time (Cycle 3)

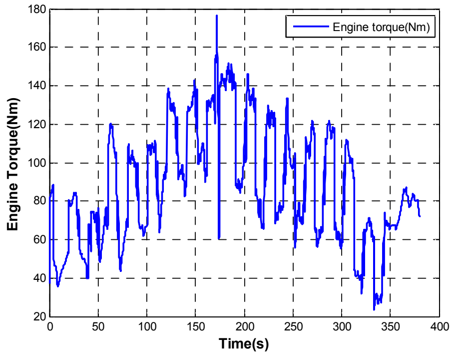

Figure 6.63 Engine Torque according to Time (Cycle 3)

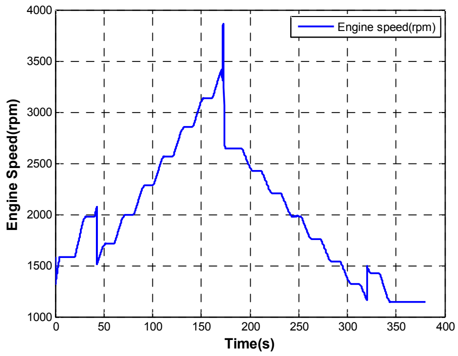

Figure 6.64 Engine Speed according to Time (Cycle 3)

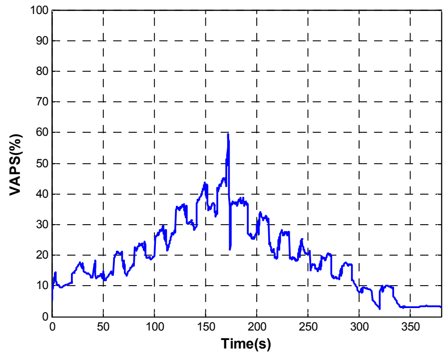

Figure 6.65 VAPS according to Time (Cycle 3)

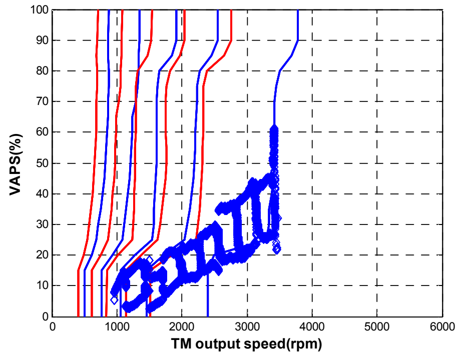

Figure 6.66 Operating Points (Cycle 3)

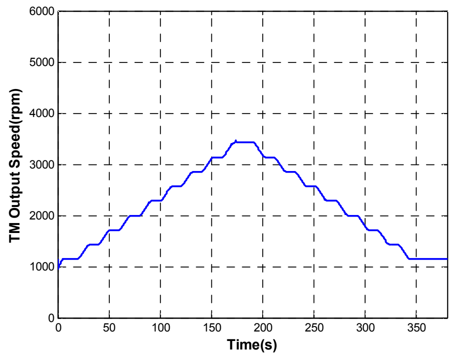

Figure 6.67Vehicle Speed according to Time (Cycle 3)

Automatic tuning did not happen in cycle 4 because it has mild fluctuation of driving load. Shifting gear does not happen in sections of constant velocity and acceleration, deceleration time appear to meet the criteria after applying auto-tuned required torque and shift-pattern of cycle 3 to driving simulation of cycle 4. Driving results are shown as follows :

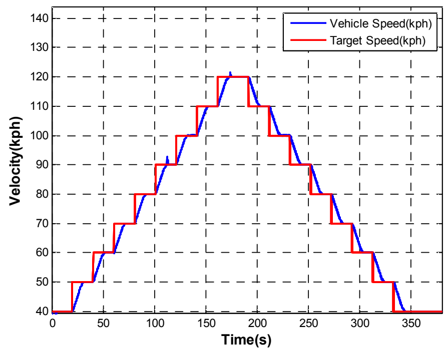

Figure 6.68 Vehicle Speed Data (Cycle 4)

