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An Automated Parameter Search Method for Vehicle Transmission System

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Abstract

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In the vehicle industry, shift quality is a major factor to evaluate the performance of a transmission unit. Following by the electric control units like ECU (Engine Control Unit) and TCU (Transmission Control Unit) took important role in the vehicle transmission, the computational parameters in the control units also took the key role to determine a shift quality. To find a set of optimal parameters, trial-and-error technique is most famous in the field. However the technique requires human experience for efficient and qualified parameter search. To generalize the quality and search time, there is a certain demand on the automation of parameter search.

The studies for automated calibration of automatic transmission system for shift quality have been placed in the automobile field. Actual vehicle and Dynamometer are used to automate the system, and they are based on the technique called Design of Experiment. Since the vehicle transmission systems are complex, exhaustive search technique is not proper to solve the problem. Design of Experiment limited parameters to handle only key factors. However the technique still requires human experience at the design level.

In this thesis, we propose a genetic algorithm based transmission parameter search method for a vehicle transmission system. In the pre-process phase, learn each parameter's effect on the target shift quality to avoid the dependency on human experience. Global search with genetic algorithm approach and local optimization is implemented. Simulink based vehicle simulator is used for experiment.

Keywords : Automated Calibration, Automatic Transmission, Vehicle Transmission System, Shift Quality, Genetic Algorithm

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Contents

List of Figures

1. Introduction

A modern vehicle consists of many mechanical and electrical parts. Electronic control units like Engine Control Unit (ECU) and Transmission Control Unit (TCU) takes important role while vehicle is moving. Since those control units are embedded computing systems, they use digital data as their control parameter. In this paper, we focus on the ECU/TCU parameters which determine the shift quality. In the industry, vehicle makers are using trial and error technique to search the electronic control unit's parameters. The performance of trial and error technique depends on the engineer's experience. To gain qualified parameter data, trial and error technique takes reasonable time for senior engineers, but it takes enormous time for inexperienced engineers. To generalize the quality and performance of the parameter search process, automation would be a reasonable solution. So many studies for automated calibration have been placed and introduced in Section 2.

To automate the parameter search, there must be a clear criteria to determine whether parameters are good or bad. In this paper, the criteria is the acceleration pattern while target vehicle shifts its state. The acceleration pattern represents shift quality. Properly optimized parameter would give desired acceleration pattern which makes shift as comfort or sporty but inadequate parameter provide uncomfortable experience to driver. To evaluate the acceleration pattern, specific constraints are given on the acceleration pattern. Figure 1 presents the usual usage of vehicle simulator and figure 2 presents the concept of parameter search automation.

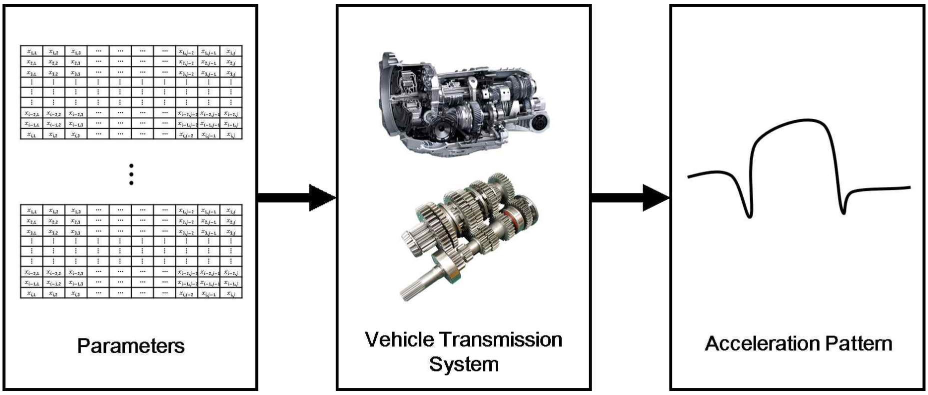


Figure 1. Vehicle transmission system

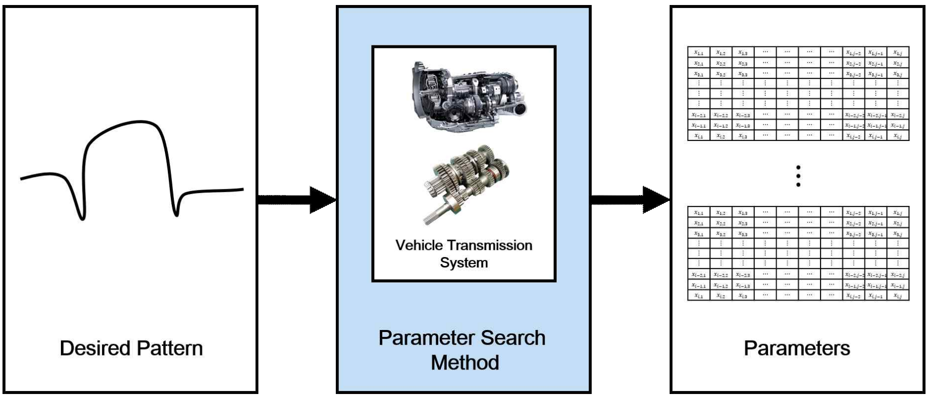


Figure 2. Parameter search automation

Simulink is a model based design and simulation tool which have been widely using in the industries. Vehicle simulation with Simulnk also has been studying for decades. Vehicle simulation has complex architecture and dynamics on both mechanical and electrical matters. [1] developed a dynamic model of vehicle with 8 or more speed automatic transmissions using Simulink. To calibrate the TCU over the dynamic model of vehicle, there are large number of parameters which enlarges the solution space. The solution space is too large to apply exhaustive search techniques.

Thus, we suggest to use Genetic Algorithm to solve the problem. Genetic Algorithm is an optimization algorithm which mimics the concept of natural evolution and applicable to wide range of problems. In biology, DNA, the genetic material forms gene, and the string of genes packaged into the structure called chromosome. Genetic Algorithm uses gene as smallest parameter and a chromosome, a possible solution consists of genes. From initial set of random chromosomes, Genetic Algorithm attempt to crossover and mutate to search a better chromosome. Genetic Algorithm only guarantees local optimum, however if the solution meets with the constraints of TCU parameter, the solution is valid.

In this thesis, we propose an automated parameter search method for vehicle transmission system while vehicle is shifting from the second gear to the third gear. This study would reduce the enormous amount of time for searching the TCU parameters for inexperienced engineers. A vehicle dynamics model in [1] used as vehicle simulator to design the experiment.

The rest of this thesis is structured as follow: we surveys the related works of Automated calibration for vehicle transmission system, Simulink vehicle simulation, Genetic Algorithm and Design of Experiment in Section 2. The background and the problem will described in Section 3. In Section 4, we are going to propose a parameter search method for vehicle transmission system with Genetic Algorithm and local optimization techniques. The Conclusion and future works are summarized in Section 5.

2. Related Work

Automated calibration for automatic transmission shift quality is well known topic in the automobile field. [11] automated the parameter calibration procedure with actual vehicle test bed. Design of experiment is used to limit the number of parameters, and driving force is measured from the test bed. [12], [13], [14] implemented the automated calibration system with vehicle dynamometer without actual vehicle. An automated calibration system determined the parameters to calibrate. However the design of experiment approach is not free from a certain model, since calibration parameter boundary decision requires human experiences.

For decades, a lot of studies have been placed for vehicle simulation. Vehicle simulation helps to reduce the physical cost of experiment and time. [1] developed a Simulink based dynamic model of vehicles with 8 or more speed automatic transmission to analyze shift quality and dynamic behavior of the vehicle while it's moving. [2], [3], [4], [5] also developed and validated Simulink based vehicle simulations. Old version of simulations were focused on the vehicle dynamics, however recent vehicle simulation like [1] considered about electronic control units such as ECU and TCU.

Grefenstette [6] attempted to determine the optimal control parameters for Genetic Algorithm. The study covered subclass of Genetic Algorithms characterized by the following six exogenous parameters: Population Size, Crossover Rate, Mutation Rate, Generation Gap, Scaling Window, Selection Strategy. Thomas Back [7] introduced several experimental studies towards searching optimal settings of certain exogenous parameters and presented a theoretical foundation for the usefulness of self-adaptation within Genetic Algorithm. Eiben, Hinterding, and Michalewicz [8] also surveyed various studies of exogenous parameter control in evolutionary algorithms.

Introduced related works to automate the parameter calibration process required human experiences. In this thesis, we are going to propose an automated parameter search method without human experience using vehicle simulator introduced in [1].

3. Background and Problem Description

3.1 Simulink Vehicle Simulation

[1] introduced and developed a dynamic model of vehicle with 8 or more speed automatic transmissions. In this thesis, we are going to use [1] as a reference vehicle simulation model. The dynamic model of vehicle is implemented with Simulink and the model consists of engine module, TCU module, transmission module, torque converter module, and vehicle module. The effectiveness of Simulink based vehicle model have been verified by comparing simulation result with the actual vehicle test data.

3.2 Clutch System

In the automatic transmission (A/T) system, clutches and brakes are controlled by hydraulic pressure of solenoid valves. TCU module contains parameter tables which A/T reference to make a decision for amount of hydraulic pressure at a certain shift phase. The tables inside the TCU module is the parameters we want to calibrate to make a good shift quality. At a shift, we usually controls one release cluch and one apply clutch. There is a vehicle system required to control two release clutch and two apply clutch at a shift, however we only considered the controls of one release clutch and one apply clutch at a shift. In our reference vehicle simulation model, release clutch controlled by two parameter tables and apply clutch controlled by seven parameter tables. During the shift, a value from table referenced following by the torque and RPM at the moment. So our solution is about how to control the clutch system.

3.3 Genetic Algorithm

Genetic Algorithm (GA) is a global optimization technique that mimics the concept of natural evolution. Grefenstette [6] described general framework for the GA in the paper. Following the description, GA impacted by the six exogenous parameters:

1) Population Size
2) Crossover Rate
3) Mutation Rate
4) Generation Gap
5) Scaling Window
6) Selection Strategy

Selection is an operation to decide parent chromosomes for crossover. There are various selection operators, however they share an identical characteristic that better solution have a better opportunity to be selected. The opportunity to be selected is controllable. The fitness gap between good solution and bad solution determines the opportunity to be selected, and the fitness gap is called selection pressure. A pure selection reproduce each chromosome in the current population proportional to its performance. The best chromosome may disappear due to sampling error, crossover, or mutation. However an elitist strategy, takes the best chromosome to the next generation with intactness.

There were many experimental studies to search an optimal setting of the exogenous parameters. Following by the [7], several studies investigated some resulting settings of population size, mutate rate, crossover rate. Unfortunately, the investigations from the studies are not applicable to our problem. Since a Simulink based simulation takes around 10 seconds, population size N must be smaller than the average exogenous parameter settings.

3.4 Design of Experiment

Design of Experiment (DOE) is general method takes role of design and control of experiments. Design of Experiment provided efficient and accurate experiments that used in the field for a long time. It reduces insignificant experiments and clarify the purpose of experiment. [12] used D-optimal design technique to solve the identical parameter search automation problem. D-optimal design makes boundaries and limit the range of the parameters. D-optimal design is useful but dependent on the human experience.