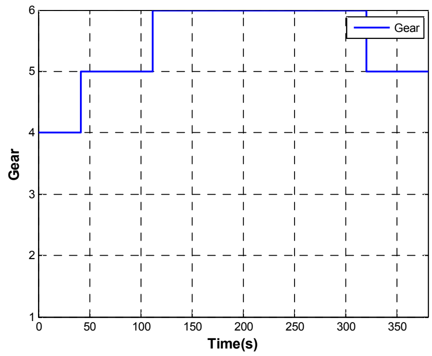

Figure 6.69 Gear Change according to Time (Cycle 4)

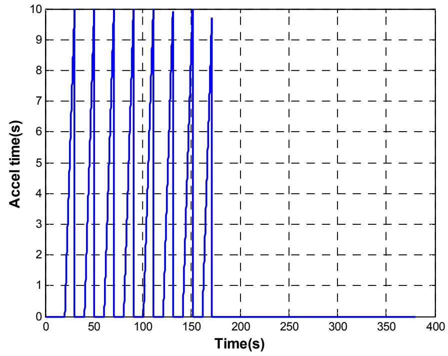

Figure 6.70 Acceleration Time (Cycle 4)

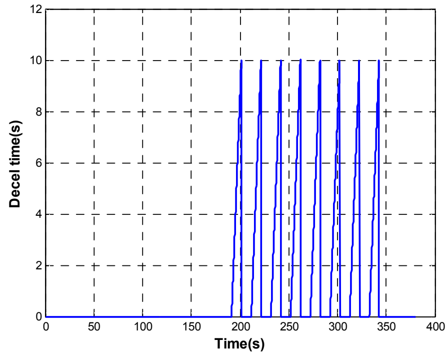

Figure 6.71 Deceleration Time (Cycle 4)

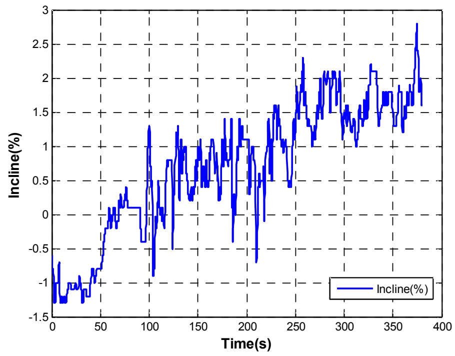

Figure 6.72 Slope according to Time (Cycle 4)

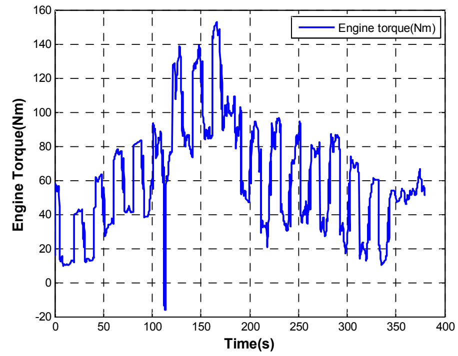

Figure 6.73 Engine Torque according to Time (Cycle 4)

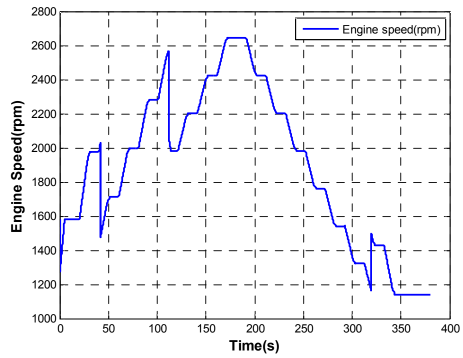

Figure 6.74 Engine Speed according to Time (Cycle 4)

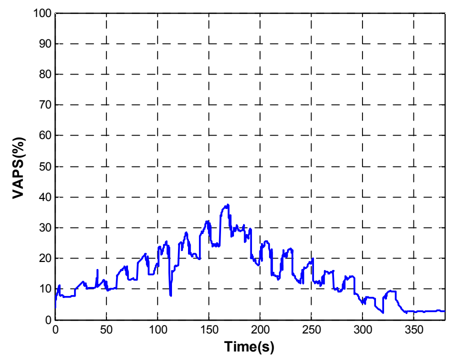

Figure 6.75 VAPS according to Time (Cycle 4)