3.5 Problem Description

Our goal is to search suitable parameters for ECU and TCU to produce desired acceleration pattern from vehicle simulator in a reasonable time budget. The target scenario tested in this thesis is transmission shift from the second gear to the third gear.

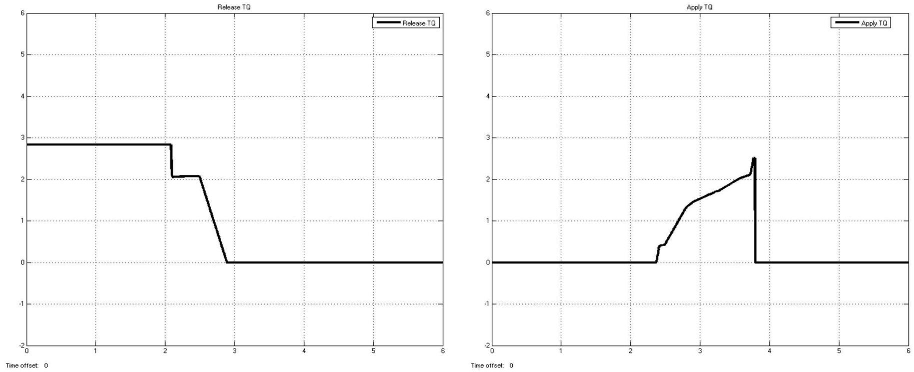
To generate an acceleration pattern, we have to control 10 parameters, $I_0 \ldots I_9$. The details of each control parameters are listed below:

- $I_0 \ldots I_1$: Release Clutch Torque
- $I_2 \ldots I_8$: Apply Clutch Torque
- I_9: Engine Torque Reduction

Torque \ RPM	416	608	800	992	1216	1504	1824	2016	2304	2592
0	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
10	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4	13.4
20	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
30	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
40	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
50	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
60	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35
70	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35
80	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35

Figure 3. An example of a parameter

As shown in figure 3, a control parameter is in form of a matrix. Row represents engine torque, and column represents engine RPM. Vice versa in Engine Torque Reduction matrix. A value from a matrix referenced following by the engine torque and RPM at the moment and used for hydraulic pressure control. As a constraint, on the matrix, $p_{ij} \geq p_{i-1j}$ and $p_{ij} \geq p_{ij-1}$



(a) (b)

Figure 4. Release clutch & apply clutch

Following by the value from the matrix, the clutch pressure changes like in figure 4. I_0 and I_1 controls release clutch pressure (figure 4-a), and $I_2 \ldots I_8$ controls apply clutch pressure (figure 4-b).

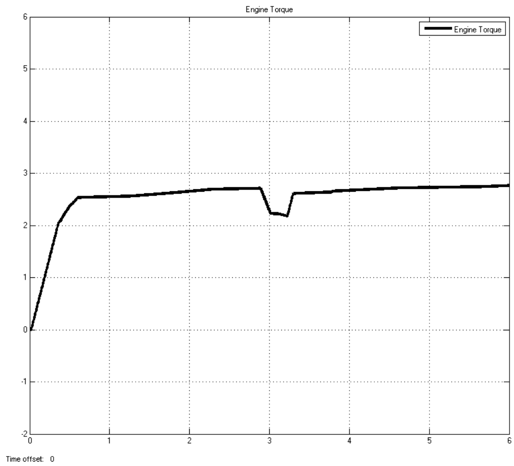


Figure 5. Engine torque reduction

Figure 5 is an engine torque reduction which controlled by I_9.

Each parameter affect on the certain points of acceleration pattern. Figure 6 marked key points on the acceleration pattern for the specified gear shift.

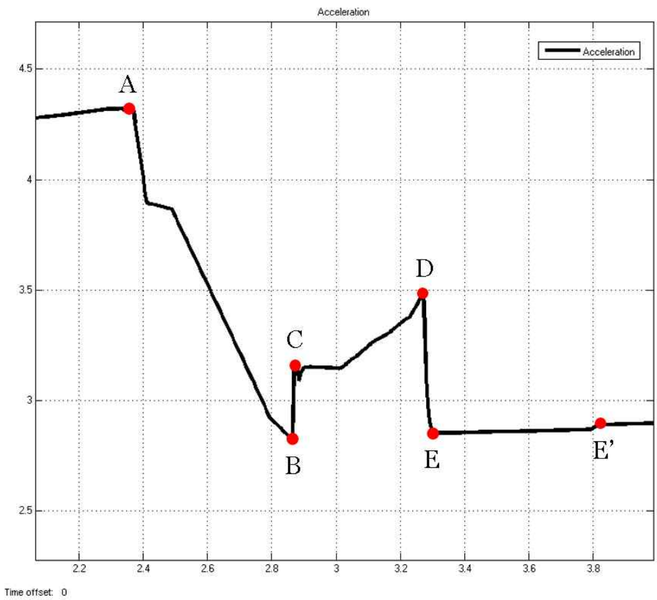


Figure 6. Key points on the acceleration pattern

Such as engine torque reduction highly affect on points D and E. If lower the engine torque reduction value, D and E goes lower. Each value on the matrix represents pressure torque which generates force in the solenoid valve in the clutch. At certain engine torque and RPM, a value from the matrix referenced and affect to make an acceleration pattern.

So the goal of this problem is to find 10 control parameter matrix which generates acceleration pattern from vehicle simulator as given desired pattern.

There are certain constraints on the problem. From shift start to C point, the time must be shorter than 0.8 seconds. Also from A point to D point, the time must be shorter than 1.32 seconds. These constraints are placed because of the limitation of actual transmission specification.

4. Proposed Solution

In this section, we propose an automated parameter search method for vehicle transmission system. First, we briefly explain the existing solutions, and then explain our approach.

4.1 Existing Solution

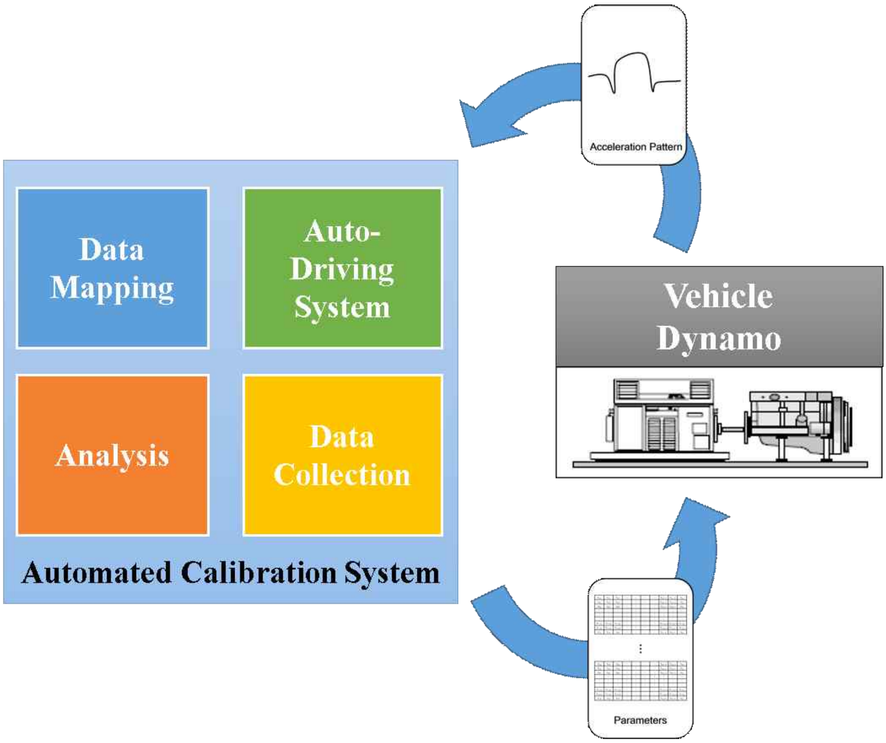


Figure 7. An example of existing solution

As stated in Section 2, automated calibration for vehicle transmission system is famous problem in the automobile field. The existing studies placed actual vehicle or dynamometer with certain tools to enable automatic driving and calibration. Vehicle and dynamometer produce the driving data including acceleration pattern, and automatic calibration system iteratively controls ECU/TCU parameters to find an expected result. The automatic calibration system is based on Design of Experiment technique. The technique set boundaries on the parameters to reduce the number of experiments, but the boundary settings require expert's experience.

4.2 Our Approach

For computational approach, exhaustive search is not a preferable solution for the stated problem since solution space is too large that exhaustive search requires too much time to search all the solution space. Because of the large solution space, and existence of multiple solutions, genetic algorithm is a better choice.

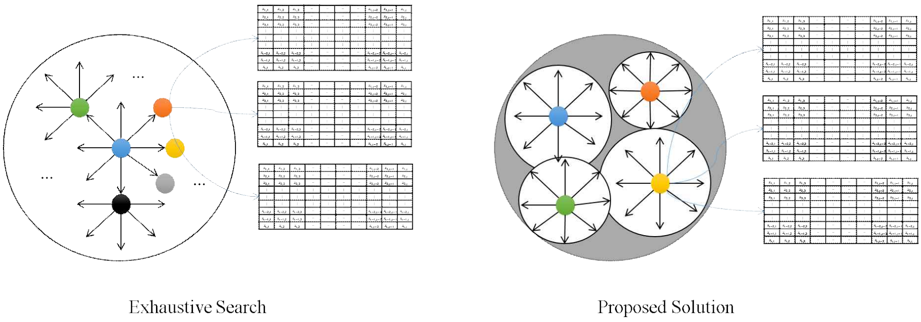


Figure 8. Overview of proposed solution

However traditional genetic algorithm also not perfectly suitable to the problem. It requires large amount of time to find a good solution, and lack of local search performance. So we decided to add a local search algorithm to the genetic algorithm. On the other hand, we tried another approach that choose initial chromosome from exhaustively searched solution. The solution gives early convergence, but also reserves a good solution. Figure 8 is an overview of proposed solution.

Figure 9 is a flow chart of proposed the solution. In the preprocessing phase, we collect the correlation data of each parameter on the acceleration pattern. To collect the data, change a parameter and evaluate the effect on the acceleration pattern. With the correlation data collected from preprocessing, local optimization search the local optimum from the initial population.