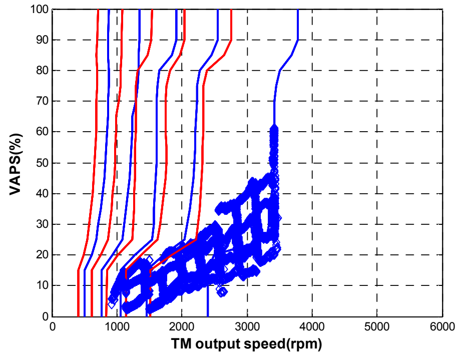

Figure 6.76 Operating Points (Cycle 4)

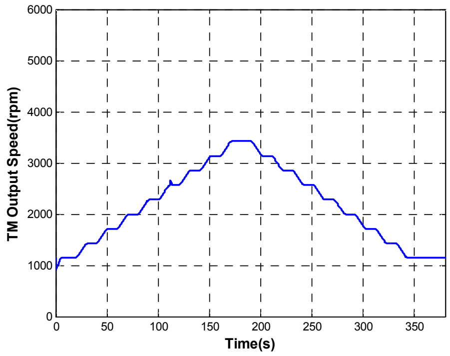

Figure 6.77Vehicle Speed according to Time (Cycle 4)

Change in the required acceleration table according to the driving environment is as follows. It can be seen that different driving environments and automatic tuning in progress makes the acceleration table converged. Large change in the driving environment is not detected.

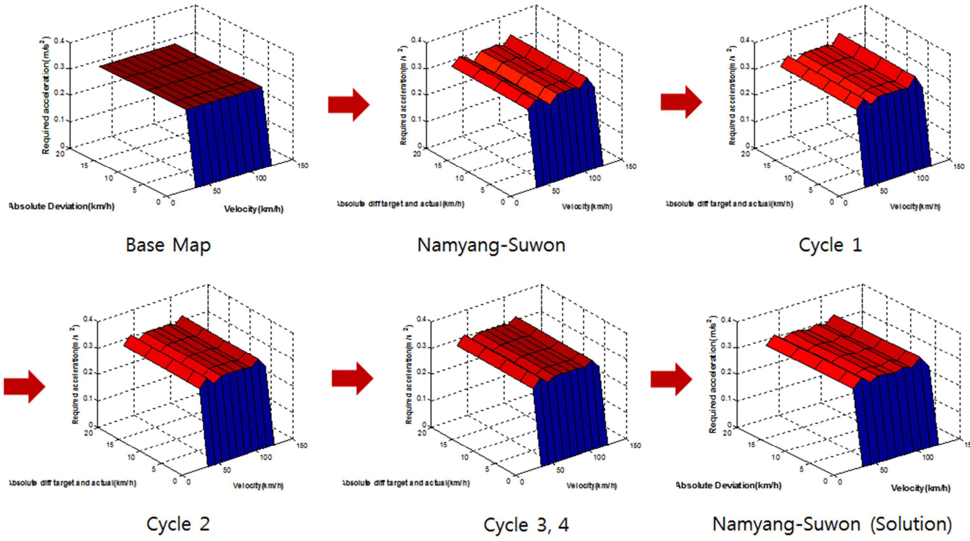

Figure 6.78Change of Acceleration Function

Change in the required deceleration in accordance with the driving environment is the table are as follows. It can be also seen that different driving environments and automatic tuning in progress makes the deceleration table converged. Even it shows less change compared to the acceleration table. Large change in the driving environment is not detected either.