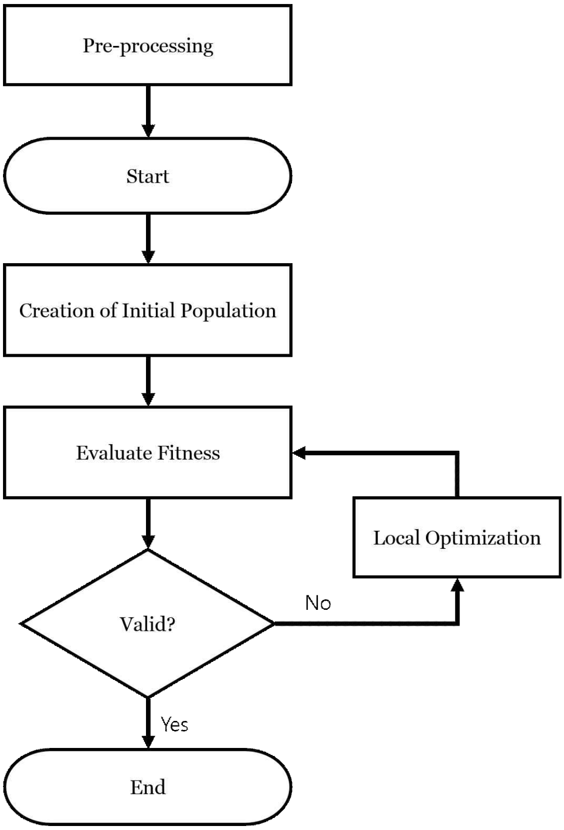


Figure 9. Flowchart of proposed solution

Genetic algorithm approach is applied in the creation of initial population phase. A gene in a chromosome is a control parameter that a chromosome consists of 10 control parameters. A gene is mutated to search the unknown solution space. Usual studies for finding optimal settings of genetic algorithm uses population size between 30 to 100. We used 3 to 5 population size for experiment, since the time budget was limited and a simulation takes about 10 seconds. Larger population gives better chance to find a better solution that if enough time budget is given, larger population is a better choice. In case of small population, the initial chromosome from genetic algorithm might be good or bad. Figure 10 shows how randomly generated initial chromosomes can affect on the result with small population. With the small size of population, exhaustively searched initial chromosome is preferable to reserve a reasonable solution. The reasonable solution might not as good as a solution from randomly generated initial chromosome, but it guarantee a good solution.

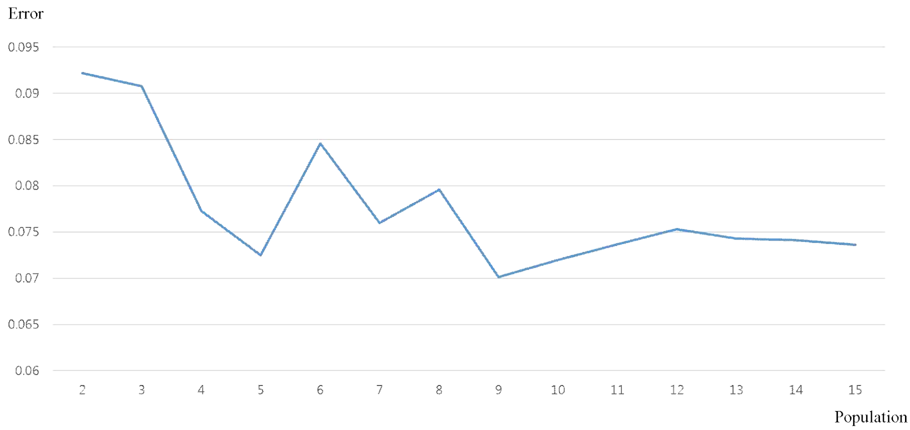


Figure. 10 An example of random solutions of genetic algorithm

Figure 11 shows the result with exhaustively searched initial chromosomes. The exhaustive search operated for small part of solution space that solution space to search determined by the correlation data from the preprocess phase.

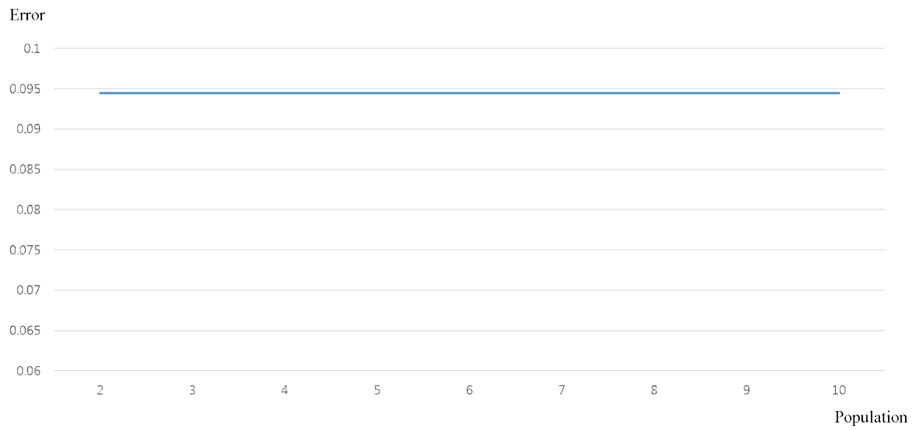


Figure 11. Result with exhaustively searched initial chromosomes

Back to the Figure 6, the values of C-E’, D-E’, and E’-E used as key criteria for estimate shift quality. Points A, B, and E’ are steady and C, D, and E are highly affected by control parameters and changes the shift quality. Especially E’-E gives strong impact during the shift, so better minimize the value. Figure 11 shows the bad example of acceleration pattern which have large value for E’-E. In the case of figure 11, engine torque reduction is too low, that D and E pulled down. To fix the problem, the program have to raise the engine torque reduction value, and it’s the job of local optimization.

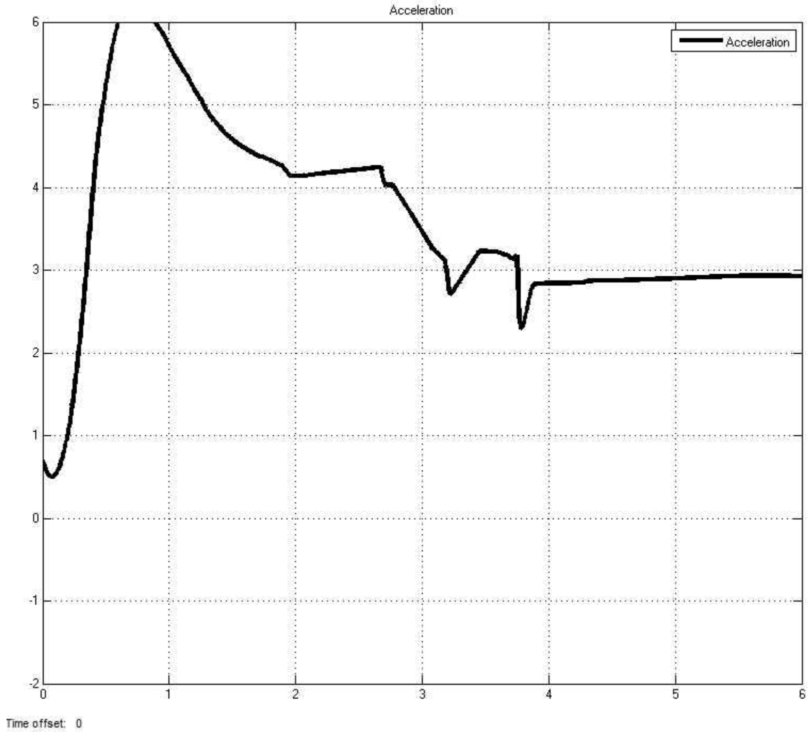


Figure 12. Bad example of acceleration pattern

Before look into the local optimization, let's mention about the pressure table. As stated above, pressure values from a table referenced at certain torque and RPM. That means we have to fill the table for all the ranges of torque and RPM. However there are certain scenarios that never happens, so we have to interpolate and extrapolate the map with achievable data.

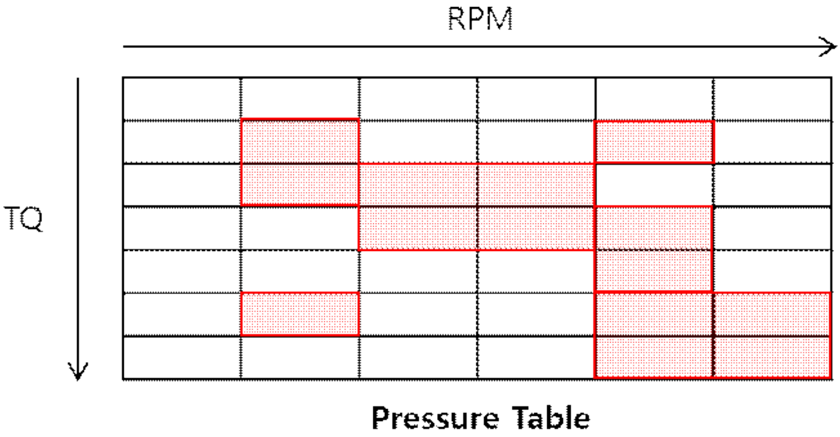


Figure 13. Coverage of pressure table

As shown in figure 13, determine some coverage on the map and fill the coverage with data. The condition can be achieved by handle throttle and initial velocity from simulator. Before fill the table, we have to remind there is a constraint of $p_{ij} \geq p_{i-1j}$ and $p_{ij} \geq p_{ij-1}$.

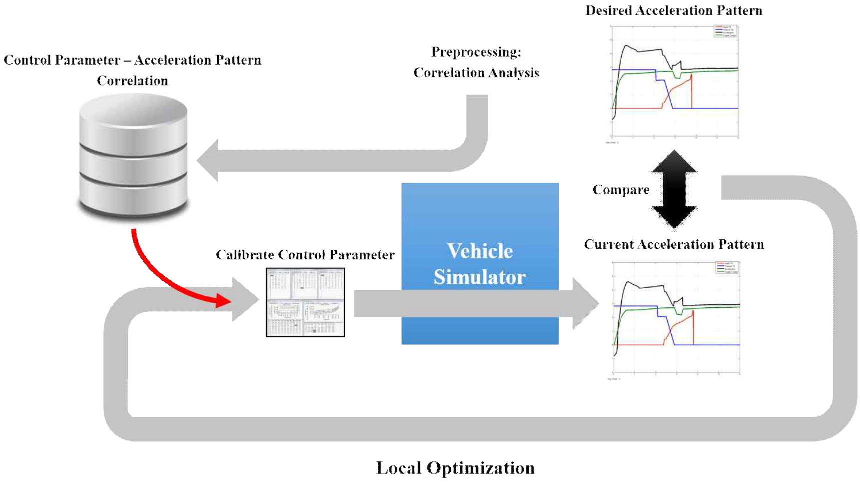


Figure 14. Local optimization

Figure 14 shows the flow of local optimization. In the local optimization phase, the program use correlation data earned from preprocessing phase to calibrate the parameters. Directed local optimization is implemented that if a result of a step of local optimization is worse than before, the change not applied and local optimization controls next parameter. Desired acceleration pattern described in terms of C–E', D–E', and E'–E. After a simulation, program compare the desired acceleration pattern with current acceleration pattern, then calculate the insufficiency for each point to calibrate control parameters.