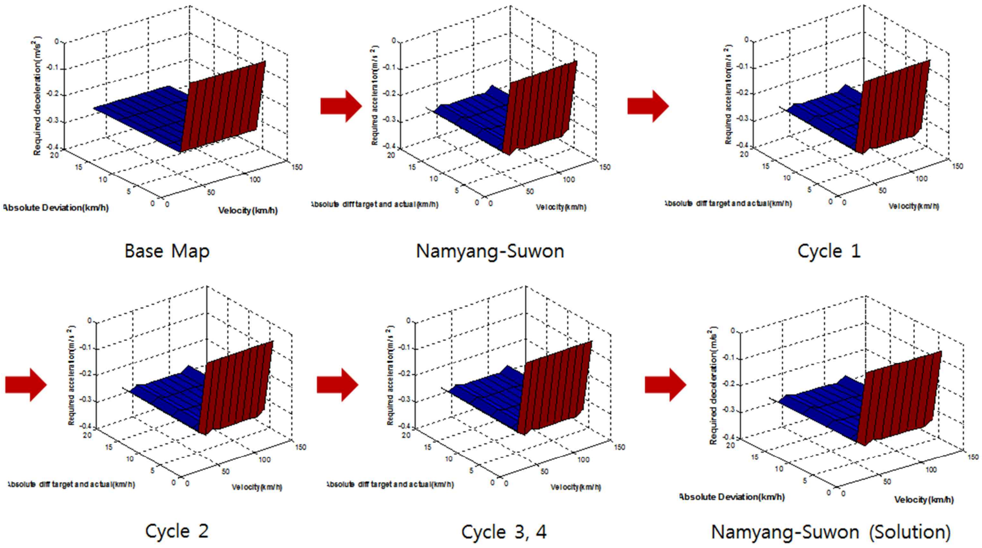

Figure 6.79Change of Deceleration Function

Change in the shift schedule in accordance with the driving environment is as follows. There is tuning of 5−6 Up−shift line for the acceleration of high speed above 100kph in cycle 1 and cycle 3, 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 in the below.

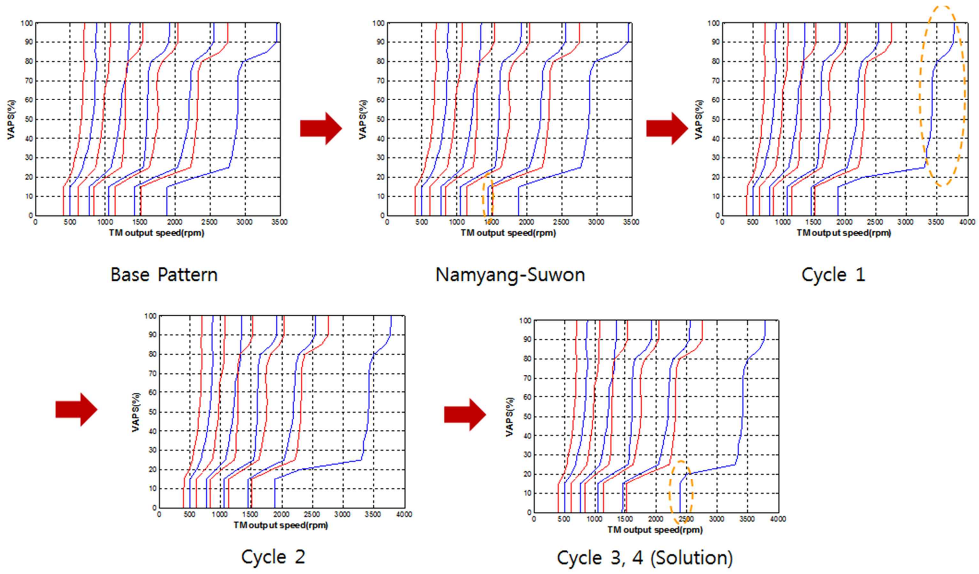

Figure 6.80 Change of Shift Pattern

6.2 Conclusion

The process of the auto cruise vehicle auto−tuning is simulated through real traffic information. Required torque by comparing the acceleration data in the actual driving to the target acceleration has been tuned automatically. It also extracts the constant speed, acceleration data samples of actual driving for tuning the shift schedule automatically. After the auto−tuning process repeated acceleration and deceleration to meet the target time at the end of driving simulation. In the constant speed section, in order to prevent shifting or hunting tuning of the shift−pattern is proceeded. Acceleration and deceleration time needs to match reference time by automatic tuning of the required torque. However, appropriate transmission gear is also applied to the vehicle in the acceleration period by tuning shift−pattern.