5. Experiment

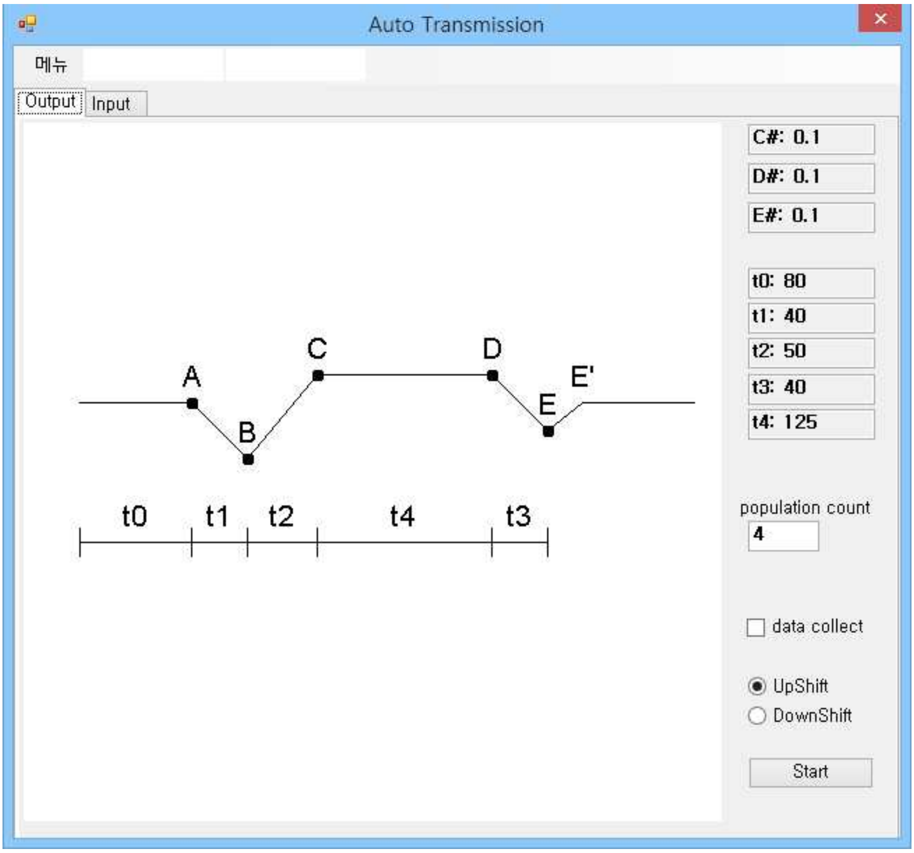


Figure 15. GUI for parameter search method

Matlab program with GUI implemented for experiment. Figure 15 is an implemented GUI of the Matlab program. In the figure, C# means C-E', D# means D-E', and E# means E'-E. GUI used to give desired acceleration pattern and population number. 0.1 is an absolute value measured in the vehicle simulator model. With a general genetic algorithm approach, large population size is preferable, however with exhaustively searched initial chromosome, small population is reasonable.

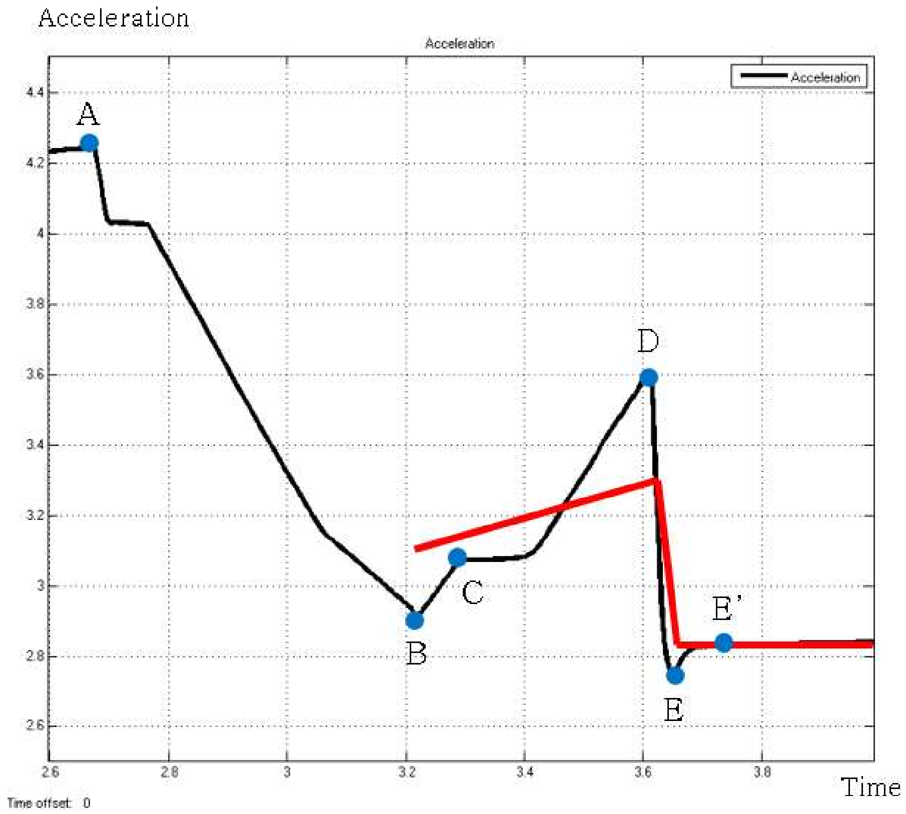
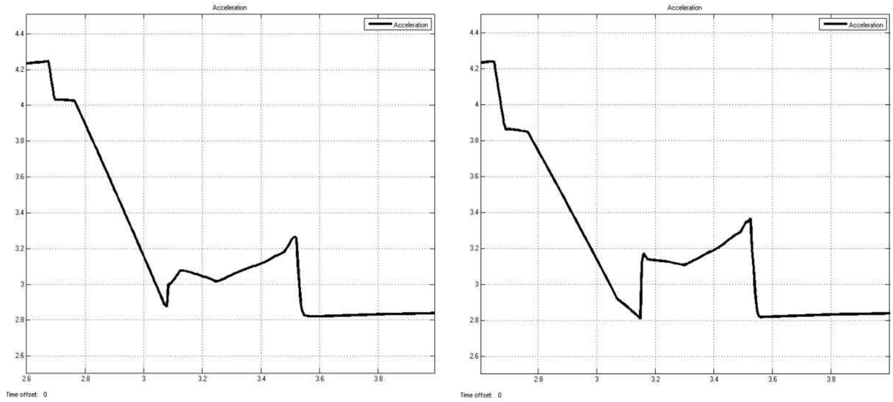