For example shift−pattern needs to be tuned in 100kph or more high−speed for driving of 5^{th} gear number instead of 6^{th}.Purposes of the automatic tuning are separated in two cases. It is to ensure driving performance to reach the target speed within the reference time in acceleration and deceleration. It is also to maintain the drivability in the constant speed. Effectiveness of the automatic tuning of the shift pattern is also shown for improvement which concluded that the effect of the auto−tuning overall increase drivability. And tuning of the shift−pattern is to ensure convergence of the required acceleration and deceleration according to the change in the driving environment. This is an important characteristic in the automatic tuning program being applied to an actual vehicle.

6.3 Future Works

The power train simulator including the auto cruise function is verified by comparing driving data of real vehicle and calculated auto tuning simulation results, but practically it is necessary to check the same between the manual and automatic tuning results of the vehicle. The powertrain simulator of its own logic is not completed so that the experiment of auto tuning was not conducted. However, the process of comparison will be needed for the verification of automatic tuning process.

Auto-tuning program can be implemented after generating driving data when the actual vehicle is stop or parked. (Transmission gear : P or N) This process can be carried out repeatedly, and there is a need to prove the convergence of the required acceleration and deceleration due to this.

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국 문 초 록

차량의 성능을 평가하고 그에 따른 변수를 튜닝하는 작업은 차량 시험을 담당하는 엔지니어에 의해 수작업으로 이루어져왔으나 시간과 비용이 많이 소모되는 단점이 있다. 이를 보완하기 위해 본 논문에서는 변수 튜닝작업의 자동화를 연구하였다. 대상 차량은 목표 속도를 추종하는 오토 크루즈 기능을 가진 엔진 차량이다. 먼저파워트레인 시뮬레이터를 제작하고 실제 주행을 통해 검증을 하였다. 파워트레인 시뮬레이터는 스위치 신호를 받아 목표 속도를 산출하고 그에 따른 요구토크를 계산하며 변속 패턴을 통해 변속 단을 지정한다. 변속 단은 일반적으로 차량 휠 속도와 스로틀 개도의 함수이지만 오토 크루즈 차량은 목표 속도를 추종, 유지하는 것이 중요하므로 가상 스로틀 개도라는 새로운 개념을 도입한다. 시뮬레이션을 시행하면 시뮬레이터의 주행데이터를 통해 목표성능을 분석하고 그에 따른 요구토크와 변속 맵을 수정한다. 수정된 변수들은 다시 차량에 적용되어 요구성능을 만족할 때까지 반복적으로 가상주행을 하게 된다. 목표성능은 차량의 가감속시 목표시간을 만족할 수 있는지, 정속 시 변속이 많이 일어나는지 여부가 포함된다. 요구 토크와 변속 패턴의 튜닝은 정속, 가속, 감속 세 가지 경우에 따라 적용되는 방식이 결정된다. 가속, 감속 주행 구간에서는 목표 속도에 도달하기 위한 목표시간을 만족하기 위해 요구 토크 계산에 적용되는 요구 가속도 함수를 조정한다. 변속 패턴의 보정은 주행 데이터에서 정속 및 가속 샘플을 추출하여 각 샘플에 대해서 튜닝을 진행한다. 먼저 각 샘플의 튜닝 대상패턴을 선정하고 그에 따른 단수를 판단한다. 그리고 구동력 부하조건과 거리비교조건을 통해 보정여부를 심사한다. 조건을 만족하지 못하는 샘플

과 대상 패턴에 대해서는 튜닝을 진행하지 않게 된다. 반복적으로 자동 튜닝이 진행된 주행 데이터를 분석하면 차량성능을 만족한다는 것을 알 수 있다. 결론적으로 엔지니어가 수작업으로 하는 변수 튜닝 작업을 컴퓨터가 대신하는 자동 튜닝은 편리성을 증대할 수 있고 기대효과 면에서도 차량 성능을 만족할 수 있다.

주요어 : 오토 크루즈 차량, 가상 스로틀 개도, 다분야 설계 최적화 이론, 자동 튜닝, 변속 패턴, 요구 가속도 함수
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