Figure 16. Parameter search result of inexperienced engineer

Figure 16 is a parameter search result of inexperienced engineer. Red line indicates the expected acceleration pattern. Even though he spent hours to calibrate the parameters, still point C and E are too low. Since E# is not soft enough, there will be a shift impact which makes bad shift quality.



(a) Result from an expert (c) Result from our program

Figure 17. Comparison of simulation results

Figure 17-(a) represent a simulation result with parameters given by industry expert. Figure 17-(b) is a simulation result from our program which tested with desired acceleration pattern of C#=0.25, D#=0.35, E#=0.

The result from implemented program is acceptable in the view of shift quality, but point C is little higher than expected pattern. It means there are still room for improvement.

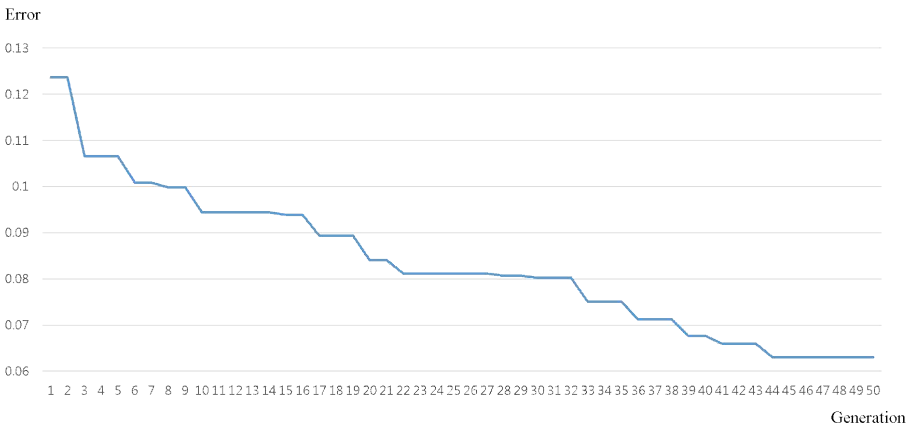


Figure 18. Error-Generation graph

Figure 18 shows that more generation gives better solution. Until 50 generation, the error rate keep decreasing. It represent our local optimization is well functioning.

Figure 17 verified our program can find a close solution to the desired acceleration pattern. Tested scenario is transmission shift from second gear to the third gear.

6. Conclusion and Future Work

This thesis proposed an automated parameter search method for vehicle transmission system using the vehicle dynamic model introduced in [1]. Genetic algorithm approach have been used to solve the described problem. Local optimization technique for the vehicle transmission parameters placed and specific transmission scenario of shift from the second gear to the third gear experimented.

As a future work, various transmission scenarios will be experimented and verified. Proposed parameter search method generally cover the problem, however there might be an issue raised during the other scenarios. To make sure the proposed solution is completely work, all the transmission shift must be verified.

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요약(국문초록)

차량 변속 시스템을 위한 인자 탐색 자동화 기법

변속감은 자동차 산업에서 변속기를 평가하는데 중요한 요소로 이용되고 있다. ECU(Engine Control Unit)와 TCU(Transmission Control Unit) 등의 전자 제어 유닛들이 차량의 변속에서 중요한 역할을 담당하게 됨에 따라 전자 제어 유닛의 인자들도 변속감을 결정하는데 중요한 역할을 하게 되었다. 최적의 변속감을 위한 인자들을 구성하기 위해 사용되고 있는 기법으로는 Trial-and-Error가 있는데, 이는 숙련된 엔지니어가 아니라면 품질을 보장하지 못하고, 또한 시간도 오래 걸리게 된다. 따라서 일반화된 결과의 보장을 위하여 전자 제어 유닛의 인자 탐색 자동화의 수요가 있다.

차량 변속 시스템의 인자 탐색 자동화를 위하여 실차를 이용한 자동화 기법과 다이나모미터를 이용한 자동화 기법 등이 이미 연구되었다. 기계공학 분야의 자동화 기법들은 실험계획법을 기반으로 하고 있는데, 차량 변속 시스템의 인자는 다양하고 복잡하기 때문에 시간이 오래 걸리는 Exhaustive Search는 적합하지 않으며, 실험계획법에서는 주요한 인자로 실험을 제한하는 방식으로 실험이 이루어지고 있다. 주요한 인자를 선정하는 과정에는 전문가의 경험이 필요하게 된다.

이 논문에서는 유전 알고리즘을 기반으로 한 변속기 인자 탐색

자동화 기법을 제안한다. 전처리 단계에서 인자들의 경향성을 탐색하고, 유전 알고리즘을 이용한 전역 탐색과 지역최적화가 구현되었다. 실험에는 Simulink 기반의 차량 시뮬레이터가 이용되었다.

주요어 : 자동 매핑, 자동변속기, 차량 변속 시스템, 변속감, 유전 알고리즘

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